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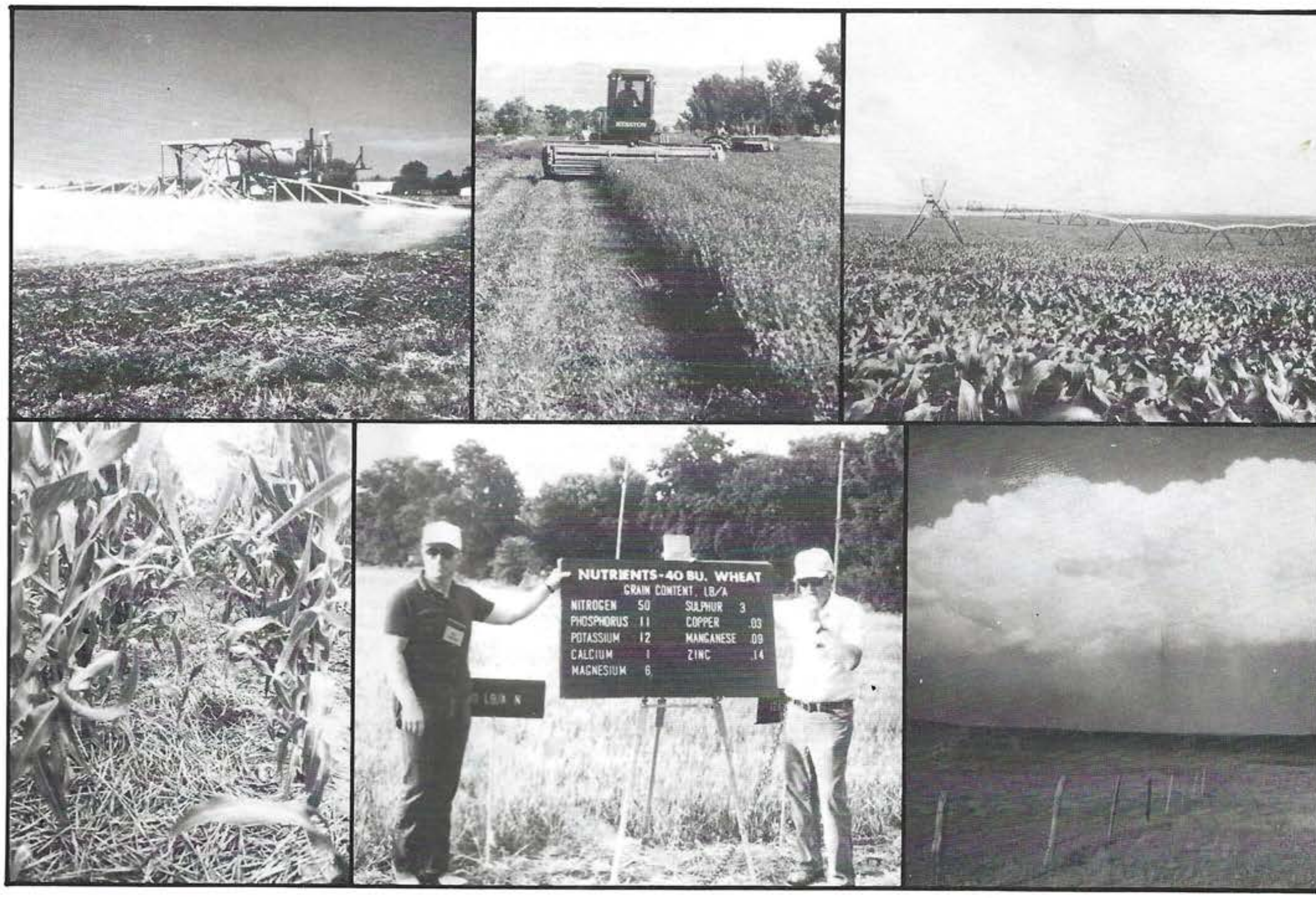
Proceedings



DENVER, COLORADO

March 6-7, 1990

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RESEARCH EXTENSION INDUSTRY

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OF THE

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USE OF GREEN MANURES IN THE GREAT PLAINS

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ABSTRACT

Research prior to about 1960 generally indicated that green manures at most Great Plains locations often reduced crop yields because of increased competition for water. Improvements in germplasm, tillage and seeding techniques, power and equipment, and knowledge of crop production systems, plus concerns about fossil fuel shortages in the 1970s caused some scientists to initiate new research on green manures. Most of this research has been conducted in the Northern (including Canada) and Central Plains, predominantly with spring-seeded crops. This research indicates that several green manure species may have potential for use in spring wheat-fallow systems or with row crops. However no systems for use in winter wheat-fallow systems have been developed. Before use of many green manure crops becomes economically feasible, new cultivars must be developed that will reseed themselves.

Green manures have historically been widely utilized to maintain soil organic matter and soil fertility since the dawn of civilization. By adding fresh organic material to the soil, green manures enhance microbiological activity and nutrient cycling, thereby maintaining higher levels of plant available nutrients, soil respiration, and soil aggregation, and reducing potential for soil erosion. In regions of higher precipitation, these beneficial effects from green manures are usually observed (Power, 1987).

For crop production in drier regions, such as the Great Plains, beneficial aspects from use of green manures in cropping systems have seldom been observed in the past (Table 1). In fact, frequently green manures in such regions have led to reduced crop yields, reduced soil organic matter retention, and sometimes to increased soil erosion. The inefficiency of green manures when used in dryland situations has been documented by many investigators. (Army and Hide, 1959; Brown, 1964; Haas et al, 1957; Sarvis and Thysell, 1936).Generally the explanation for relatively poor performance of green manures under dryland was often based on changes in water regimes imposed by green manures. Usually green manures were evaluated as a summer-fallow substitute in which the green manure was allowed to grow until June or early July at which time it was plowed in. This management system resulted in considerable soil water use by the actively growing green manure, thereby reducing soil water storage and subsequently reducing yield of the following grains crop (Table 2). The reduced growth of the grain crop (near failure in drier years) plus the bare fallow resulting after the green manure crop was plowed in both contributed to enhancement of soil erosion by wind and water. This problem was accentuated by the fact that failure to establish a good stand of the green manure crop was not infrequent and that dry matter production by the green manure was often limited. These factors all added to problems of soil organic matter decline, loss of aggregation, and increased erosion. Most of the investigations referred to above were conducted prior to 1960, before we had developed acceptable reduced and no-tillage methods, had available improved cultivators and herbicides, and had sufficient power and equipment to manage the soil in alternative ways.

Table 1. Percentage change in nitrogen of surface soils, with and without green manure, at 13 locations in the Great Plains

Location	Years of cropping	No green manure	Rye, green manure	Legume, green manure
	Number	Percent	Percent	Percent
Mandan, N.Dak.	30	-31	-32	-30
Dickinson, N.Dak.	40	-50	-48	-50
Havre, Mont.	31	-37	-36	---
Moccasin, Mont.	39	-32	---	-32
Sheridan, Wyo.	30	-21	-18	-19
Archer, Wyo.	34	-34	-30	-33
Akron, Colo.	39	-37	-37	-33
Colby, Kans.	30	-28	-27	-30
Hays, Kans.	30	-18	-14	-17
Garden City, Kans.	30	-18	-22	---
Garden City, Ks., Annex	15	-25	-25	-24
Woodward, Okla.	33	-62	---	-61
Lawton, Okla.	31	-48	---	-47
Average of 8 locations	31	-30	-29	-30

Table 2. Average wheat yields (37 years) following green manures and fallow at two Montana locations (Army and Hide, 1959)

Previous crop	Moccasin	Huntley
	Wheat yield, bu a^{-1}	
Fallow	16.3	23.3
Fieldpea	16.9	16.1
Sweetclover	15.6	11.8
Rye (Secale cereale)	16.9	15.9
Annual precipitation (inches)	12.7	10.7

Unfortunately however, partly because of the unfavorable results of the early research, we did not begin to utilize new technologies in green manures research in the Great Plains until this last decade. Problems with deteriorating soil structure and especially those arising from the fossil fuel crises of the 1970's led some scientists to recognize the need to re-evaluate the potential role of green manure in dryland agriculture, utilizing the new management technologies available. This led to active new research programs on green manures at a few locations, primarily in the Northern Great Plains and Canadian Prairies. To prepare this report, a letter requesting information was sent to 20 scientists throughout the Great Plains. Results reported from the research reported by these scientists and conducted by the author will be briefly discussed in the remainder of this paper. Brief summaries of some of their research were included in a recently published symposium (Power, 1987).

Canada: Most of the current research in Canada in being conducted in Saskatchewan, but some coordinated research is also being conducted in neighboring provinces. Principal investigators includes Drs. Biederbeck, Slinkard, Campbell, Zentner, and others. Research has been conducted in the Brown, Dark Brown, and Black soil zones. Most of their research has been in a spring wheat (Triticum aertivum) fallow rotation in which 21 months of fallow and three months of crop are common. Criteria required for an effective green manure (Biederbeck, 1989) in this system include:

1. Provide early ground cover.
2. Exhibit high rate of growth and N_2-fixation.
3. Exhibit high water-use efficiency.
4. Be competitive with broadleaf weeds.
5. Provide emergency feed in dry years.
6. Produce ample seed in "leave" strips.
7. Have sufficient height in "leave" strips to trap snow.

The management systems investigated generally involve an early spring-seeded species which is allowed to grow to early bloom (6 to 8 weeks). It is then either disked in or killed with a herbicide. If killed with a herbicide, winter wheat can be no-till seeded into the residue, with the residue providing enough cover and snow trapping to control winter-kill. Spring wheat could also be seeded. If the green manure is disked in, usually only spring wheat can be used because of winter-kill.

Legume species most suited for this system include Austrian winter peas (Pisum sativa arvense) and Tangier flatpea (Lathyrus tingitanus) grown alone or in mixture. Other species with promise include chickling vetch (Lathyrus sativus) and black lentil (Lens culinaris). The Indianhead cultivar of black lentil has been developed for Saskatchewan conditions. In more humid regions of northern and eastern Saskatchewan, legumes may be grown in rotation with wheat in place of summer fallow with grain or forage harvested from the legume. Non-dormant alfalfa (Medicago sativa) cultivars may also be used as annual green manures.

Results from two comprehensive experiments at several in Saskatchewan are presented. The first experiment, initiated on the Dark Brown soils at Swift

These results, which included an extremely dry year (1988) indicate that legumes can be used as a partial fallow substitute in Canada. Feasibility of doing so will depend on economics, government policies, and other factors. Benefits of the green manures, other than direct economic effects, could include improved soil properties and better soil erosion control. In additional studies using ^{15}N isotopes, Janzen et al (1990) found that about twice as much of the N applied to the soil in legume residues remained in the soil organic fraction than occurred when N was added as fertilizer, suggesting long-term sustainability of soil organic matter with legumes.

A second experiment (Campbell et al., 1989) conducted at several locations in Saskatchewan since 1960 involves comparisons of several rotations including sweetclover (Melilotus alba) used as a partial fallow substitute with two years of spring wheat. Also included in these comparisons was a six-year rotation of three years of brome (Bromus inermis) alfalfa rotated with fallow and two years of wheat. On a thick Black soil at Melfort, yields (25-year average) for both the first and second wheat crop following sweetclover were 10 to 15% less than those for fertilized wheat grown one and two years after summer fallow, but were considerably greater than yields for continuous wheat (fertilized). On a thin Black soil at Indian Head, first year wheat yields after sweetclover were slightly greater than those from fertilized wheat growing on fallow, but second year wheat yields were 20% less. Soil organic C and total N contents were also monitored. More detail and data on this experiment are reported by these authors later in this conference.

MONTANA: Much of the research on green manures in Montana has been conducted by Dr. Jim Sims and his associates at Bozeman and at District Stations throughout Montana. They have identified 25 legume species that have potential for use as a green manure crop under Montana conditions. Black medic (Medicago lupulina), a short-lived perennial that can be managed as an annual, appears to be well adapted. Sims et al. (1985) developed and released the "George" cultivar for use in areas with at least 13 inches annual precipitation. In a trial at Bozeman, Sims (1989a) showed that, compared to fallow, a number of medic cultivars increased soil nitrates but reduced soil water storage very little when sampled at time of spring wheat seeding (Table 5). Wheat yields following most medic cultivars equalled or exceeded those from fallow. Outstanding were wheat yields following the growth of George black medic as a green manure. Comparable yield responses were observed when the experiment was repeated in 1983. Additional trials at Bozeman, with many more medic and sub-clover (Trifolium subterraneum) species, likewise produced grain yields which were often considerably greater for wheat after green manure than after fallow.

Additional experiments were conducted at a number of District Stations across Montana in which the effects of various legumes as partial fallow substitutes were evaluated in regard to growth, water use, and effects on the following grain crop. Barley (Hordeum vulgare) yield data from several of these trials are presented in Table 6. In all instances, barley yields following Austrian winter peas (Pisum sativum), when used as green manure, were greater than those for barley (unfertilized) grown on fallow.

Current (12 inches annual precipitation), compared wheat production for four annual legumes [black lentil, fieldpea (Pisum sativum), Tangier flatpea, and chickling vetch] used as a partial fallow substitute to that for continuous (fertilized) wheat and wheat-fallow (Beiderbeck, 1988). The legumes were seeded as early as possible and either disked in or killed with herbicides six to seven weeks later at full bloom, with an additional part of each plot untreated allowing legumes to mature. All residues were incorporated at wheat seeding the next spring. Generally dry matter production and N_2-fixation was greater for fieldpea and chickling vetch than for the other two legumes (Table 3). Dry matter production averages ranged from about 1400 to 2800 lb a^{-1}.

Table 3. Dry matter produced at full bloom and water use efficiency (WUE) by annual legumes at Swift Current in 1985, 1986 and 1987 (Biederbeck, 1988)

Type of Legume	1985	1986	1987	3-yr Avg.	1985	1986	1987	3-yr Avg.
	Dry weight, lb a^{-1}				WUE, lb H_2O/lb dry wt			
Black lentil cv Indianhead	1340	1510	1720	1520	704	976	632	771
Tangier flatpea, cv. Tinga	1410	1290	1650	1450	656	1130	622	803
Feedpea, cv. SEMU-SI	2270	2840	2000	2640	440	597	403	480
Chickling vetch cv. NC8-3	1800†	2460	2230	2190	-	636	431	535
AVERAGE OF LEGUMES	1730	2030	2100	1950	553	835	522	637

† Production estimated based on 1984 DM yield and adjusted for 1985 growth conditions by correlation with feedpea yields.

Water use by these legume species was largely confined to the upper two feet of soil, considerably shallower than for continuous spring wheat. By freeze-up, soil water reserves under legume plots were usually 65 to 75% of those for fallow. These legumes averaged using 500 to 800 lbs water per lb dry matter produced, generally with higher values for black lentil and Tangier flatpea (Table 3).

Legume species had essentially no effect on wheat yields the following year. When legumes were incorporated into the soil at bloom stage, five-year average wheat yields were equal to those for wheat produced on summer fallow, and considerably greater than those for fertilized continuous wheat (Table 4).

Table 4. Yield of spring wheat grown after wheat, summer fallow, and several annual legumes at Swift Current, Saskatchewan, 1985-1989 (Biederbeck, 1988 and personal communication).

	Year					
Treatment	1985	1986	1987	1988	1989	Average
Summer fallow	18.8	45.6	32.5	16.1	36.4	29.2
Cont. Wheat	12.3	39.1	17.1	4.9	25.2	19.8
Annual Legumes†						
Incorporated	18.3	56.3	24.7	8.0	37.3	29.0
Desicated	-	43.9	21.5	6.5	29.0	-
Matured	13.2	27.8	17.9	1.6	24.4	16.9

†Average of 4 species, incorporated or desicated with herbicide at bloom or allowed to mature.

Actually, average yields for barley on fallow and barley following Austrian winter peas cut for hay were very similar. Lentils and spring peas also performed well at most locations. Black medic was not evaluated in these trials.

Table 5. Soil water and nitrate-N content (4 ft) at seeding and spring wheat yields following fallow or several medic cultivars (Sims, 1989a).

1980 Land Use	Soil Water (1981)	Nitrate-N (1981)	Wheat Yield (1981)	Wheat yield (1983)
	inches	Lb a^{-1}	bu a^{-1}	bu a^{-1}
Fallow	8.8	46	29.0	39.1
Barrel medic (Ghor)	8.5	98	38.1	32.9
Barrel medic (Jemalong)	8.5	60	37.8	33.3
Barrel medic (Cyprus)	8.1	80	36.4	33.5
Strand medic (Harbinger)	8.3	93	41.1	35.6
Snail medic (Robinson)	8.2	100	33.8	34.8
Black medic (George)	8.3	118	55.8	43.1

Table 6. Barley grain yield (unfertilized) at five Montana locations as affected by previous crop (Sims, 1989a)

Previous Crop	Kalispell 1983	Kalispell 1984	Kalispell 1985	Bozeman 1983	Huntley‡ 1983
AWP (GM)†	123	49	44	51	109
Fallow	118	42	31	42	-
AWP (Hay)	109	49	38	38	101
Lentil	108	55	44	39	105
Spring pea	107	55	45	34	104
Fababean	93	59	47	28	94
Chickpea	84	50	40	31	96
Barley	69	38	41	13	73
Wheat	67	38	40	18	-

† Austrian winter pea (green manure)

‡ Irrigated

At most locations (except Huntley) when fertilizers were applied, responses similar to those shown in Figure 1 were observed. Fertilizer N had little effect on yields of barley following Austrian winter pea (green manure) or fallow. Some response was observed for the other legumes, and a large response was measured when barley followed a grain crop (wheat or barley). With sufficient fertilizer, barley yields from the latter two practices eventually equalled yield of unfertilized barley for the first two practices.

In additional experiments, Sims (1989b) demonstrated that soil water extraction by the green manure can be controlled within a cm or two by utilizing evapotranspiration models (or by soil sampling) as a guide in deciding when to terminate growth of the green manure. Utilizing this technology, along with other developments regarding green manures and the flexible cropping philosophy, Sims (1989b) recently developed the CREST farming strategy for dryland regions. This acronym is developed from the words "control," resistance," "evasion," "sustainable," and "tolerable." By using these approaches to problems, he proposes that a sustainable and profitable agriculture can be maintained in the Great Plains. Examples of practices used for control, resistance, and evasion include controlled growth of green manures (terminating growth at pre-determined water use indices), snow management, early seeding, drought and insect/disease resistant cultivars, flexible cropping patterns, conservation tillage practices, controlling fertilizer and chemical inputs, and so forth. Utilizing these and other practices is the optimum manner is the essence of the CREST system.

<u>NORTH DAKOTA :</u> The research reported on from North Dakota is primarily from unpublished data collected by the author in 1977 and 1978 before transferring away from Mandan. New research has recently been initiated at Mandan, but no data are yet available. The earlier research consisted of two years of field studies at Mandan in which the growth rate, water use, and N uptake (fixation) of a number of legume species were evaluated periodically during the growing season. Each species was seeded at several dates in an attempt to identify candidate legume species to grow for varying time periods during different parts of the growing season. A green manure crop growing after harvest of wheat would encounter markedly different growing conditions than one growing after corn harvest. Also, several opportunities exist for seeding date of a green manure used as a partial fallow substitute. Thus knowledge is needed of growth characteristics, water requirements, and N_2 - fixing ability to identify best species to use for a given situation. Generally such knowledge is lacking for many legume species.

In these experiments, legume species were seeded on clean-tilled stubble during the first week of May, June, July and August each year. Plots were periodically sampled for dry matter production, total N uptake, soil water content, and N_2 - fixation rate by acetylene reduction (1978 only), and ground cover was estimated at the end of each season. As expected, dry matter production, percent ground cover, and total N uptake were closely related, and 2 year average data for total N uptake are presented in Table 7. For all planting dates, growth and N uptake was initially outstanding for field pea and faba bean (Vicia faba). These species and soybean (Glycine max) another annual legume, continued to grow well throughout the summer until they approached maturity. Sub-clover grew surprisingly well during the hot part of the summer (producing over 10,000 lb = 1 dry weight in 1977). Hairy vetch (Vicia villosa), a winter annual, made best growth during the cooler parts of the season. Perennials [alfalfa, sweetclover, lespedeza (Lespedeza stipula) and birdsfoot trefoil (Lotus corniculatus)] were slow to establish and grew slowly initially, followed by more rapid growth late in the season. Generally this slow initial growth and N uptake exhibited by the perennial species would often severely limit their use for a short-term green manure crop. Unfortunately in most of the early research, sweetclover and other perennials were used almost exclusively. This probably accounts for poor results often obtained in research prior to 1960.

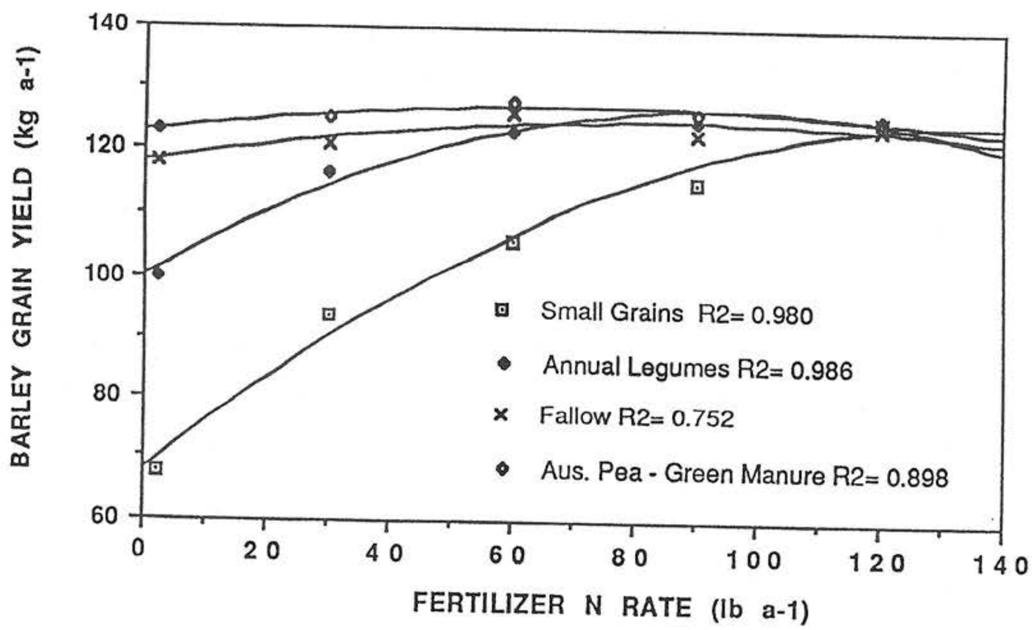

Figure 1. Barley yield as a function of fertilizer N rate for each previous crop at Kalispell, Montana in 1983 (Sims, 1989a).

Techniques utilized in this research did not permit direct measurement of N_2 fixation. However in 1978, a number of samples were collected from the field and potential N_2 - fixation was determined using the acetylene reduction technique. As might be expected, there was a close relation between rates of dry matter production or N uptake with potential N_2 - fixation rate (data not shown). Consequently, soybean exhibited outstanding N_2 - fixation rates (all legumes were inoculated with appropriate Rhizobia culture at seeding.)

Soil water content at various sampling dates generally declined most rapidly for those species exhibiting most rapid growth at times of sampling (Table 8). Thus, during the first month or two after seeding, lowest soil water content was usually observed for the annual legumes, especially fieldpea and faba bean. During mid-summer soybean and sub-clover also often exhibited most rapid growth and soil water extraction. Perennial species often used water most rapidly late in the season, at which time water removal under annual species slowed greatly as these plants approached maturity. These data suggest that there is no such thing as a free lunch--water use is increased when growth increases.

These results suggest a possible green manure management system for the spring wheat region of the Great Plains. With the 21 months of fallow associated with the crop-fallow system, much previous research shows that little water is normally stored in fallow after early July of the fallow year, and precipitation received the remainder of the growing season is lost to evaporation (sometimes some stored soil water is also lost during that period). These data suggest that one could seed an annual legume in early July of the fallow year and expect to accumulate 35 to 45 lb N a^{-1} by frost without greatly depleting soil water storage. If 5 to 10 lb flax seed a^{-1} (*Linum usitatissimum*) were mixed with the legume seed, this would serve to trap snow and recharge any soil water used by the legume. From these data and those available from Saskatchewan and Montana, one would expect to maintain or increase yield of the following grain crop without N fertilization as well as conserving soil organic matter and controlling soil erosion. However this system remains to be field tested, and development of self-reseeding legume cultivars may be required to make the system economically feasible.

Table 7. Total N uptake for various legume species at several seeding dates (2 year average), Mandan, North Dakota

Species	Planting date / Sampling date	May				June		July	Aug	
		6/20†	7/12	8/1	9/19	7/12	8/1	9/19	9/19	9/19
		Total N uptake, kg ha-1								
Hairy vetch		10.6	23.9	29.2	33.3	7.0	7.0	37.5	5.4	9.6
Subclover		10.6	43.1	86.9	M‡	3.3	7.2	18.4	9.6	-
Soybean		17.3	20.9	39.2	M	17.0	26.9	39.2	42.8	-
Birdfoot trefoil		3.6	7.7	12.6	23.6	0.4	2.1	22.2	2.4	-
Field pea		51.6	61.8	67.2	M	16.0	24.2	M	46.8	21.3
Alfalfa		5.8	31.1	36.6	56.0	8.8	7.3	42.7	26.3	-
Lespedeza		1.6	9.3	17.8	55.2	1.7	4.7	36.4	9.0	-
Fababean		38.1	28.7	36.5	M	26.7	34.0	8.5	49.8	24.2
Sweetclover		7.3	30.6	48.3	55.4	3.4	14.7	45.3	37.7	-
Red clover		0.9	6.2	13.2	30.8	1.6	2.3	32.8	2.8	-

† Sampling date was ±1 d of actual sampling date shown each year

‡ Crop matured

NEBRASKA: Considerable green manure research has been conducted in the more humid eastern regions of Nebraska in recent years by Drs. Walters and Shapiro, in addition to this author. To date, very little field research has been conducted on the use of green manures in the drier parts of Nebraska, especially in the winter wheat-fallow regions.

One of the first experiments conducted by the author in Nebraska was a greenhouse follow-up to the field research reported for North Dakota. Working with John Zachariassen, a graduate student, an experiment was conducted in which growth, N_2 - fixation, and water use rates were determined for several legumes grown at 10, 20, or 30^oC in temperature-controlled greenhouse tanks. Species evaluated included sweetclover, white clover (Trifolium repens), crimson clover (Trifolium incarnatum), lespedeza, soybean (both nodulated and non-nodulated), field pea, faba bean, and hairy vetch, along with non-legume controls of winter wheat and Kentucky bluegrass (Poa pratensis). In general, three types of responses were observed. One group consisted of fast-growing annuals which often grew well at cooler temperatures, and included faba bean, field pea, crimson clover and hairy vetch. A second group were the slower-growing perennials and included lespedeza, sweetclover, and white clover. The third group consisted of soybean, a species exhibiting exceptionally rapid growth at all but low (10^oC) temperatures.

Relative growth rate of the different species are arranged by rank in Table 9. Soybean was outstanding in growth rate compared to other species--almost without exception both nodulated and non-nodulated soybean were ranked in the top three species except at 10_C and at later growth stages. In many instances soybean dry weights were double that of the second place species. Faba bean also exhibited outstanding growth rates up to day 63 by which time the species was in the reproductive phase of growth. For 63 d or more of growth, white clover and crimson clover performed well at cooler temperatures and lespedeza at warmer temperatures. At 10^oC, hairy vetch exhibited a relatively good growth rate throughout the 105 days.

Table 8. Soil water content for various legume species at several seeding dates (2 year average), Mandan, North Dakota

Species	Planting date	May				June		July	
	Sampling date	6/21†	7/12	8/3	9/19	7/12	8/3	9/19	9/19
		soil water to 4 ft, inches							
Hairy vetch		7.5	6.6	6.5	6.3	7.5	6.3	7.3	8.3
Subclvoer		8.0	7.1	5.3	M‡	7.6	6.4	6.8	-
Soybean		7.4	6.7	5.7	M	7.2	5.9	6.9	7.9
Birdfoot trefoil		7.9	7.1	6.1	7.2	7.7	6.5	7.5	-
Field pea		7.3	6.3	6.0	M	7.3	6.2	7.3	7.9
Alfalfa		8.0	7.0	5.3	6.7	7.8	6.4	7.4	7.9
Lespedeza		8.2	7.2	6.0	7.1	7.8	6.5	7.8	8.3
Fababean		7.3	6.9	5.7	M	7.2	5.8	7.1	7.9
Sweetclover		7.9	6.8	5.2	6.9	7.7	5.9	6.8	7.6
Red clover		8.0	6.9	5.9	7.2	7.5	6.2	7.9	

† Sampling date was ±1 d of actual sampling date shown each year
‡ Crop matured

Soybean was also outstanding in water use efficiency (Table 10). In only a few instances did another species exhibit greater water use efficiency. For a given temperature, there was a general positive relationship between growth rate and water use efficiency. Thus, in early stages water use efficiency was generally better for annuals than for perennials, and the opposite was often true at later stages. In general, water use efficiency declined with increased soil temperature and with time.

Data are presented in Table 11 on amount of N_2-fixed per pot by each sampling date. Again soybean was outstanding in N_2-fixation ability. At 20^oC, amount of N_2 fixed by soybean was at least 3-fold greater than that for any other species. Also, as with growth rate, at 10^oC soybean did not perform well. Hairy vetch and faba bean initially exhibited high rates of N_2-fixation when grown at cooler temperatures. At 30^oC, only soybean fixed N_2 rapidly by 42 d, but by 105 d, several perennial (sweetclover and lespedeza) had accumulated considerable fixed N. In general, N_2-fixation data showed a general positive relationship to plant growth data, as one might expect.

The controlled greenhouse study was followed by several years of field study similar to those conducted in North Dakota. A number of legume species were seeded at several dates, and they were sampled periodically for growth, N-uptake, and water use. Dry weight data for the 1985 experiment are shown in Table 12.

Table 9. Relative rate of growth (rank) of eleven species† studied at three soil temperatures and five sampling dates.

Time	Soil	Rank										
(Days)	Temp.	1	2	3	4	5	6	7	8	9	10	11
	°C											
21	10	FB	SB⁻	SB+	FB	HV	CC	SC	WW	WCL	LD	BG
	20	FB	SB⁻	SB+	CC	SC	HV	FP	WCL	LD	WW	BG
	30	SB⁻	FB	SB+	FP	HV	CC	SC	WW	LD	WCL	BG
42	10	FB	SB+	SB⁻	HV	CC	FP	SC	WCL	BG	LD	WW
	20	FB	SB+	SB⁻	CC	FP	WCL	SC	LD	BG	HV	WW
	30	SB+	SB⁻	FB	LD	WW	SC	WCL	CC	HV	BG	FP
63	10	FP	WCL	HV	SC	CC	BG	LD	WW	FB	SB+	SB⁻
	20	SB+	SB⁻	SC	CC	LD	WCL	HV	WW	FB	BG	FP
	30	SB+	SB⁻	LD	WCL	SC	HV	WW	BG	FB	CC	FP
84	10	WCL	CC	LD	HV	SC	SB+	WW	SB⁻	BG	FB	FP
	20	SB+	SB⁻	LD	CC	SC	WCL	BG	FB	WW	FP	HV
	30	SB+	LD	BG	SB⁻	WCL	WW	FB	CC	FP	SC	HV
105	10	WCL	CC	HV	SB+	FB	LD	FP	WW	SB⁻	BG	SC
	20	SB+	LD	SB⁻	WCL	HV	FB	WW	SC	BG	CC	FP
	30	SB+	LD	SC	SB⁻	BG	WW	WCL	HV	FB	CC	FP

† SB+ = nodulated soybean; SB⁻ = non-nodulated soybean; FB = fababean; FP = field pea; HV = hairy vetch; CC = crimson clover; SC = sweetclover; WCL = white clover; LD = lespedeza; BG = Kentucky bluegrass; WW = winter wheat.

Again, as in the greenhouse study, dry matter production by soybean was outstanding when planted before mid-summer. Weights were often as much 2-fold greater than those for Tangier pea, hairy vetch, or rose clover (Trifolium hirtum), the highest yielder of the remaining entries. For later plantings, hairy vetch was again productive, as were black medic and rose clover. Water use, N uptake (and presumably N_2-fixation) followed patterns very similar to that for dry matter production. (data not shown).

Table 10. Water use efficiency of various species* as affected by soil temperature and plant age (Zachariassen and Power, 1987).

Time (Days)	Soil Temp.	Species: SB+	SB-	FB	FP	HV	CC	SC	WCL	LD	BG	WW
	°C	lb/lb^{-1}										
21	10	5.8b†	5.6b	4.4c	5.3b	2.8e	4.3c	3.6d	7.1a	‡	‡	2.9e
	20	3.6a	3.9a	3.2ab	1.5d	2.0c	2.6b	2.3c	2.8cb	2.2c	2.4bc	1.4d
	30	2.5ab	2.8a	2.2b	2.9a	1.8c	1.9bc	1.7c	1.4d	1.7e	1.6c	1.6c
42	10	4.7a	4.0b	3.0c	3.1c	2.8d	2.9cd	2.3d	3.1c	3.6b	3.3c	1.2e
	20	2.4b	2.1b	2.0bc	2.1b	1.4d	1.9c	1.5cd	2.4b	2.0bc	3.0a	1.3d
	30	1.5a	1.4ab	1.2b	1.6a	0.9c	1.3b	1.3b	1.2b	1.4ab	0.5c	1.8a
63	10	3.3a	2.5b	2.1bc	3.4a	1.8c	2.4b	1.7c	2.0c	1.7c	1.8c	1.0d
	20	2.2a	1.6b	1.5b	1.8ab	1.3c	1.9a	1.6b	2.2a	1.9a	1.7b	1.0e
	30	1.7a	1.2b	1.1b	0.9c	0.9c	1.1b	1.0bc	1.4ab	1.7a	0.4d	1.2b
84	10	2.8a	1.8c	§	§	2.1b	2.4ab	1.5c	2.2b	2.5a	1.3d	0.9d
	20	2.1q	1.4bc	§	§	0.9c	2.0a	1.5b	1.7b	2.0a	1.5b	1.0c
	30	1.8a	1.3b	§	§	0.7c	1.0bc	0.9c	1.3b	1.7a	0.7c	1.3b
105	10	2.6a	1.3c	§	§	2.1b	2.7a	1.2c	2.2b	2.5a	1.0c	1.1c
	20	2.3a	1.5b	§	§	1.1c	1.3bc	1.2c	1.7b	2.3a	1.1c	1.0c
	30	2.0a	1.2b	§	§	0.7c	0.8c	1.0b	1.1b	2.3a	0.9bc	1.2b

† Values within a line followed by the same letter are not significantly different at 0.05.
‡ No data, insufficient growth
§ Plants maturing, no data
* SB+ = nodulated soybean; SB^- = non-nodulated soybean; FB = fababean; FP = field pea; HV = hairy vetch; CC = crimson clover; SC = sweetclover; WCL = white clover; LD = lespedeza; BG = Kentucky bluegrass; WW = winter wheat.

Table 11. Amount of N_2 fixed in legumes as affected by soil temperature in greenhouse tanks (Zachariassen and Power, 1987)

Species	Soil Temperature	Time (d) 42	63	84	105
	°C	mg N fixed pot^{-1}			
Hairy vetch	10	113	123	167	253
	20	52	100	77	139
	30	17	10	15	35
Sweet clover	10	25	53	77	75
	20	59	98	146	139
	30	48	52	57	119
Fababean	10	175	149	153	138
	20	155	142	138	152
	30	26	14	13	5
Lespedeza	10	0	5	4	0
	20	10	34	106	164
	30	18	26	69	200
Field pea	10	41	55	43	59
	20	44	24	14	10
	30	14	12	7	0
White clover	10	23	62	100	185
	20	45	89	123	174
	30	3	1	46	44
Soybean	10	36	38	43	39
	20	132	244	358	471
	30	108	186	295	330
Crimson clover	10	49	50	82	122
	20	61	90	98	64
	30	11	2	16	7

Table 12. Dry weight of legumes planted and harvested at several dates in 1985, Lincoln, Nebraska.

Species / Planting date / Harvest date	May 17 7/8	8/12	11/1	July 1 11/11	Aug 1 1/1
Crown vetch	-	540	1710	1520	520
Arrowleaf clover	220	1780	3250	3300	780
Drawf English trefoil	-	-	-	1380	330
Sickle-keel lupine	-	-	-	140	120
Hairy vetch	1130	5600	4400	3100	1720
Salton alfalfa	130	2210	1990	1670	930
Tangier pea	1460	4850	5220	2090	1140
Soybean	2040	10460	8000	810	300
Facto flatpea	-	1040	2350	280	-
Cicer milkvetch	-	530	230	530	170
Big trefoil	-	-	-	590	-
Rose clvoer	450	4850	4820	3170	1380
Mesilla alfalfa	90	1140	1540	1290	820
Black medic	-	610	1330	3060	1170
Austrian winter pea	1730	390	-	740	890
Cowpea	880	2380	4260	2620	1550
Lupine	-	-	-	580	240
Rye	1220	1990	1050	760	1130

Table 13. Total N content of green manures, soil (0 to 6 inches) nitrate-N content at planting and grain yields of corn following green manures, Lincoln, Nebraska 1985-1986.

Green manure	Total N content	Soil Nitrate-N	Corn Grain
	Lb a^{-1}	ppm	bu a^{-1}
Hairy vetch	260	13	148
Salton alfalfa	80	11	133
Tangier pea	150	11	143
Soybean	310	10	135
Rose clover	100	9	139
Rye	60	9	131

In 1986, these plots were uniformly planted to corn (Zea mays), and resulting corn yields were measured (Table 13). Unusually good growing conditions were experienced, resulting in exceedingly high yields of dryland corn. Data presented are for the May, 1985 legume planting date only. Legumes were disked in before corn planting. Maximum values for total N content of the legumes are also presented in Table 13, and values generally follow legume dry matter data presented earlier. Soybean and hairy vetch both accumulated approximately 300 lb N a^{-1}, whereas non-dormant alfalfa (Salton) and rye accumulated less than 90 lb N a^{-1}. These differences were not reflected in soil (0-6 inches) nitrate N content at corn planting the next spring. Likewise, corn grain yields did not reflect the quantity of N returned by the green manure. Least corn yields were recorded for rye and Salton alfalfa, however, but values were not statistically different from those for corn following soybean green manure. Greatest yields were obtained with hairy vetch and Tangier peas.

The foregoing research has identified characteristics of various legume species and suggests how they might be used as green manures. For continuous corn cultures (or for almost any full season row crop) in eastern Nebraska, hairy vetch has been identified as the best species to use for green manuring. This crop is overseeded into corn around September when corn is starting to mature. The hairy vetch establishes during the fall, will survive Nebraska winters, and grows rapidly in early spring. It can then either be disked in or killed with herbicide (for no-till planting) when corn is planted. A number of variations of this general management scheme are possible.

A number of field experiments have been conducted in eastern Nebraska in recent years in which the effects of hairy vetch green manure were evaluated for dryland corn production. Corn grain yields resulting from one such experiment are presented in Table 14. In this experiment, the effects of hairy vetch disked in or killed and left on the soil surface (no-till) were compared to plots with no vetch but with 0 and 55 lb fertilizer N a^{-1}. In the three years studied, one very good year and two relatively poor years for corn production were experienced. Total N content of the hairy vetch averaged 30 to 40 lb N a^{-1}. In all years, corn grain yields from plots on which the hairy vetch had been disked in equalled or exceeded that for corn grown with 55 lb fertilizer N a^{-1} (Table 14). However when the corn was no-till planted after killing the hairy vetch with herbicides, corn grain yields were low. Distribution of Total N uptake data between corn grain and stover suggests that much of the N in incorporated hairy vetch may have mineralized and was taken up by the corn during the grain-fill period, whereas N in hairy vetch residues left on the soil surface failed to mineralize sufficiently to meet the N requirements of corn during grain fill. In this experiment, soil water used by the hairy vetch did not affect corn establishment or production. However in other experiments, especially in years with below-normal spring precipitation, soil water extraction by hairy vetch severely reduced corn emergence and often reduced yield. Without irrigation this use of a green manure cover crop could occasionally lead to serious problems of maintaining yield.

Table 14. Corn grain yield and N uptake in grain and stover (3 year average) as affected by hairy vetch cover crop (Power, et al.. 1990)

Treatment	Corn grain yield	Total N Uptake	
	bu a^{-1}	Grain	Stover
No vetch, no N	43	34	11
No vetch, 60 kg N ha^{-1}	46	39	11
Vetch disked in, no N	53	43	9
Vetch no till, no N	31	22	9

OTHER STATES: Research on use of green manures in other Great Plains states appears to be quite limited. Vigil (1989) at Kansas State University summarized a number of published incubation studies (Table 15), and showed that generally C/N ratio, N concentration, and square-root of N concentration of crop residues were all good predictors of mineralization of N in the residues. These regression coefficients could be improved slightly by including residue lignin content in the regressions. Using ^{15}N tagged soybean and sorghum residues he was able to show that MINIMO (a subroutine of the CERES-Maize model) accurately predicted N mineralized from the residues. Between 5 and 25% of the N in these residues was recovered by the following crop.

In Colorado, Dr. C.E. Townsend is continuing research to develop Cicer milkvetch as a dryland legume and has released improved cultivars. However essentially no field evaluations of the utilization of these new cultivars as green manure crops have been made. Dr. T.H. Dao and S.C. Rao at El Reno, Oklahoma have been conducting considerable research on using various seed legumes in double cropping with wheat, with considerable success. There appears to be considerable potential to develop such a cropping system in central Oklahoma.

Other Great Plains states surveyed did not report any research on green manures, and this author is aware of no other research. Some research is being conducted in states outside the Great Plains that may have some relevance. Research in Minnesota by Heichel and co-workers has led to development of new alfalfa cultivars that may have potential for use. However, the sweetclover research at Nebraska and other locations has been closed out and little if any research is currently in progress on improvement of this widely adapted legume found throughout the Great Plains. Considerable research on green manures is being conducted in the southeast United States by Frye and Blevins (Kentucky), Tyler (Tennessee), and Hargrove and Langdale (Georgia). Also some research is in progress in the Palouse region of the Northwest (Bezdicek in Washington, Rasmussen in Oregon). Many of these studies may have some application to the Great Plains.

Table 15. Coefficients and statistics of equations relating percent N mineralized to C/N ratios, N concentration and the square root of N concentrations

Study	Independent variable	Intercept B_0	B_1	B_2	Root MSE	n	F of regression
W. T. Frankenberger †	C/N	76.07	-2.68	0.61	18.1	12	15.7**
	N conc.$_{1/2}$	-19.55	1.70	0.74	14.9	12	28.0***
	N conc.	-74.84	19.87	0.74	14.7	12	29.1***
M.H. Fu	C/N	50.98	-1.16	0.93	5.7	12	143.19***
	N conc.$_{1/2}$	-23.23	2.14	0.75	1.05	12	30.07***
	N conc.	-58.28	17.87	0.82	9.4	12	45.86***
H.L. Jensen	C/N	54.11	-1.49	0.99	4.5	7	437.4***
	N conc.$_{1/2}$	-50.88	2.61	0.70	23.4	7	11.7*
	N conc.	-110.23	25.79	0.84	17.1	7	26.1**
H.C. Millar	C/N	47.99	1.02	0.83	9.8	12	48.1***
	N conc.$_{1/2}$	-12.70	1.65	0.42	18.0	12	7.4*
	N conc.	-42.91	14.73	0.52	16.4	12	11.0**
D.A. Van Schreven	C/N	83.26	-2.43	0.91	14.1	4	19.2*
	N conc.$_{1/2}$	-63.13	4.60	0.97	8.5	4	57.2*
	N conc.	-134.67	37.10	0.95	9.9	4	41.1*
M.F. Vigil field study	C/N	40.68	0.84	0.73	4.7	10	21.7***
	N conc.$_{1/2}$	-5.27	13.90	0.57	6.0	10	10.7*
	N conc.	-27.66	11.29	0.62	5.7	10	13.1**
M.F. Vigil lab study	C/N	74.86	-1.97	0.83	9.9	26	115.8***
	N conc.$_{1/2}$	-9.87	1.63	0.91	7.3	26	230.6***
	N conc.	-49.06	16.62	0.91	7.1	26	244.3***
M.G. Wagger	C/N	51.81	-1.01	0.50	8.2	4	2.6
	N conc.$_{1/2}$	8.32	2.14	0.43	8.9	4	4.9
	N conc	-37.32	15.83	0.44	8.7	4	4.2
All data	C/N	59.69	-1.41	0.75	12.3	87	256.6***
	N conc.$_{1/2}$	-12.77	1.67	0.66	14.5	87	162.7***
	N conc.	-51.21	16.67	0.70	13.5	87	201.7***

*, **, *** significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
† Each study is referenced by the first author of each paper.

CONCLUSION

Several conclusions are apparent from this survey of research on green manures in the Great Plains. These are summarized as follows:

1. Knowledge exists for the potential use of green manures in cropping systems involving spring grains and row crops, but little information is available for dryland winter wheat systems. Use of green manures offers potential to maintain soil quality, control pollution and maintain or enhance grain yields.

2. For spring grain regions, several annual legumes appear to have considerable potential for use. However much more research is needed to develop improved germplasm and management systems that economically incorporate green manure usage into management systems, especially during the 21 months of fallow in crop-fallow systems.

3. With row crops (particularly in the eastern Great Plains), a few cultivars are available and offer potential for use as green manures. Again much research is needed to develop germplasm and economically feasible systems. Lack of spring precipitation may jeopardize emergence of a row crop following a green manure.

4. Suitable legume germplasm is usually lacking for use as green manures and much more effort is needed in germplasm development. In essentially no instance do we have a green manure cultivar that will normally reseed itself, thereby greatly reducing production costs. Add to this the fact that USDA and most universities have been decreasing research funds devoted to legume development suggests that it will be extremely difficult if not impossible to develop widespread economically acceptable green manure management methods soon. This is unfortunate because research reported here indicates a great potential exists.

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LISA-USDA PHILOSOPHY, PAST, PRESENT AND FUTURE

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ABSTRACT

The Food Security Act of 1985 authorized, and the 1988 Appropriations Bill funded, a research and demonstration program in USDA that has come to be known as LISA--low-input sustainable agriculture. This is the second attempt by Congress to generate interest in USDA in "alternative" agricultural systems. This time, evidence of substantial public support increases the likelihood of a sustained and productive program to elucidate the merits of lower inputs.

INTRODUCTION

In 1985, Congress included a less-than-clear section in the Food Security Act, as Subtitle C of Title 14, entitled Agricultural Productivity Research. Funding, to the tune of $3.9 million to CSRS (and $200,000 to other agencies) came in FY 88. From the Committee reports, it is clear what the Congress expected, even if the original authorization was obscure in the language. Here, I shall 1) outline the nature of the program that has evolved so far from this legislation, 2) attempt to put it in some historic context, and 3) speculate briefly on its future.

LISA

Early in 1988, an intensive effort got underway to organize and implement a program that would ultimately become known as LISA: Low input, sustainable agriculture. This program was to explore alternative ways of farming to the prevailing practice with heavy dependence on purchased inputs. The essence of the congressional mandate was to establish a data base and information system that would make the results of past and future work and/or experience readily available to all, i.e. to scientists, institutions, farmers, environmentalists or whoever asked for it; and to establish a research/demonstration/education system that would involve not only the traditional Land-Grant system and ARS, but other institutions, foundations, farmer organizations and farmers as well. Congress also specified an organizational structure that called for peer review panels and scientific overview, again including representatives from across society.

The result was an organization that looked somewhat like the following. Using the existing regional structure of the State Agricultural Experiment Stations, one such station was picked in each region as an administrative center, the available funds (about $850K each after overhead and centrally funded activities) were divided equally among the regions, and an Administrative Council was appointed in each region. These councils had representation from Agricultural Experiment Stations, Extension Services, ARS, SCS and private groups. In the West, the University of California became the focal point; in the North-Central Region it was the University of Nebraska. Patrick Madden, then Professor of Agricultural Economics at Penn State, was recruited as national program leader.

It fell to the councils, with guidance from Dr. Madden, to define the nature of the program, set in motion a modus operandi and, in general, to work out an organization framework. As ARS representative on the Western Administrative Council, I shall bias my remarks to the Western experience.

First, there had to be a certain degree of agreement as to what was meant by low-input, or alternative, farming systems. Though even today there is disagreement as to an exact definition, it seems clear that the congressional intent--and that of those who lobbied the Congress--was to search for or advocate farming systems that depended less on purchased, off-farm inputs than most conventional farms, that were sustainable in the natural resource sense, but obviously also sustainable in the economic sense, and that would minimize insults to the environment. It was expected by some, but not by others, that such systems would favor (or protect?) the family farm against the large, corporate enterprise. It was implied that they would depend far less heavily on chemical fertilizers and pesticides, but it was not considered necessary or likely that they would refrain totally from the use of chemicals.

In the West, we concluded early on that the emphasis needed to be on integrated farming systems and that experimental work of necessity would be long-term and interdisciplinary. Thus, we solicited two types of proposals: Relatively small, short-term proposals of an educational nature, such as a literature review and assessment or a conference; and long-term, multidiscipline, multi-institution proposals that would test "alternative" systems over several years. We hoped for joint proposals from academic institutions or research organizations and private farmer groups and/or individuals. We asked for, and insisted upon, an extension or technology transfer component in each proposal. Given the one-year available funding, we opted for a small number of 2-year contracts with the intent to renew them.

In 1988, the Western Region funded 10 projects with the $850K available; three of them were funded at over $200K each, 4 were small planning grants to induce unsuccessful bidders to develop stronger proposals for the next round, one financed a conference, one established a data base and one falls outside my classification scheme.

For the second and third years, Congress appropriated $4.45M. Thus, with an implied commitment to renew or extend the larger projects funded in 1988 and 1989, we found ourselves without resources for substantial new commitments for FY90. Just the same, I believe we made the right decisions, in principle. At present, a process of on-site review is underway; the extension from 2 to 4 years will not be automatic, but contingent on reasonable progress. Rather than soliciting proposals, and possibly receiving 150 out of which only one or two could be funded, the "left-over" funds for FY 90, in the West, will be used to sponsor some special activities in the form of workshops or symposia.

The process followed the first year to solicit and select the projects was a bit flawed but reasonably successful. The council prepared an RFP that was widely distributed, appointed a technical review panel of interested scientists, and then acted upon the recommendations of the technical review panel. Too many of the good proposals were associated with members of the panel--an outcome not unexpected when it is recognized that the panel members were chosen because of their competence and their interest in low-input systems. To avoid any conflict of interest, in subsequent years ad-hoc reviewers were assigned to review proposals. This resulted in substantial extra administrative work to achieve an increase in perceived integrity.

AN ASSESSMENT

LISA is a program that was generated not in the Department of Agriculture, but in spite of the Department, by public pressure on members of the Congress.

An earlier attempt was made by the Congress to develop interest within USDA in alternative methods of agricultural production, then called organic farming. It led to a thoughtful committee report, in 1980, that concluded that there was sufficient, often anecdotal, evidence of economic success among organic farmers to warrant detailed follow-up studies (USDA, 1980). However, testimony before the House Subcommittee on Department Operations, Research and Foreign Agriculture on 22 April 1982 made it plain that any efforts in USDA to establish a viable research and demonstration program were, at that time, feeble at best. Shortly thereafter, they were abandoned.

When the LISA program came into being, following the 1985 Food Security Act, a genuine and--given the resources available--productive effort was initiated with enthusiasm and dedication. For example, in a press release February 4, 1988, Assistant Secretary Bentley was quoted as referring to LISA as "an idea whose time has come".

However, not all parties agreed. Gary Myers, representing the Fertilizer Institute, viciously attacked Dr. Bentley for supporting unwarranted and unproven accusations against farmers (Sinclair, 1988). Within USDA (and the Land-Grant community) there also was a great deal of skepticism. My own agency, ARS, took (and still takes) the formal position that over 20% of its research budget is devoted to LISA related projects, obviating the need for a special program. An ARS spokesman assigned as liaison with CSRS leant to the view that anything that increases net return contributes to sustainability, thus overlooking the primary LISA objectives: environmental quality, soil resource conservation, healthy soils and healthy crops and livestock, as well as a wholesome rural community, together with economic viability. It probably is accurate, though a guess, to state that most professionals associated with agriculture are still highly skeptical.

On the other hand, in 1989, about 150 proposals were received in the West to compete for some $900K. That could be interpreted as hunger on the part of the research community, but I reject that interpretation; scientists are smart enough in grantsmanship to recognize the odds. To me, it illustrates a genuine and deepseated interest among many of the scientists. Furthermore, one cannot ignore the tremendous interest in the farming community and among the public at large. As Bentley said, it indeed is an idea whose time has come.

Consider: Iowa passed a Groundwater Protection Act in 1987 that taxes farm chemicals to support research and demonstration projects to reduce chemical use, environmental insults and threats to health; in 1989, an organic food standards act will go into effect in Iowa. California appropriates about $500K/annum for research and education in sustainable agriculture through the University. These are just two examples of State initiatives. Howell (1989) recently released a publication that lists much of the action taking place at the State level; he details some activity, from adopting standards to taxing chemicals to an active education program, in 30 states. The Federal government needs to run to catch up with the trends.

Some feel that LISA is nothing but emotion and hype. Some warn that the public is too easily duped by unconscionable scientists, and I am fully aware that science, or scientists, don't have a particularly good record when it comes to presenting strictly unbiased facts. On another "in" topic, global warming, it may well be that the public (and the Congress) have taken hold of the issue in an irrational manner, urged on by a few scientists of questionable ethics. Alston Chase (1989) quotes climatologist Stephen Schneider, a leading greenhouse "enthusiast", as follows: "[scientists] need to get some broadbased support, to capture the public's imagination. That of course entails getting loads of media coverage. So we have to offer up scary scenarios.... Each of us has to decide what the right balance is between being effective and being honest."

In my view, the situation with LISA is quite different. I believe the public is ahead of the science community. It is encouraging that many scientists, however, are interested. We need this genuine and widespread interest, because the literature to date is heavily weighted to anecdotal accounts and poorly documented case histories. One of the key responsibilities of the LISA program is to develop and release carefully documented, scientific evaluations of the hypotheses that are about.

Recently, the Board on Agriculture (NRC, 1989a) released a report on alternative agriculture that made a similar case. It devoted a substantial portion of its text to case studies. A debate is going on at present, with some claiming that some of the data in that report were improperly presented or interpreted. The jury is still out. However, even if some errors have crept into that report, I doubt that they will change the overall conclusion.

THE FUTURE

My tea leaves are no better than anyone else's. I am satisfied that the current LISA program, underfunded as it is, is having a significant impact. It also has a loyal and dedicated following. It has strong support in Congress among a few congressional heavy weights. Thus, I have no doubt that it will be maintained at its present level of funding.

The real question is whether, as an earmarked program, Senator Leahy and others will be successful in increasing the budget.

The USDA is closing ranks behind the Board on Agriculture's proposal (NRC, 1989b) for a $500M increase in agricultural research funds, all of it for competitive grants. The Bush administration, generally, is concerned with budget deficits and thus has but limited enthusiasm for new programs or new funding.

In that climate, it will be an uphill fight for members of Congress to get agreement on a substantial increase in funds for LISA. My best guess is that we'll see a token increase from the present $4.45M. However, I would not be surprised to see an increasing effort, financed with new State funds or redirected funds, to respond to the public concern with the current trends in conventional agriculture.

The Presidential initiative on groundwater quality, a new thrust that received substantial, even if less than anticipated, new budgetary support in 1989, is another area where public concern has led to administrative as well as congressional action. Some have advocated that the water quality initiative and LISA should be merged. Though they reflect similar concerns, it would be surprising if that came about.

One should expect some adjustments or changes in the next farm bill that will address built-in biases in the present institutions and regulations against crop rotations, against legumes, against flexibility in cropping practices and against the family-sized farm. The need for such adjustments has been identified in several recent studies (e.g. NRC 1989a). Together, these trends are likely to provide more visibility and more acceptability for changes in farming systems towards low input and sustainability.

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RESEARCH FOR A SUSTAINABLE AGRICULTURE

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ABSTRACT

Research leading to sustainable agricultural systems should support effective competitive strategies for farmers and for U. S. agriculture as a whole. It should lead to ecologically sound farming practices and safe, affordable, high quality food. Sustainability research should help farmers cope with the complex systems integration problems associated with agriculture. If sustainability research is to be more effective, it will be necessary to change the way it is currently evaluated, to organize it differently, and to increase public support for this important activity.

INTRODUCTION

A great many adjectives are being used to describe a more desirable agriculture. These include sustainable, low-input, regenerative, and organic, among others. The adjective "sustainable" is apparently acceptable to more individuals and groups than any other, probably because its meaning is more widely understood. Its hard to imagine anyone arguing that agriculture should not be sustainable.

Disagreements arise, however, as to whether agriculture as currently practiced in the U. S. is sustainable, and, if not, what strategies should be employed to achieve sustainability. Some think they already know the answers to these questions and strongly advocate various approaches. Others, including me, think we do not know these answers and we need to seek them, through research. That research needs to meet certain specifications, to be described in the remainder of this paper. Much of the necessary research will be adaptive research.

The typical soil fertility experiment conducted in the field is a good expample of adaptive research. In adaptive research, alternative input products and practices of agriculture are tested and compared. Information is generated that enables farmers and agribusiness people to integrate appropriate products and practices into profitable, environmentally acceptable, resource-conserving production systems. Sound adaptive research leads to production systems that are tailored to the specific soil, climatic, and socio-economic situations in which farmers must operate.

SUSTAINABILITY RESEARCH SHOULD SUPPORT COMPETITIVE STRATEGIES

William Hatch, the Missouri congressman who authored the Hatch Act of 1887, which created the state experiment station system, supported his proposal on the grounds that research would help U. S. farmers meet growing international competition for grain markets. Hatch's strategy was effective. Until recently, the U. S. dominated international agricultural commodity markets. In the late 70's and early 80's, however, the U. S. lost market share, particularly in soybeans and coarse grains, including

Basic Res — application
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Goal oriented Competitive Grants

corn.

U. S. loss of market share was paralleled by rapid growth of U. S.-style, capital-intensive agriculture in other nations, including Brazil and Argentina. The prospect for the future is that competition for international agricultural markets, especially commodity markets, will be strong. Commodity markets will probably expand, stimulated in part by greater participation of formerly socialist nations. Markets will probably not grow as fast as the world's productive capacity, however, at least for the next few years.

If protectionist policies are phased out as planned, each nation's competitiveness in the global economy will be based its productivity and efficiency and on the quality of its products. This presents a great challenge to the U. S. agricultural research and development system. It must enable U. S. farmers to be the earliest and most effective adopters of productivity-enhancing, cost-cutting, quality-improving agricultural technology.

Unfortunately, research on agricultural productivity has been unpopular in recent years. Agricultural leaders at all levels have spoken against production-oriented research, claiming that it contributes to overproduction. Having only recently faced strong competition from other nations, U. S. agriculturalists are not used to thinking about agriculture in terms of competitive strategies.

Manufacturing firms conduct research and development (R&D) to achieve competitive advantage. Various strategies are employed, most of which fall into the categories of cost, differentiation, innovation, alliance, and growth (Wiseman, 1988). The basis of competition in commodity markets is cost of production. This is because commodities, by definition, have about the same value over the entire market. Only by lowering costs of production and marketing below those of competitors can a manufacturer of commodities gain economic advantage. The same is true of producers of agricultural commodities.

Through research, special agricultural products are being developed for niche markets. Niche markets are, by definition, small and are not viable opportunities for most commodity producers. Achieving differentiation within commodity markets will be difficult, because the related technology will be disseminated rapidly around the world by international agribusiness firms.

Growth strategies, such as diversification and vertical integration, are not likely to work for small or medium-sized farms operated within fixed land areas and labor supplies. The loss of scale economies associated with reducing one enterprise to make room for another may lead to higher costs. In spite of the publicity given these strategies, they are not usually successful in industry (Hall, 1980).

Commodity producers should be aware that some of our competitors are employing a particularly important strategy. I learned of it during a talk on research management by Eliseu Alves, who at the time of the presentation was President of EMBRAPA, the Brazilian equivalent of the USDA-Agricultural Research Service. When his excellent presentation on research management was over, I asked, "What is the Brazilian agricultural research strategy?" He said, "We realize that Brazil doesn't have the resources to mount an aggressive basic and early stage developmental research effort like you have in the U.S. or in other highly developed nations. So we are focusing our limited resources on developing an excellent system of research farms and other farm-scale research facilities and an excellent extension system. Then we will be in a position to take the promising basic developments and new input products and practices from all around the world and adapt them as rapidly as possible to Brazilian agricultural conditions."

The more effectively agricultural production systems are tailored, through adaptive research, to the specific soil, climatic, and socio-economic conditions under which a nation's farmers must operate, the more productive and efficient their operations will be. Well-adapted systems are less valuable to competitors, who face a different set of conditions. To remain competitive, the U. S. must improve and expand its institutional capacity to conduct adaptive research.

SUSTAINABILITY RESEARCH SHOULD ENABLE ECOLOGICALLY SOUND FARMING PRACTICES

Not only must information generated in agricultural research programs contribute to profitability and competitiveness, but this information must enable farmers to minimize the impact of their operations on the environment and conserve natural resources. Public concerns about these issues dictate that these ecological dimensions must be added to many agricultural experiments, particularly those involving tillage, fertility, pest control, and crop sequences.

Current trends in agricultural research funding are making us less able to conduct adaptive research, which is required to address ecological questions. For example, the federal money for water quality research is being allocated through a federally-administered competitive grants program, designed to support water quality research centers (four or five in the midwest). The field research is to be conducted at relatively few locations.

The centers approach is justified on the grounds that limited resources must be concentrated at few locations in order to support meaningful programs and assemble "critical masses" of researchers. The problem with that approach is that the quantitive and qualitative nature of the water quality problem is different in virtually every watershed in the nation, because of climatic, topographic, and soil differences.

The appropriate technological approaches to preventing ground and surface water contamination differ on virtually every farm. Each farm differs from others, not only in the aforementioned features, but also in pest problems, livestock systems, machinery systems, human resources, and a host of other technical and socio-economic factors. The government could spend a trillion dollars on water quality research at a few centers without generating information relevant to most of the situations in which farmers operate.

A sizeable portion of federal water quality research resources could be allocated by formula to experiment stations, with a broad mandate to address the water quality problem as it exists in each state. Given those resources, experiment station scientists and administrators could add the water quality dimension to many experiments, including tillage, fertilizer, pesticide, and animal experiments, that will be conducted anyway.

In this manner, the tremendous amount of state and private support required to cover the basic costs of conducting these experiments would be offsetting costs of water quality research. Failure to recognize the ability of experiment station people to blend federal, state, and private resources in multidimensional research leads to incomplete, redundant, and ineffective programs.

Failure to recognize that critical masses of scientists exist in each land-grant institution leads to inefficient use of human resources. Failure to appreciate fully the site- and situation-specificity of the results of applied agricultural research leads to inadequate information.

STAINABILITY RESEARCH SHOULD ENABLE SAFE, AFFORDABLE, HIGH-QUALITY FOOD

Consumers are understandably concerned about the safety of food. They want to be sure that food products are not contaminated with any toxic materials that may have been used in agricultural production. Some are so concerned about minimizing this risk that they advocate eliminating the use of any chemical pesticides or fertilizers even if this means returning to a much more labor-intensive agriculture. There are other concerns that must be balanced against this one, however.

At a meeting of the Illinois Fruit and Vegetable Growers Association some years ago, I talked to a grower who had just installed a $300,000 cooling facility, so that his produce could be loaded directly into semi-trailors, driven into the facility, and cooled rapidly after harvest. He said the large urban markets he served would not accept produce in less than semi-trailor loads, and that the produce had to be cooled to the high 30's Fahrenheit to be acceptable. Another grower told me that it takes 150 semi-trailor loads of potatoes per day to meet Chicago's demand.

If the quantity, temperature, and other requirements are not met, the wholesalers and retailors simply cannot get the large quantities of produce required to feed Chicago on the shelves and maintain its quality until the consumers can purchase and use it. Therefore, if a producer does not meet these specifications, he will probably have to turn his truck around and take the produce home.

A few days after talking to these growers, I gave a talk on biotechnology to a general audience at the Chicago Academy of Sciences. During the discussion period, I was asked by a young man if the trend toward larger, more capital-intensive farms was causing a decrease in the quality and diversity of agricultural products available to Chicago consumers. I pondered not only how to answer his question but also why he asked it. Then it dawned on me that, if for no other reason, agricultural production had to increase in scale and capital intensity to meet the logistical demands of feeding large urban populations.

There is plenty of evidence in the major metropolitan areas of the world that urban populations cannot enjoy high-quality, affordable food if the supply is only available from inefficient producers who must deliver raw produce to the city in carts or small trucks. The higher the quality and the lower the price demanded by a population, the greater the logistical challenge that must be met to produce and deliver the products. The typical farmers' market meets a very small part of the total demand for food in a major metropolitan area in the U. S.

Those who think that safer, better quality, and more affordable food can be provided by going back to less capital-intensive production and marketing procedures should consider the logistics of delivering food to large urban populations. We need more research on these logistical problems and their relationship to scale economies and production and marketing efficiency.

SUSTAINABILITY RESEARCH SHOULD ENABLE SYSTEMS INTEGRATION

Each farmer faces the challenge of trying to select and integrate the optimum combination of input products and practices, suited to the specific conditions of his/her farm, that will lead to maximum profit or minimum loss. This must be done within the constraints of environmental quality, food safety, and resource conservation. The complex physical, chemical, biological, economic, social, and political environment of farming, with all of its complicated interactions, makes this planning process particularly difficult. It is a typical systems integration problem.

Sustainability research should help farmers accomplish this task. Agricultural scientists are becoming more narrowly specialized, both in training and practice. In most areas of science, particularly basic science, such specialization is necessary and effective. It does cause a problem, however, when it is necessary to integrate information from several areas of specialization into total production, processing, and/or marketing systems. Besides deep knowledge of their specialty, researchers engaged in systems research need a broad perspective and an appreciation for the complex interactions among various components of a system.

Interest in low-input, sustainable systems has rekindled interest in agricultural systems research. This is a positive effect, but some experiments are being conducted in which entire tillage and cropping systems are treated as individual factors. The effects in such experiments are often so confounded that it is impossible to attribute observed differences to any specific factor. Results of such experiments can easily be misinterpreted. The factorial design, used traditionally in fertility experiments, avoids this problem. Of course, when there are many factors in an experiment and each factor is present at several levels, factorial experiments become very large, often prohibitively so.

There are a number of useful and valid approaches to performing research on systems. In general, systems research needs to be conducted in the context of models. Models are useful summaries of what is known about complex systems. Much valuable information can be obtained simply by simulating system function based on what is already known about the system.

Systems simulation helps identify areas in which lack of knowledge makes it hard to predict outcomes. This helps researchers focus their efforts on the most important problems and helps producers manage risks. The results of factorial experiments, even if they are limited in scope, can be incorporated into models, contributing to their refinement. Among other advantages of the systems simulation approach, plot-, field-, and enterprise-scale models can be interfaced with larger scale economic models to study potential effects of wide-scale application of new technology.

Effective managers tend to accumulate knowledge by remembering experiences or cases in which a specific outcome was associated a with specific set of conditions. The emerging science of artificial intelligence promises to make the case history approach to studying production systems much more effective. In some situations, large databases of case histories can be assembled and analyzed using various machine-learning approaches associated with artificial intelligence. There are several examples in which such analyses led to new generalizations and rules of thumb of which human experts were not previously aware. Computers can store and rapidly process much larger sets of data than humans can store and process in their heads. Machine learning, knowledge engineering, and other dimensions of artificial intelligence promise to enhance human expertise on complex systems.

Systems science is a discipline in itself, but few agricultural scientists are trained in it. An agricultural systems science curriculum would include such subjects as systems analysis, systems engineering, operations research, and logistics, as well as courses in business systems and ecology. Just as specialists obtain an MBA (Masters of Business Administration) to add the business dimension to their expertise, some agricultural scientists should take additional training in systems to help them work effectively with other scientists on systems integration problems.

SUSTAINABILITY RESEARCH MUST BE EVALUATED APPROPRIATELY

Much sustainability research will necessarily be adaptive research. Unfortunately, such research is regarded as mundane by many researchers and tends to be expensive, labor-intensive, and time-consuming. Many researchers think that adaptive research is not intellectually challenging and can by conducted by less competent or well-trained researchers. For this reason fewer and fewer agricultural scientists are inclined toward adaptive research and few are being trained for it. This bodes ill for the future of U. S. agriculture.

Adaptive research is inevitably less glamorous than basic research. It reveals opportunities for small incremental improvements in productivity, rather than dramatic breakthroughs that are reported in the media.

Actually, dramatic innovation only occurs in the laboratory and the media. Almost all new agricultural knowledge, no matter how dramatic its discovery, is eventually implemented as small, incremental improvements in productivity, enabled by adaptive research.

Some adaptive research is of relatively low quality. However, it is often evaluated using the same criteria as are used to evaluate basic research, which is inappropriate. In general, basic research is expected to be innovative, that is, to reveal previously unknown relationships and phenomena. Also, conclusions of basic research are expected to be broadly applicable, that is, to be generally true.

In adaptive research, however, it is often necessary to repeat previous experiments with only small changes. Variety, tillage, fertility, and pest control experiments must be repeated in many environments, over periods of years. It may be necessary to repeat fertility experiments when new germplasm, tillage methods, and pest control strategies are introduced. Often the goal is not to reveal exciting new responses, but to get better quantitative estimates of responses and particularly of interactions. These estimates may not be of great scientific interest, but they may have great economic value.

From the standpoint of the constituency served by an adaptive research program, the results are more useful if they are not broadly applicable. To the extent that the information generated applies only to a region or locale, the producers in that region or locale gain competitive advantage from the research. These observations lead me to think we should apply other than the usual criteria when evaluating adaptive research.

The experiments of adaptive research should be designed to minimize the economic, environmental, or other risks that may be incurred by errors of inference, known to researchers as type 1, type 2, and type 3 errors. Carmer and Walker (1988) described ways to do this. The degree of variability in experimental soils and plants and how this relates to variability in farming regions should be measured in preparation for conducting adaptive research and drawing conclusions from it. The relatively new field of geostatistics provides measures of spatial dependence that should join means and variances as important parameters to be estimated in field experiments.

Researchers and users of adaptive research information should develop greater expectations for this activity. Adaptive research could be conducted in a much more sophisticated manner than is common practice now, if more of what is currently known about field experimentation were applied. The general lack of appreciation for the importance and technical difficulty of field experimentation and failure to commit adequate resources to this important activity contribute to the problem. Also, relatively little has been done to improve the equipment of adaptive research or to automate this very labor-intensive activity.

SUSTAINABILITY RESEARCH MUST BE WELL-MANAGED

I believe attempts should be made to improve the coordination of agricultural research, with the goal of speeding the process of conceiving, developing, and implementing new technology. The U. S. agricultural research and development system involves basic, developmental, and adaptive research, and technology transfer. Now these tend to be conducted sequentially, with each step being completed before the next step is begun.

There is great potential in conducting these activities in parallel rather than in series. Such an approach would start with identifying appropriate market, environmental, or social goals and assembling teams representing the four functions listed above. These teams would analyze the entire process leading to achieving the goal and identify the contraints to that achievement. Research and development resources would be directed toward removing those constraints.

The agents by which new agricultural knowledge will be implemented in practical operations, whether they be extension advisors, private consultants, or agribusiness people, should be involved in the planning and management of sustainability research. In this manner, it may be possible to anticipate problems associated with implementation and deal with them in research programs. The mechanism of implementation should be established as part of the research program, so as to integrate and expedite the various stages of research and development.

This organizational approach could be fostered without top-down management, which is detrimental to sustainability research. If, for example, competitive grants programs were conducted as goal-oriented instead of discipline-oriented programs, there would be financial incentives to organize self-managed, cross-functional teams to address important sustainability issues.

SUSTAINABILITY RESEARCH MUST BE WELL-SUPPORTED

Revitalizing and increasing the U. S. institutional capacity to conduct sustainability research, as described in this paper, will require considerably higher levels of public understanding and support. The payoff, however, in terms of more competitive, environmentally sound, resource-conserving, quality-oriented agricultural systems more than justifies this investment.

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CROP ROTATIONS ON THE CANADIAN PRAIRIES

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ABSTRACT

Long-term crop rotation experiments have been conducted at Agriculture Canada Research Stations in the Prairie Provinces of western Canada for many decades. More than 68 crop rotation studies have been conducted; twenty are ongoing. Topics that have been assessed include the effects of: rotation length, crop sequence, summerfallow substitute crops, and N and P fertilization on crop production, grain and forage quality, N and P uptake by plants, crop pests, soil moisture conservation and its efficient use, economic returns, non-renewable energy efficiency, and changes in physical, chemical, and biological properties of the soil. This paper highlights some of the recent findings from these studies.

INTRODUCTION

A crop rotation is a planned sequence of crops grown in recurring succession on the same area of land. Crop rotations have been studied in western Canada since the 1890's. Most studies were carried out by Agriculture Canada, but a few have been conducted by universities (Poyser et al. 1957, Robertson 1979, Robertson and McGill 1983). Ripley (1969) presented a comprehensive summary of crop rotation research carried out by Agriculture Canada up to 1965, including a thorough review of pertinent literature. We (Campbell et al. 1990) recently wrote a book that summarizes the findings of Agriculture Canada's crop rotation studies up to 1988. This paper focuses on some of the main findings and conclusions.

MATERIALS AND METHODS

More than 68 long-term crop rotation experiments have been conducted at Agriculture Canada Research Stations throughout the major soil zones of the Prairie Provinces (Figure 1). Of these studies, 20 still continue. The focus was on the effects of rotation length, crop sequence, summer-fallow substitute crops, and N and P fertilization on crop production, grain and forage quality, uptake of N and P by plants, crop pests, conservation of soil moisture and its efficient use, economic returns and non-renewable energy efficiency, and on changes in physical, chemical, and biological properties of the soil. This paper draws on published and unpublished data collected mainly since the early 1960's.

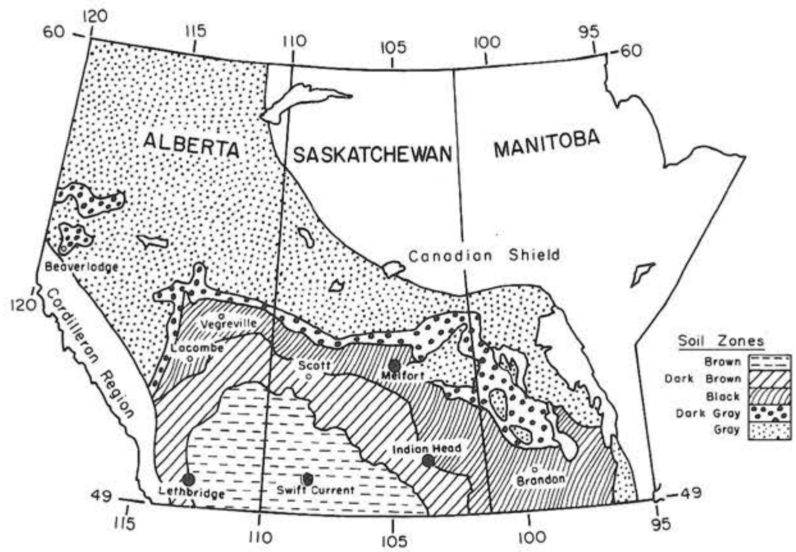

Figure 1. Location of Research Stations and major soil zones

SUMMARY OF RESULTS

Crop Production and Quality

Grain yields of crops grown on summerfallow were seldom twice those obtained from previously cropped land; thus, total output was generally highest for rotations in which the land was continuously cropped and lowest for rotations with high proportions of fallow.

Year-to-year variability in grain yields was considerably lower for fallow- than for stubble-seeded crops, reflecting the greater amount of moisture available to the former.

In the dry Brown soil zone, with recommended management practices, stubble-seeded wheat yields average 71-74% of those for fallow-seeded wheat; in the more moist Dark Brown soil zone they average up to 81% and, in the wet Black soils, up to 88% of fallow-seeded wheat yields.

The benefits of soil testing to determine appropriate rates of P fertilizer for fallow-seeded crops, and both N and P fertilizer for stubble-seeded crops were demonstrated.

Grain yields did not decline with time; in several studies they generally increased. However, the use of improved production technologies may have masked any decline resulting from reduced soil productivity.

Cropping sequence influenced yields, particularly in the Black and Gray soil zones, where cereal grain yields were often higher when grown on stubble of oilseed crops than on stubble of another cereal.

The inclusion of flax in the rotation often reduced subsequent wheat yields because greater weed infestations often developed in flax.

Rotations that included grass-legume forage crops or legume green manure crops may be practical in the Black and Gray soil zones, but their effects on subsequent cereal yields were neither always consistent nor beneficial; problems with plant establishment and competition for scarce moisture limited their suitability in the drier regions.

Grain quality (protein and density) was good under all treatments but generally decreased from the Brown to Dark Brown to Black and Gray soil zones.

Crop Pests

The limited results on agricultural pests showed that summerfallow and intertilled cropping systems had the least problems with weeds.

Flax and sweetclover were highly susceptible to the herbicides used to control weeds, whereas continuous cereals often succumbed to grassy weeds after 5-6 years of cropping.

Use of mixed cereal-forage rotations helped to suppress weeds in the Black and Gray soil zones.

The dry conditions common to the Brown and Dark Brown soil zones and the inherent resistance of hard red spring wheat to disease combined to minimize crop pest problems in these regions.

Soil Moisture

The quantity of moisture conserved in fallow and stubble soils has not changed compared to 30-40 years ago.

In the Brown and Dark Brown soil zones about 33% of the precipitation received in the 9 months between harvest and seeding of stubble crops, and between 18 and 20% of that received during the 21-month fallow period, were stored in the soil.

In the Black and Gray soil zones moisture conserved was often less than 10% of that received. Consequently, stored soil moisture commonly influenced yields in the drier areas, but rarely in the more humid areas.

In the Brown and Dark Brown soil zones, fallow systems had about 44 mm more moisture in the root zone than stubble systems at seeding. By the shot-blade stage of plant development this advantage had disappeared and by harvest both systems generally had no remaining available soil moisture.

Amount and distribution of rainfall received over the growing season was very important in determining final grain yields in the drier areas.

In all cropping systems, moisture availability during the grain filling period was most critical for final grain yields, but for stubble-seeded crops, having adequate moisture at seeding time was also important to ensure good seedling establishment.

Relationships between spring wheat yields and total moisture use showed that the average initial yield point (moisture required to produce the first bushel of grain) occurring at about 2.8 ins available moisture and each additional inch of moisture produced 3.5 bu per acre.

Use of perennial hay crops in cereal rotations in the drier regions depleted soil moisture reserves much more than annual crops; thus, subsequent grain yields were often reduced for several years.

In the Black and Gray soil zones, even though forage crops may cause significant reductions in soil moisture, they had little effect on yields of subsequent grain crops.

Nitrogen and Phosphorus Dynamics

Considerable amounts of NO_3-N can be leached below the rooting depth of spring wheat even in the normally dry Brown soil zone. Nitrate leaching was greatest under fallow systems. Losses were reduced by proper management of fertilizer, by use of continuous cropping rotations, and by growing fall-seeded crops such as fall rye.

Frequent applications of P fertilizer enriched available P in surface soil, especially when a crop was present and particularly in heavy-textured soils.

In the Black and Gray soil zones, plow-down of legumes and grasses increased the soil-available N. This extra N increased N uptake by the subsequent cereal crops; sometimes both yield and grain protein were enhanced, but in other cases only the latter was increased.

Soil Quality

The results confirmed the degradative effects of frequent fallowing on soil quality, evidenced by organic matter loss, depreciated organic matter quality, reduced microbial activity, and enhanced susceptibility to erosion.

Inclusion of legume green manure and grass-legume forage crops in the rotation with cereals benefited soil productivity. However, soil quality maintained by these rotations usually did not exceed that under adequately fertilized continuous wheat, perhaps because of the inclusion of fallow in the cereals-forage rotations.

Economic Performance

The realities of short-term economic survival will likely prevent producers from adopting rotations requiring annual cropping despite their long-term benefit to soil productivity. This situation is especially so in the Brown and Dark Brown soil zones where net returns were often much higher for rotations that included fallow.

The major deterrents to adoption of extended crop rotations in these regions were the higher cash outlay required to purchase the additional inputs (e.g., fertilizers, herbicides, and capital items) and the high risk of financial loss resulting from highly variable weather during the growing season.

In the Brown soil zone, producers could beneficially move from the traditional 2-year fallow-wheat rotation to a 3-year fallow-wheat-wheat rotation even though there is some additional cost and risk.

In the Dark Brown soil zone, although no evidence was found that producers could profitably extend rotation lengths beyond the 3-year fallow-wheat-wheat or fallow-canola-wheat, none of the studies in this, or in the Brown soil zone included intermediate length rotations (e.g., 4- or 5-year), thus it is unknown whether extending rotations beyond 3 years would be more, or less profitable.

In the Black soils, producers have the widest choice of cropping systems. Rotations that include only cereals, cereals and oilseeds, cereals and forages, and cereals and legume green manure crops combined with periodic use of summerfallow were all economically attractive under some cost-price situations. Only wheat in continuous monoculture was sometimes questionable because of problems with disease and, more recently, insects.

Energy Considerations

The limited results on energy considerations showed that in the Brown soil zone non-renewable energy inputs and metabolizable energy for human consumption were directly related to cropping intensity.

Inclusion of legumes in the rotation with cereals where moisture was less limiting, considerably reduced the requirements for non-renewable energy inputs, especially for N fertilizer, and thus improved energy efficiency.

CONCLUSIONS

Summerfallow remains a legitimate option in the cropping systems of western Canada, though its role and recommended use vary depending on edaphic and climatic conditions. In the Black and Gray soil zones, where moisture deficits are relatively small, summerfallowing can be justified only for control of otherwise unmanageable pests or in the event of potential drought. In the Brown and Dark Brown soils, however, where moisture stress is the primary yield-limiting factor, the replenishment of soil moisture during fallow reduces economic risks and warrants the inclusion of some summerfallow in crop rotation. Although frequent inclusion of fallow enhances soil degradation, this effect can be minimized by using techniques for conservation tillage, by use of partial fallows (e.g., green manure or cereal hay crops), or by reducing the frequency of fallow in the rotation. Economic analyses indicate that the optimum frequency for using fallow in the Brown and Dark Brown soil zones is about once in 3 years, though that value varies depending on soil and economic variables.

Inclusion of perennial forages in crop rotations represents an important means of improving soil quality, crop nutrition, and crop yields in the Black, Dark Gray, and Gray soil zones. Economic analyses indicate that extended rotations of spring wheat, with several years of forage grown for hay, generate favorable net economic returns. In the Brown and Dark Brown soil zones, the inclusion of perennial forages is not recommended because of excessive depletion of soil moisture by these deep-rooted crops.

The influence of one crop on the yield of a subsequent crop in the rotation is largely contingent on use of soil moisture by the first crop, residual fertility effects, and effect on pest populations. Oilseed crops (flax and canola) generally deplete soil moisture to a lesser extent than cereal crops and thereby increase the potential yields of subsequent crops in drier soils. These same crops, however, particularly flax, do not compete well with weeds and may therefore suppress the yield of subsequent crops by allowing weeds to proliferate. Regardless of cropping system, periodic rotating of crops is recommended for the control of certain weeds, diseases, and insects.

Fertilizers are assuming progressively greater importance in cropping systems as indigenous soil fertility declines and cropping systems are intensified. Appropriate application of fertilizers generally increases expected net returns, except in rotations having high frequency of fallow or forage and when costs of fertilizers are high. Aside from directly increasing yields, fertilizer application has three effects. It increases the efficiency of moisture use by stimulating root growth; it improves moisture conservation and snow-trapping by increasing surface crop residue, and it enhances long-term soil productivity by increasing the content and quality of organic matter. Ammonium-based fertilizers may depress soil pH, though significant acidification will likely occur only over the long term in most soils.

Long-term crop rotations indicate that agronomic practices greatly affect soil quality. They demonstrate, further, that soil productivity can be maintained indefinitely by adoption of economically viable, conservation-oriented management practices. Although most soils have exhibited an inevitable decline in concentrations of organic matter following initial cultivation, this trend has been halted or even reversed by the use of appropriate crop sequences and fertilizer strategies. Crop yields have generally increased over the decades since inception of arable agriculture, though the relative contributions of technological advances and soil quality dynamics to this trend are uncertain. Results of these studies therefore suggest that the dire predictions of inevitable declines in soil productivity are not necessarily a <u>fait accompli</u>, at least not for all producers.

The findings reported in the publication by Campbell et al. (1990) will benefit both the agricultural extension and scientific communities. Results presented represent the basis for the formulation of agronomic strategies which could be disseminated to producers. For the scientific community, this publication not only will provide background information, but also will serve to identify areas requiring research attention. As well, these studies may represent opportunities for the development or verification of simulation models, and in-depth, critical examinations of specific mechanisms.

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from Campbells Book

1. stubble as a % of fallow

Dry ~~75~~%
↓ ↓
wet 80%

2. wet land does not insure higher yields
disease etc

3. High N lowers pH .6 - .8 units

4.

used Stanfords method
to identify mineralizable N.

A TEAM APPROACH TO NITROGEN MANAGEMENT FOR PROFITABILITY AND GROUNDWATER PROTECTION - A RED RIVER VALLEY SUCCESS STORY

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ABSTRACT

Sugarbeet production practices have changed drastically in the last two decades in Minnesota and North Dakota. Changes in grower payment systems mandated change to production of high sugar content low impurity level beets. Development, refinement and extensive use of the soil nitrate-N test in concert with the sugar company quality payment program resulted in greatly reduced N fertilizer use while increasing crop yield and quality.

DISCUSSION

Sugarbeet production in the Red River Valley of Minnesota and North Dakota began in 1919 with 11 acres raised near Crookston, Minnesota. Interest in sugarbeet raising increased to the point where the American Beet Company (presently American Crystal Sugar Company) began operating a factory at East Grand Forks, Minnesota in 1926. More than 10,500 acres of sugarbeets were grown that year. Eventually American Crystal Sugar Company expanded to four factories with about 1,500 growers producing nearly 300,000 acres of sugarbeets. In 1972 Red River Valley sugarbeet growers organized a successful effort to buy the privately owned company. American Crystal Sugar Company became a cooperative when purchased by the growers for $66,000,000 in 1973. Three additional grower owned cooperatives were established at Wahpeton and Hillsboro, North Dakota in 1974 and Renville, Minnesota in 1975 respectively. The Hillsboro cooperative merged with American Crystal Sugar Company in 1975. In 1989 2,300 grower-owners produced over 500,000 acres of sugarbeets for these seven factories. The sugarbeet industry of Minnesota and North Dakota represents nearly 40% of the United States sugarbeet acreage. Sugarbeets are big business in the Red River Valley providing 30,000 jobs and over one billion dollars in economic impact to the region.

Before 1973 the privately owned American Crystal Sugar Company mandated many production practices to its contracted growers. Sugarbeets were produced with crop rotations that included summerfallow and a legume green manure crop. Nitrogen fertilizer application was strongly discouraged. The company maintained strict control of acreage contracts with few incentives for growers to produce a high quality, yet high yielding sugarbeet crop.

Numerous changes in Red River Valley sugarbeet production accompanied the purchase of the private sugar company by this group of progressive growers. Acreage allotments for sugarbeet contracts were now determined by the amount of stock the grower owned in the cooperative, one acre per one share of stock. The new grower-owners became concerned about profitability of the sugar company as well as their payment for sugarbeets delivered. Acreage allotments to growers expanded significantly in the 1970's. Major improvements were made in the processing factories along with sugarbeet piling and handling equipment. Farming practices began to rapidly change as well. Acreage of summerfallow declined sharply as federal government farm policies changed. By 1970 very few livestock enterprises were located in the Red River Valley and green manure crops essentially disappeared from crop rotations.

From 1970 to 1979 sugarbeet growers were paid on gross sugar delivered to the factory. Therefore it was to the growers advantage to raise the largest tonnage crop possible for maximum profit. Little regard was given to sugar content and crop quality. Nitrogen fertilizer application to all sugarbeet acreage greatly expanded in the early and mid 1970's. More nitrogen was routinely applied to beet fields than was required for maximum root yields. Even though the nitrate-nitrogen soil test was already available at North Dakota State University as early as 1968 less than two percent of the fields received fertilizer nitrogen recommendations based on the test. In the mid to late 1970's high yielding-low quality sugarbeet varieties became widely available to sugarbeet growers. In an attempt to produce even more tons per acre, over-fertilization with nitrogen became widespread. Extensive production of poor quality sugarbeets resulted in serious problems efficiently processing these beets. Cost of factory operations became much greater than necessary to produce a pound of sugar.

In response to these escalating factory operation costs, the growers adopted a new payment system in 1980 (Phase I), which paid a small premium for sugarbeets which had greater than average sugar concentration. This occurred because better quality sugarbeets allowed for more efficient sugar processing at the factory and more profit for the factory owners, the growers. Still under Phase I if a grower was located close to the factory it was to his benefit to raise a high tonnage crop. Phase I mandated a higher awareness of the value of high quality sugarbeets, thus more profit for all growers from more efficient factory operations.

The grower-owners took the quality concept another step forward in 1982. They then adopted a new beet payment system (Phase II) which put a much greater value on quality sugarbeets. A part of this payment system was a processing charge on a per ton basis against each individual field of beets raised by coop grower-owners. Grower return per ton declined sharply if they produced high tonnage beets with mediocre sugar content and low purity. This payment system put total emphasis on growers producing the highest possible levels of recoverable sugar per ton and per acre. Table 1 illustrates the effect of beet payment scale on return per acre from the 1980 versus the 1989 American Crystal Sugar Company crop.

Table 1. Effect of the American Crystal Sugar Company beet quality improvement program on the value[1] of a ton of sugarbeets

Payment Parameters	1980	1989
Recoverable sugar/ton (lbs)	268.0	298.0
Other sugar losses/ton (lbs)*	-48.9	-48.9
Recovered sugar/ton (lbs)	219.1	249.1
Value of sugar per ton (.24723/lb)**	$54.16	$61.68
Value of by-products ($/ton)**	$ 6.21	$ 6.21
Value of sugar and by-product/ton	$60.37	$67.79
Cost Of processing sugarbeets ($/ton)***	$27.33	$27.33
Net value of sugarbeets ($/ton)	$33.04	$40.56
Increased value of one ton of sugarbeets in 1980 versus 1989 = $7.52/ton		

[1]Based on American Crystal Sugar Company Grower Practices Record System Data (D. Hilde)
*Storage losses from beet piles, etc.
**Assumed mean realistic value of sugar and by-products for the 1980's.
***Assumed mean realistic cost of sugar factory operations

Assuming a total average production of 6,000,000 ton of sugarbeets per year, grower-owners of American Crystal Sugar Company would receive $45,000,000 dollars more for the high quality 1989 crop than the low quality 1980 crop.

What effect did this evolution of payment system have on crop characteristics and production practices? Table 2 lists root yield, sugar concentration, recoverable sugar per acre, and recoverable sugar per ton over the ten year period as payment systems changed. Yield and quality of beets produced increased steadily during this time.

The growers benefited in both productivity and profitability because of increased sugar yields, more efficient use of crop production inputs, especially nitrogen, and increased processing efficiency at the sugar factory. Another positive aspect from the increased factory efficiency is that the sugarbeet acreage available to growers could be increased without increasing factory size or capital expenditures.

Table 2. American Crystal Sugar Company root yield, sugar concentration, recoverable sugar per acre, and recoverable sugar per ton, 1980-1989

Year	Yield Ton/A	Sucrose Content %	Recoverable Sucrose Lb/Ton	 Lb/A
1980*	14.3	15.63	268	3832
1981	18.7	14.97	255	4769
1982	17.3	16.04	283	4896
1983	17.4	15.09	262	4559
1984	16.2	17.23	311	5038
1985	16.7	16.71	307	5046
1986	17.6	17.08	312	5491
1987	19.3	18.08	329	6350
1988*	13.4	18.25	330	4422
1989*	14.5	16.72	298	4321

*Much below average rainfall. (D. Hilde)

What management practices did Red River Valley sugarbeet producers adopt to meet the challenges of the 1970's and 1980's to increase crop quality?

1. Crop rotation: Crop rotation changed from those with sweet clover and summerfallow to rotations with grain crops, mainly spring wheat and barley. This reduced the amount of mineralized N from the rotation available to the sugarbeet crop. This change also caused an increase in use of inorganic N fertilizer which has made management of N inputs easier.

2. Soil Nitrate Test: The use of the soil nitrate test to depths of two or four foot each year sugarbeets are grown in the rotation and to a two foot depth during the other years of the rotation has become an invaluable N management tool. With semipermeable soils and annual rainfall of 22 inches or less in the Red River Valley where sugarbeets are grown, this soil test is very accurate in predicting N needs of each crop in the rotation. The adoption of the Phase I quality payment program in 1980 increased the use of soil nitrate testing particularly to a two foot depth.

Table 3 lists the number of fields soil tested to two and four foot depths from 1979-1989. Rapid increases in soil testing to a four foot depth occurred after adoption of the Phase II payment system in 1983, because of the knowledge of detrimental effects of soil N below two feet on quality of sugarbeets. Today approximately 80% of the sugarbeet acreage is sampled to a two foot depth and 50% sampled to the four foot depth. In other words the sugarbeet producers in the Red River Valley know that soil testing pays.

Table 3. Percent of American Crystal Sugar Company sugarbeet fields tested for N fertilizer recommendations, 1979-1989. (D. Hilde)

Year	Percent of Fields Sampled	
	0-2 feet	2-4 feet
1979	28	1
1980	42	5
1981	59	5
1982	72	6
1983	73	13
1984	77	26
1985	76	38
1986	78	40
1987	82	39
1988	71	41
1989	71	45

3. Reduction of Fertilizer N use: From 1972 to 1979 the maximum recommended N level was 260 lb/A for a 26 ton yield goal. This was a combination of soil nitrate-N in the 0 to 4 foot depth plus applied fertilizer N. This recommendation was reduced to a maximum of 175 lb/A for the period 1979 to 1983. This reduction occurred because of the application of Phase 1 economics to N rate research findings. This recommendation would not always produce maximum root yield, but gave the maximum <u>economic</u> yield. In concert with emphasis on high quality sugarbeet production programs the type of sugarbeet variety available to growers changed drastically to high quality types. The current N recommendation for most profitable sugar production is 120 lb/A as soil nitrate-N in the 0 to 2 foot depth plus fertilizer N. Reducing N rate recommendations was not an easy practice to convince the growers to follow. Because of this reluctance a long term (9 years) N fertilizer experiment was established at the University of Minnesota's Northwest Experiment Station at Crookston, MN to demonstrate what N rate was needed to maximize economic returns. The results, Table 4, substantiate the current recommendation with maximum gross return to the grower occurring between 100 and 125 lb of available residual soil nitrate-N in the 0 to 2 foot depth plus applied fertilizer N.

Cooperative extension service educational programs throughout the 1980's emphasized production practice changes to produce high quality sugarbeets. The American Crystal Sugar Cooperative agricultural staff worked closely with growers, North Dakota State University and University of Minnesota extension specialists and a cooperative allied industry to assure proper nitrogen fertilizer use. The joint effort of all these groups resulted in the successful production of high quality beet crops by the mid 1980's.

Table 4. Effect of level of available soil plus fertilizer nitrogen on sugarbeet yield and quality, 1978-1986.

Nitrogen Soil + Added 0-24"	Yield	Sugar	Recoverable Sugar			Phase II*	Gross Return/
lb/A	T/A	%	lb/A	%	lb/T	$/T	Acre($)
100	20.3	16.1	5639	87.5	281	26.07	529
125	20.6	16.0	5695	86.7	279	25.64	528
150	21.3	15.7	5740	86.4	272	24.11	514
175	21.2	15.2	5501	85.9	263	22.16	470
200	21.7	15.1	5489	84.5	255	20.42	443
Statistical Sig.	NS	**	**	**	**	--	--
B.L.S.D. (.05)	--	.2	246	.9	6.0	--	--

*Basis (Recoverable sugar/ton - 47.2 lb sugar lost to storage and processing x sugar price $21.73/cwt + $4.75 by-product revenue - membership cost) (L.J. Smith, Sugarbeet Agronomist, Northwest Experiment Station, University of Minnesota, Crookston, MN)

These production practice changes besides being economically attractive are also environmentally sound. Nitrogen fertilizer use is now about 65,000,000 lb less per year than it was in 1972 for sugarbeet production in Minnesota and North Dakota. The reduction in N fertilizer application has greatly reduced the amount of fall applied fertilizer N in the soil over winter and subject to movement before the year of sugarbeet production. The use of intensive soil testing has increased grower awareness of residual N levels in the soil, and provided for proper use of fertilizer N for high yield, high quality dryland sugarbeet production. At the same time an environmentally safe N use program minimizes the likelihood of surface or ground water contamination by improper N fertilizer use.

NEBRASKA'S APPROACH TO AGRICULTURAL NON-POINT POLLUTION

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ABSTRACT

Ground water quality and abundance in Nebraska is very good compared to the water resources of other states. Increasing public involvement, however, has brought attention to both organic and inorganic substances in water. Nitrate concerns have directed changes in agricultural practices. Legislation enabled two primary institu- tional agencies in Nebraska to effect change with authority given to them. Nebraska's Department of Environmental Control (DEC) coordinates effort with one or more of 23 Natural Resource Districts (NRD) to designate ground water Special Protection Areas (SPA) and to develop an Action Plan (AP) for the SPA which will attempt to stabilize or reduce nitrates in ground water. A unique feature of the working relationship between the two public agencies is a series of hearings which take place during the development of an Action Plan. In the designated area of the SPA, local urban dwellers, farmers, ranchers, consultants, fertilizer suppliers can contribute to development of restric- tions and requirements. It is the local, grass-roots, segment which must implement the provisions, requirements or restrictive use of commercial nitrogen fertilizer.

TEXT

Water is societies most precious resource impacting on the quality of life for each and every individual. Water abundance and scarcity both exists and initiate challenges for management, for priority uses and for quality maintenance. Each region of the United States provides a different set of circumstances for water policy and within each state the water resources provide a different framework from which water policy decisions are made. Today, I'll give you a brief perception of the groundwater concerns on Nebraska, leading to an active 1986 year of water legislation which generated a grass-roots fertilizer use plan.

Nebraska's groundwater is characterized as very abundant. Yet one must also address scarcity where rural and urban communities must depend upon programs to obtain water for household use. The abundant water supply lies within the Ogallala acquifer system. The system contains water bearing material from several geological formations, only one of which is the Ogallala formation. The Ogallala is extensive, reaching into seven states, but has 70 percent of its water supply in the central Sandhills area of Nebraska. Parts of Wyoming, South Dakota, Colorado, Kansas, Oklahoma and western Texas obtain water from the Ogallala formation. A perception of the underground water supply of Nebraska can be given as follows: If the underground water were placed on the surface of the state, it would cover the state to an average depth of 34 feet.

Nebraska rivers flow west to east from elevations of 5000 to 6000 feet on the west to 900 feet above sea level on the east. Inflow of water into the state is much less than outflow. Approximately 9 times more water flows out of the state than water entering into the state. The outflow is largely initiated from the Ogallala system or large underground pool which flows out through the Loup rivers. These rivers are steady flowing without seasonal or climatic cycle variation. The Ogallala aquifer system is maintained by underground water and by rainfall recharge. Snow melt in the eastern slopes of Wyoming and Colorado percolate downward in geological sandstone and gravel formations at very deep zones under the elevated foot slopes. These surface into the Ogallala pool. Rainfall recharge is effective due to a 14 million acre Sandhills region where surface runoff is negligible. Rainfall ranges from 34 inches per year in the very southeast corner of the state and gradually declines to 12 inches per year in the very northwest corner of the state. The Sandhills region ranges from 17 to 20 inches of rainfall annually to provide a significant recharge for the Ogallala formation.

The earliest record of irrigation is in the year 1926 in western Nebraska. In the next two decades irrigation developed along the major rivers on first or second terrace soils. By 1960 the state irrigated acres reached 2 million acres. Subsequently a rapid growth period averaging 250,000 acres per year continued until 1980 to reach at 8.4 million acres of irrigated land. Irrigation development and increased nitrogen fertilizer use were simultaneous. Availability of more local feed grains gave rise to cattle feeding enterprises. Today, Nebraska leads the nation with cattle on feed and exports red meat throughout the nation.

Interest in the nitrate content of groundwaters had its inception with a well-water survey (Hoover, 1962). Three percent of 1165 water samples had nitrate levels above 10 ppm (Table 1). One decade later (Muir et al., 1973), 547 of the original 1165 wells were sampled again (Table 2). These 547 water samples registered an average increase in nitrates of 29 percent. Most of the increase occurred in eight counties which registered a 50 to 170 percent increase. Granted, an increase from 2 ppm NO_3-N to 3 ppm represents a 50 percent increase. However, some wells registered changes of 10 ppm NO_3-N going from 20 to 30 ppm. In the decade between well water analysis.

Table 1. Nitrate-nitrogen content of Nebraska groundwater.

Nitrogen ppm	Number of Samples	Percent of samples	N in an acre foot of water lbs
< 0.9	440	38	0 - 2.4
1-9	695	59	2.7 - 24.5
19-19	24	2	27.2 - 51.7
> 19	6	1	> 51.7

Table 2. Ten-year change in NO_3-N

Number of Wells	Year	Average NO_3-N	% change in NO_3-N
		ppm	
547	1962	2.52	
547	1972	3.24	+29%
Eight Counties			+ 50 to 170%

irrigation wells, corn acreage, nitrogen fertilizer use had increased. Nitrogen fertilizer use nearly quadrupled, leading to renewed efforts to document the extent of NO_3-N in groundwater from fertilizer.

One can conclude that any of man's activities which generates more nitrogen than is generated in uninhabited, native land areas will result in an enrichment of waters above the natural system. Mineral N loads in river waters are greater during the months of September to March when no crops are actively growing.

In the 1986 banner year of legislation, two legislative acts directly affected agriculture practices. One is the chemigation bill. Its primary requirement is the installation of safety devices on center pivot irrigation systems used to apply herbicides, and insecticides with injection systems. Under this bill some 30 percent of center pivot operators who inject chemicals will spend $400 to $700 for eight devices that can insure safe and reliable chemical application. The eight devices will nearly eliminate any possible backflow of chemical into the well water source. The devices must be installed by the grower then inspected by the Natural Resource District (NRD) who has responsibility for soil and water resources management. The devices include the following requirements.

1. An interlock connecting the irrigation and the injection pump.
2. A low pressure drain.
3. A main pipeline check valve.
4. An inspection port.
5. A solenoid valve.
6. Chemical resistant hoses, clamps, fittings.
7. An injection line check valve.
8. Chemical suction line strainer.

In the same 1986 legislative year the Ground Water Contamination Act was passed. Its emphasis is on nitrate, however all contaminants of ground water are addressed. The legislation provides for Special Protection Areas (SPA) to be designated by the State Department of Environmental Control (DEC). Once groundwater contaminant has been documented by the DEC, the DEC can designate a Special Protection Area for a given non-point contaminant. Subsequently, the Natural Resource District (NRD) must develop a plan to stabilize, reduce or provide corrective measures for the designated area. A sequence of public hearings on measures take place with final approval by the DEC and for final implementation with NRD authority. The sequence spreads responsibility to a wide group, heavily influenced by farmers, from which one can expect reasonable corrective measures. Thus far, one area has been functioning as a SPA along Platte river counties (See Figure 1). The Central Platte NRD has implemented rules for governing nitrogen fertilizer use in this 450,000 acre area.

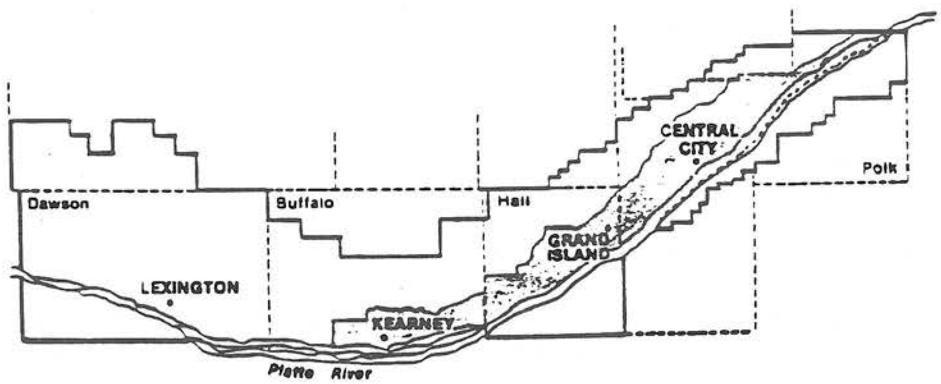

Figure 1. The Central Platte NRD area. Rules for Phase II practices apply only to the shaded portion of the area.

In the development of comprehensive ground water management plan the CPNRD (Central Platte Natural Resource District) implemented three levels of nitrogen management requirements. Increasing restrictions on provisions for nitrogen management increased with ground water nitrate levels. The levels of management restriction are as follows:

Phase I	Areas having an average ground water nitrate level between 0 and 12.5 ppm.
Phase II	Areas having an average ground water nitrate level between 12.5 and 20 ppm.
Phase III	Average ground water nitrate level above 20 ppm.

<u>Phase I Requirements</u> (0-12.5 ppm)

I-1. Fall and winter application of commercial nitrogen fertilizer is prohibited on sandy soils.

I-2. Nitrogen fertilizer can be applied on sandy soils after March 1st of the crop year.

Phase II Requirements (12.6-20 ppm)

II-1. All Phase I requirements apply here.

II-2. Fall application of nitrogen on fine textured soils is allowed after November 1 (soil temp 50° for less) and a nitrification inhibitor must be used.

II-3. Farm operators using nitrogen fertilizer must be certified.

II-4. Deep soil samples for residual nitrate soil tests must be done annually.

II-5. Irrigation water analysis for nitrate must be done annually.

II-6. An annual report must be submitted to the NRD by December 31 of the crop year.

Phase III Requirements (greater than 20 ppm)

III-1. All requirements of Phase II apply here.

III-2. Spring application of commercial nitrogen must be split (spring preplant, less than 50% of the total and side-dress remainder) or use of nitrogen inhibitor if preplant nitrogen is greater than 50% of the total commercial nitrogen application.

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CROPPING SYSTEMS AND FERTILIZATION FOR EFFICIENT WATER USE AND SUSTAINABILITY[1]

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ABSTRACT

The winter wheat-fallow system of farming usually is not the most efficient cropping system for utilization of precipitation in the Great Plains. This study evaluated the effects of N fertilization on crop yield, crop water use efficiency (WUE) and crop rotation precipitation use efficiency (PUE) in a winter wheat-corn-fallow and a winter wheat-sorghum-fallow rotation under dryland conditions. The study was conducted on a Planter loam soil using a no-till farming system. These 3-year rotations used precipitation and stored soil water more efficiently than a winter wheat-fallow rotation. Nitrogen fertilization improved crop yield, WUE and PUE significantly. Under current economic conditions, adequately fertilized 3-year rotations have a greater profit potential than the winter wheat-fallow rotation.

OBJECTIVE

Winter wheat-fallow is the dominant cropping system in the western portion of the Central Great Plains (Greb et. al., 1974; Greb, 1979b). Plant available water is limited and highly variable in this area (Greb, 1979a and 1979b; Greb et. al. 1974 and 1979). Thus, diversification in crop production has been limited, and producers have had few economic alternatives in years when wheat was in surplus and/or soil water supply was plentiful.

The winter wheat-fallow system usually is not the most efficient cropping system for utilizing precipitation with modern tillage technology. Reduced tillage and no-tillage cropping systems in the Central Great Plains have increased precipitation storage efficiency and increased the amount of soil water available for crop production (Greb, 1979a and 1983; Smika and Wicks, 1968; Wicks and Smika, 1973; Greb et al., 1974 and 1979; Mickelson, 1982). This additional soil water savings increased the opportunity for successfully growing spring planted crops such as proso millet, grain sorghum, and corn in rotation with winter wheat. For example, the winter wheat-proso millet-fallow rotation has been proven to be successful (Anderson et. al., 1986). Nitrogen management information for optimizing economic yields and water utilization within these 3-year cropping systems is limited.

This study evaluated the effects of N fertilization on crop yield, crop water use efficiency (WUE) and crop rotation precipitation use efficiency (PUE) in a winter wheat-corn-fallow and a winter wheat-sorghum-fallow rotation under dryland conditions. A no-till system was used to enhance the feasibility of cropping more intensively (2 crops in 3 years) than is

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[1]Contribution from USDA, Agricultural Research Service. In Proc. of 1990 Great Plains Soil Fertility Conference, March 6-7, 1990, Denver, Colorado.

currently being done in the Central Great Plains with the winter wheat-fallow system. The study objectives were: 1) To determine the long-term grain yields of each respective crop in a wheat-corn(sorghum)-fallow rotation under dryland conditions; 2) To determine the N fertilizer requirements to obtain optimum economical grain yields in these 3-year rotations; and 3) To determine the effects of N fertilization on crop water use efficiency and crop rotation precipitation use efficiency. The purpose of this paper is to present a summary of the yield and crop water use data from this study.

PROCEDURES FOLLOWED

Nitrogen treatments (0, 25, 50, 75, and 100 lb N/acre) were arranged in a randomized complete block design with 4 replications. Identical sets of plots were established in the fall of 1984 on 3-adjacent areas to allow each crop of each rotation to be grown each year. Winter wheat was planted on the area that had been previously summerfallowed. During the second year of the rotation, the wheat plots were split with half the plot planted to corn (Pioneer 3732) and half to grain sorghum (Pioneer 8790). During the third year of the rotation, the plots were chemically summerfallowed to maintain the plots in a no-till condition. Glyphosate or paraquat were used to control weeds immediately after wheat harvest, with atrazine being applied soon after wheat harvest to provide residual herbicide control of weeds through the corn or sorghum crops. In 1986 and 1987, bladex and dual were used to control weeds in the corn and sorghum rather than atrazine. Glyphosate plus 2,4-D or paraquat was used during the summerfallow period as well as bladex (short term residual) to control weeds. The number herbicide applications needed to control weeds varied with yearly climatic conditions. Broadleaf weeds were controlled in the wheat with 2,4-D. The study was located on a Platner loam soil at the Central Great Plains Research Station, Akron, CO.

The plot areas were planted to the appropriate crop each year following the established winter wheat-corn(sorghum)-fallow rotation. Winter wheat (Vona, 1984; Tam 105, 1985, 1986; Tam 107, 1987-89) was planted about September 20, corn (Pioneer 3732) about April 25, and grain sorghum (Pioneer 8790) about May 15 each crop year. Nitrogen fertilizer was applied at the specified rates prior to or at planting each crop year.

Soil samples from the 0- to 4-ft and where possible 0- to 6-ft depth in increments of 0-6", 6-12", 1-2', 2-3', 3-4', and 4-6' were collected just prior to seeding of each crop and/or each spring and again after winter wheat, corn and sorghum harvest. Soil water content was determined gravimetrically. The Platner loam soil used in this study had a sand and gravel layer below the 4-ft depth; therefore, a representative soil sample could not always be obtained. For this reason, soil water use measurements were limited to the top 4 ft of soil. Precipitation was monitored daily during the study. Grain yields were measured and crop water use or evapotranspiration (growing season precipitation plus soil water use) determined for each crop. Standard statistical procedures were used to analyze the data.

RESULTS AND DISCUSSION

Winter wheat grain yields (5-yr average) increased significantly with increasing N rate (Fig. 1). The application of 75 lb N/a increased winter wheat yields 17 bu/a over the check (no N) treatment. Corn yields in Fig. 1 represent a 3-year average grain yield (1986,1988, 1989) and a 4-year average which includes 1987 data when at least 60% of the yield was lost to hail on August 4th. Sorghum yields were also affected by the hail. Therefore, a 3- and 4-year average grain yield is also presented for sorghum. Corn grain yields increased significantly with increasing N rate up to 100 lb N/a. Sorghum yields increased up to 50 lb N/a and then declined with further increases in N rate. The year x N rate interaction was significant for each crop. This occurred because of periods of limited water supply and crop water stress during the 1988 and 1989 crop production years that limited yield responses to N fertilization. For purposes of this paper, only the average yields will be presented realizing that response to N fertilization can vary from year to year with climatic conditions.

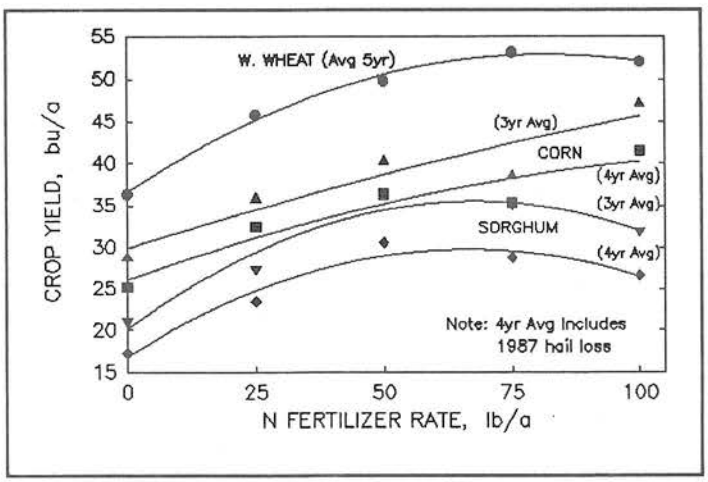

Fig. 1. Average winter wheat, corn, and sorghum yields as a function of N rate.

The effects of N fertilization on water use efficiency (WUE) by each crop are shown in Fig. 2. Soil water use (0- to 4-ft soil depth) by each crop generally was not greatly affected by increasing N fertilizer rate. Therefore, crop WUE was calculated as grain yield divided by evapotranspiration (ET), where ET was calculated as the sum of the precipitation received between the time of spring soil water determination and soil water determination after crop harvest plus the water depleted from the soil in the 0- to 4-ft depth. Nitrogen fertilization significantly increased the WUE of winter wheat (5-yr average), with WUE increasing with N rate up to 75 lb N/a. At this N rate, 4.4 bu/a of winter wheat were obtained for each inch of ET. The WUE of corn (3-yr average) also increased with increasing N rate, with 3.5 bu/a obtained for each inch ET at the 100 lb N/a rate. Sorghum WUE (3-yr average) was optimized (2.9 bu/a/in) with the application of 50 lb N/a. Crop WUE was in the order winter wheat>corn>sorghum under the conditions of this study. These data show that N fertilization is essential in the Central Great Plains if water use by crops is to be optimized.

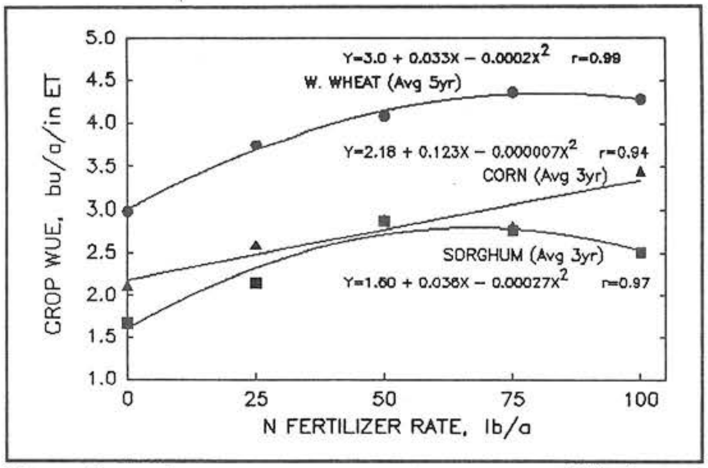

Fig. 2. Average crop water use efficiency (WUE) as a function of N rate.

Precipitation use efficiency (PUE) of each 3-year cropping system was calculated for four completed sequences of each rotation, including the reduced corn and sorghum yields caused by hail in 1987. The precipitation totals are for a 36-month period starting with the summerfallow period on October 15 after corn(sorghum) harvest and ending with corn(sorghum) harvest 36 months later. Precipitation totals for the 4 sequences used here were 50.7" for October 15, 1984 to October 14, 1986; 50.9" for October 15, 1985 to October 14, 1987; 50.4" for October 15, 1986 to October 14, 1988; and 49.9" for October 15, 1987 to October 14, 1989. The long-term (81 yr) average 36-month total precipitation is 49.6". Therefore, the years evaluated in this study received normal precipitation levels, although timeliness and distribution of the precipitation was a problem for crop production in 1988 and 1989. The PUE was calculated by summation of the total pounds of grain produced per acre (i.e. wheat + corn) over the 3-year sequence and dividing the result by the 36-month precipitation total. The PUE of the wheat-corn-fallow sequence increased significantly with increasing N rate, with the highest PUE (112 lb grain/a/in water) obtained with the 100 lb N/a treatment (Fig. 3). The PUE of the wheat-sorghum-fallow sequence increased significantly with increasing N rate up to 75 lb N/a which had a PUE of 98 lb grain/a/in water. The wheat-corn-fallow sequence had a higher level of PUE than the wheat-sorghum-fallow rotation at this location. This would probably change for other areas of Colorado, such as southeast Colorado where sorghum is better adapted than corn. Nitrogen had a significant impact on precipitation utilization by these dryland crops in the Central Great Plains. The PUE of these 3-year rotations were higher than that of a long-term winter wheat-fallow rotation (85 lb grain/a/inch) conducted at a near by site at the Akron Station (Smika, 1990). These more intensive rotations made better use of the precipitation received and will reduce the potential of leaching agricultural chemicals through the soil profile toward the groundwater table.

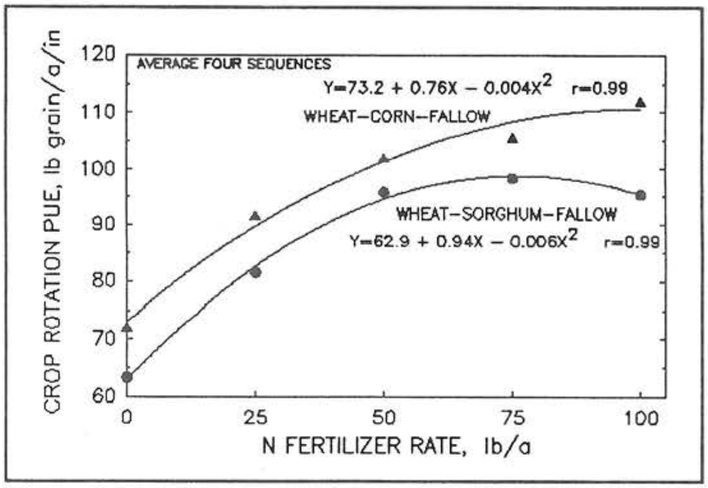

Fig. 3. Crop rotation precipitation use efficiency (PUE) as a function of N rate.

wheat-fallow
mz4 at 68^{00}/A/yr

An estimated gross income, less N fertilizer cost, is shown in Fig. 4 for the average winter wheat (5yr), corn (3yr), and sorghum (3yr) yields obtained in this study. Assumptions made were: wheat = \$3.80/bu; corn = \$2.40/bu; sorghum = \$2.13/bu; ammonium nitrate applied to wheat = \$0.23/lb N; and anhydrous ammonia applied to corn and sorghum = \$0.10/lb N. Based on these assumptions, maximum economic yield was obtained with 75 lb N/a on wheat, with 100 lb N/a on corn, and with 50 lb N/a on sorghum (Fig. 4).

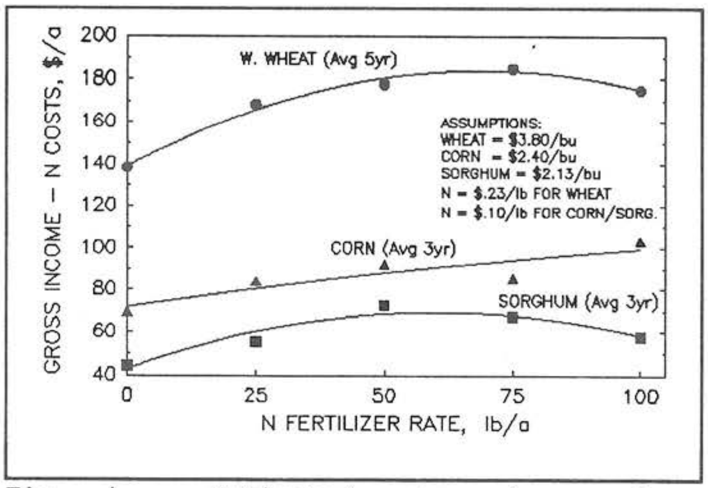

Fig. 4. Estimated gross income less fertilizer cost based on average crop yields.

Total gross income, less N costs, from each rotation expressed on a per year basis (includes fallow year) shows that per year income was higher for the wheat-corn-fallow rotation than for the wheat-sorghum-fallow rotation (Fig. 5). Yearly gross income for the winter wheat-corn-fallow rotation at optimum N rate was \$93/a/yr and for the winter wheat-sorghum-fallow rotation \$84/a/yr. This compares to an estimated \$68/a/yr return for the last five wheat-fallow cycles of the long-term study of Smika (1990) which received 50 lb N/a. Thus with adequate N fertilization, profit potential is greater with the 3-year rotations.

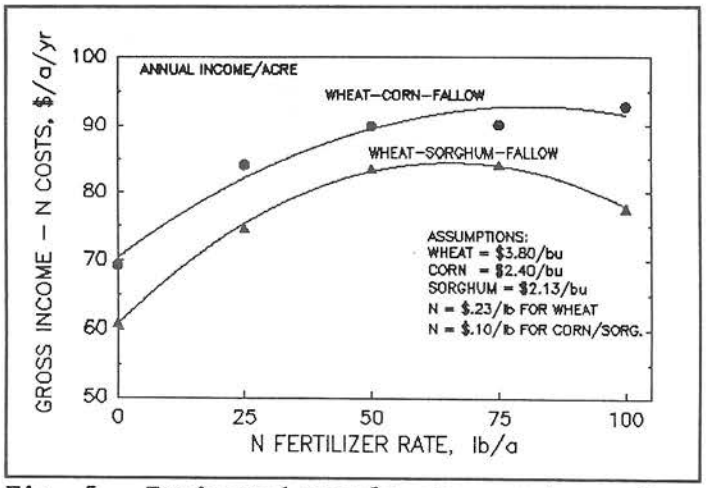

Fig. 5. Estimated yearly gross return minus N costs for the 3-year rotations as a function of N rate.

Other potential benefits from a 3-year rotation vs winter wheat-fallow would be: a reduction in the severity of winter annual grassy weed problems, especially downy brome and jointed goatgrass; reduction in amount of soil erosion due to a reduction in time that a crop is not covering the soil surface, and added surface residues due to reduced tillage system; a reduction in weed, disease, and insect problems by crop rotation; reduced risk of crop failure due to weather (hail, low precipitation) by having greater crop diversification; more efficient use of farm machinery as a result of more acres in crop production per farm unit; and spreading the work load out over more of the year. With the current emphasis on environmental quality and economic sustainability of agriculture, the 3-year rotation offers great possibilities for improved crop production in the Central Great Plains.

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USDA-ARS SOIL FERTILITY RESEARCH AT AKRON, COLORADO

The purpose here is to briefly outline the soil fertility research projects being conducted by USDA-ARS and cooperators at the Central Great Plains Research Station at Akron, Colorado.

PROJECT TITLE: Effect of N fertilization on water use efficiency by winter wheat, barley, and corn in the Central Great Plains.

Objective: Determine the effects of N fertilization on crop yields, quality, and water use efficiency with reduced tillage and annual cropping under dryland conditions.

Personnel: Ardell D. Halvorson and C. A. Reule, USDA-ARS, Akron, CO.

PROJECT TITLE: Management of P fertilizer for dryland winter wheat in reduced tillage systems.

Objective: Determine most efficient method of P placement for optimum economic yields and the value of residual fertilizer P for future wheat production.

Personnel: Ardell Halvorson, USDA-ARS, Akron, CO and John Havlin Kansas State University, Manhattan.

PROJECT TITLE: Crop rotation and N fertilization for efficient water use.

Objective: Determine the potential of producing economical dryland corn or sorghum yields following winter wheat in a wheat-corn(sorghum)-fallow rotation using reduced tillage systems. The N fertilizer requirements for optimum crop production and efficient water use are being evaluated.

Personnel: Ardell Halvorson and David Nielsen, USDA-ARS, Akron, CO.

PROJECT TITLE: Winter wheat variety response to N fertilization.

Objective: Determine the interaction between winter wheat varieties and rate of N fertilization under dryland conditions.

Personnel: Jim Quick, CSU Agronomy Dept., Fort Collins and Ardell Halvorson, USDA-ARS, Akron, CO.

Winter wheat - Corn - Fallow maxed income at AKRON (3 yr)

CROP ROTATION AND TILLAGE EFFECTS ON SOIL ORGANIC C AND N

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Kansas State University

D. E. Kissel
University of Georgia

ABSTRACT

Sustaining or increasing soil productivity may depend on soil and crop management practices which maintain or increase soil organic matter. This study was conducted to determine the effects of tillage and crop rotation on soil organic carbon (C) and nitrogen (N). Two long-term tillage/rotation studies were conducted on a Grundy sicl and a Muir sil soil in eastern Kansas. Soils were sampled from conventional (CT) and no-tillage (NT) treatments applied to continuous sorghum, continuous soybean, and sorghum-soybean rotations. At both locations, increasing the frequency of sorghum in the rotation increased the quantity of residue produced and increased soil organic C and N (continuous sorghum > sorghum-soybean > continuous soybean). Compared to CT, maintaining crop residues on the soil surface with NT generally resulted in greater soil organic C and N. Crop management systems that include high residue-producing crops and maintenance of surface residue cover with reduced or no-tillage results in greater soil organic C and N, which may improve soil productivity.

INTRODUCTION

Numerous soil chemical, biological, and physical properties contribute to the 'productive capacity' of soil. Many of these properties can be used to indicate or assess relative soil productivity, although soil organic matter content has been the most common soil property used. Unfortunately, cultivation of soils for food and fiber production has resulted in substantial declines in soil organic matter and, in most cases, native soil productivity.

Several long-term tillage studies have quantified soil organic matter losses with cultivation (Haas et al., 1957; Bauer and Black, 1981; Tiessen et al., 1982). These studies showed that in most Great Plains soils, soil organic matter contents have declined approximately 50% after 40 or more years of cultivation. The decline in organic matter in cultivated soils over time is primarily related to (1) the 'biological oxidation' of soil humus resulting from increased soil aeration with tillage, and (2) the 'physical loss' of unprotected, organic matter rich topsoil by water and wind erosion processes. Therefore, increasing surface residue cover or increasing surface soil 'protection' with crop residues, and reducing the intensity of cultivation should increase, maintain, or at least reduce the decline in soil organic matter content.

The objectives of this research were to evaluate the influence of cultivation and crop rotation on soil organic C and N in several Kansas soils.

MATERIALS AND METHODS

Long-term tillage/crop rotation studies were initiated in eastern Kansas on a Muir sil (Agronomy Farm-Ashland) in 1975 and on a Grundy sicl (Powhattan Experiment Field) in 1974 (Table 1). Continuous sorghum, continuous soybean, and sorghum-soybean rotations were grown at each site and NT and CT treatments were used with each rotation. All crop residues were maintained on the soil surface in the NT treatments, while all of the crop residue was incorporated in the CT treatment with chisel and/or disk operations. Soils from each tillage-rotation treatment were sampled prior to planting in April, 1987, at 0 to 1, 1 to 3, 3 to 6, and 6 to 12 inch depths. Soil samples were analyzed for total C by dry combustion using a LECO carbon analyzer and for total N by salicylic-sulfuric acid digestion followed by analysis on a Technicon Auto Analyzer. Ammonium and NO_3-N also were determined by extraction with 2 M KCL and colorimetric analysis similar to that used for total N. Organic N was calculated as the difference between total N and NH_4-N + NO_3-N. Soil organic matter was estimated by multiplying organic C% by 1.8.

Table 1. Soil characteristics and tillage management for the two locations.

	Soil Series	
	Grundy sicl	Muir sil
County	Brown	Riley
Soil class.	fine,mont.,mesic Aquic Argiudoll	fine-silty,mixed,mesic Cumulic Haplustoll
pH	5.8	5.5
CEC (me/100g)	27	20
Clay (%)	38	26
Fall tillage+	none	chisel plow
Spring tillage+	disc	disc

+ Tillage practices applied to CT treatments only.

RESULTS AND DISCUSSION

At both locations organic C and N decreased with soil depth and tillage/crop rotation effects were primarily observed in the surface six inches, thus only these data are presented. Increasing the frequency of sorghum in the rotation increased soil organic C and N in both soils, although the treatment effects were greater for the Muir soil than for the Grundy soil (Table 2). Compared to CT, maintaining crop residues on the soil surface with NT resulted in greater organic C and N content, except in the soybean rotations on the Grundy soil. Rotation and tillage had a greater effect on the Muir silt loam (28% clay) compared to the Grundy silty clay loam (36% clay), most likely because of differences in soil texture.

Differences in organic matter content, calculated from organic C data, with tillage and rotations were directly related to the quantity of residue produced and left on the soil surface after harvest (Fig. 1). In both soils the quantity of residue produced decreased with increasing frequency of soybean in the rotation (continuous soybean < soybean/sorghum < continuous sorghum). These data show that increasing the quantity of residue returned to the soil by increasing the frequency of high residue producing crops in the rotation will increase soil organic matter greater than including soybean in the rotation (Fig. 1). This effect is more pronounced under NT compared to CT. Estimates of soybean grain N removed and soybean residue N returned to the soil showed that each soybean crop actually depleted soil about N 22 lb N/a/yr.

Recent studies in Ohio also demonstrated the effect of tillage management and crop rotation on soil organic C and N (Dick et al, 1986a, 1986b). After 19 years, organic C and N in the surface three inches of soil were 1.5 and 1.3 times greater, respectively, under NT compared to CT management. Even though soybean residue has a higher N content than non-legume residues, organic C and N levels were greater with continuous corn than with corn/soybean rotation. These differences were greater under NT than under CT. In these studies, the crop rotations producing the greatest quantity of residue resulted in higher organic C and N contents. Reducing tillage intensity magnified the rotation effects.

Since these data demonstrate that rotations which maximize residue production increase soil organic matter, then increasing yields should have a similar effect. Results from N rate studies in Kansas showed that soil organic matter increased about 10% after ten years or more of 200 lb N/a applied to continuous corn or sorghum, compared to the unfertilized treatments (data not shown). The difference in organic matter between N fertilized and unfertilized soils was directly related to dry matter or yield response to fertilizer N. At one of these sites, increasing the frequency of soybeans in the rotation (i.e. lower crop residue produced) decreased organic matter content compared to continuous corn.

CONCLUSIONS

Results from these and similar studies demonstrate that (1) maintaining surface residues by reducing tillage, (2) increasing the quantity of residues with appropriate rotations, and (3) supplying sufficient fertilizer N to optimize grain yield can increase, maintain, or reduce the decline in soil organic matter content. Crop rotations that include grain legumes will always be economically viable rotations; however, the importance of maximizing grain yields to produce high residue levels, combined with maintaining surface residue cover, will help sustain the productive capacity of our soils for future generations.

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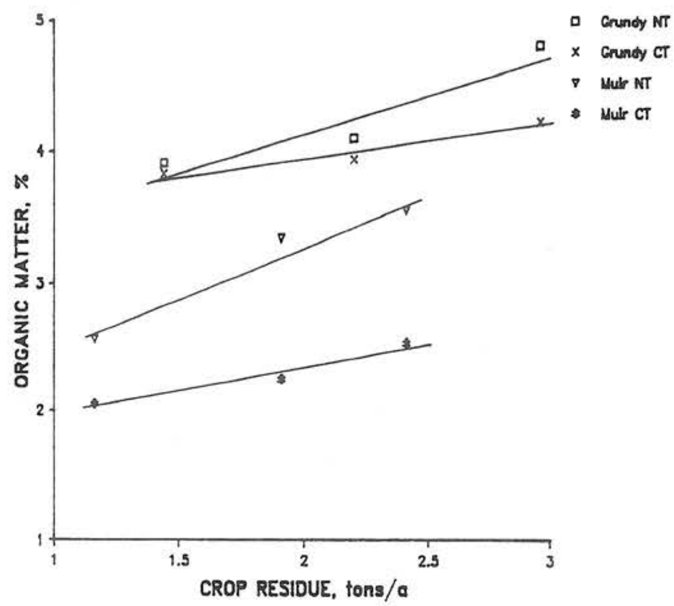

Figure 1. Effect of crop residue level and tillage on soil organic matter content in the Grundy and Muir soils. The three data points, left to right on each line, represent continuous soybean, soybean/sorghum, and continuous sorghum rotations.

Table 2. Crop rotation/tillage effects on soil organic C and N in the Muir sil and Grundy sicl soils.

Rotation	Depth	Organic C		Organic N	
		CT*	NT*	CT	NT
	in.	%			
Muir sil					
Cont. Soybean	0-1	1.14	1.43	0.109	0.126
	1-3	1.13	1.13	0.104	0.102
	3-6	1.10	1.10	0.100	0.099
Soybean/Sorghum	0-1	1.25	1.86	0.114	0.156
	1-3	1.23	1.30	0.114	0.114
	3-6	1.16	1.19	0.099	0.088
Cont. Sorghum	0-1	1.41	1.98	0.120	0.168
	1-3	1.36	1.25	0.118	0.112
	3-6	1.26	1.16	0.113	0.103
Grundy sicl					
Cont. Soybean	0-1	2.17	2.13	0.177	0.178
	1-3	2.09	1.98	0.163	0.153
	3-6	2.02	2.00	0.151	0.155
Soybean/Sorghum	0-1	2.19	2.28	0.176	0.189
	1-3	1.94	1.98	0.148	0.152
	3-6	1.83	1.87	0.139	0.141
Cont. Sorghum	0-1	2.35	2.67	0.186	0.205
	1-3	2.15	2.26	0.163	0.168
	3-6	2.07	2.08	0.158	0.155

ANOVA		Organic C	Organic N
Muir sil	df	P > F	P > F
Tillage	1	0.01	0.03
Rotation	2	0.01	0.04
Depth	3	<0.01	<0.01
Grundy sicl			
Tillage	1	0.17	0.13
Rotation	2	<0.01	<0.01
Depth	3	<0.01	<0.01

*CT = Conventional tillage NT = No-tillage

John showed a corn study
where adding 1.2 extra ton of Residue
increased the 0-1" O.M. by .3%

Tons	OM
6.2	1.9
2.8	1.6
1.2	.3

1. 2×10^6 # soil/6" = $.33 \times 10^6$ #/1"

2. $.33 \times 10^6 \times .003$ = 990 # om added (increased)

3. $\frac{1.2 \times 2000}{990}$ = # straw/# om
= 24# Residue/# om

4 $\frac{990}{24000}$ = ~ 4%

AMMONIUM THIOSULFATE RESEARCH, 1988-1990

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Research was begun in the winter of 1983-1984 to evaluate the effects of ammonium thiosulfate (ATS, 12-0-0-26S) on urea hydrolysis, ammonia volatilization, and nitrification. Much of this research has been published. The purpose of this presentation is to report on the highlights of our unpublished ATS research.

ATS-DCD mixtures as nitrification inhibitors

A major fertilizer company has introduced both solid and liquid fertilizers containing urea, ATS and dicyandiamide (DCD) as a slow-nitrifying product. Published studies on the interactive effects of ATS and DCD on nitrification have not been found, so laboratory and field experiments of ATS-DCD mixtures as nitrification inhibitors were undertaken.

A laboratory study was conducted as follows. A Williams loam or Fargo clay was incubated in French square bottles in a growth chamber. Solubilized urea was mixed with 5 levels of DCD in the solution (0, 0.5, 1, 2, or 5% of N as DCD-N) or two levels of ATS (0, or 8.7% vol/vol) in a factorial arrangement. The level of urea was adjusted so that all solutions contained 18.6 g of N/100 mL. The treatments were applied as a 0.100 g droplet on the soil surface. After incubation (about 17 days), and the soils were extracted and analyzed for ammonium, nitrite and nitrate. Incubation time varied with soil type, but was designed to coincide with about 80% of the added N being nitrified in the urea-only treatment.

A summary of the laboratory results are shown in Table 1. As expected, DCD gave a pronounced inhibition of nitrification at every level tested. Nitrification was very slow at a DCD rate of 5% of added N, a rate commonly recommended for field use.

The addition of ATS also inhibited nitrification. However, adding ATS alone led to some nitrite accumulation (20 ppm). Adding even 0.5% of N as DCD-N (about 0.15 g/100 mL of fertilizer solution) reduced the nitrite accumulation to a negligible level (3 ppm). No nitrite accumulated when DCD was applied at levels $\geq$1% of N. It was apparent that ATS-DCD mixtures gave superior control of nitrification than comparable rates of DCD alone.

This laboratory study gave us encouragement to test ATS-DCD mixtures in the field. The field evaluations were conducted at 10 sites in North Dakota during 1988 and 1989. The solutions used were similar in composition to those used in the lab study. Urea, ATS, and DCD were formulated so that two levels of ATS were studied (0 and 10% vol/vol), two levels of DCD were studied (0 and 2% of N as DCD-N), and a total N content of 18.6 g of N/100

Table 1. Nitrite and nitrate production by two soils after incubation with a droplet of solubilized urea containing various levels of ATS or DCD.

DCD level	ATS level	Nitrite	Nitrate
% of N	% vol/vol	-------ppm N+-------	
0	0	0	195
0.5		0	101
1.0		0	66
2.0		0	38
5.0		0	15
0	8.7	20	42
0.5		3	45
1.0		0	34
2.0		0	20
5.0		0	11

+Nitrogen levels reported as the increase above unfertilized control soils.

Field nitrification rates were studied using a "buried bag" technique. In short, 300 g of topsoil was gently packed in a nylon mesh bag placed in a 10 cm diameter form, a droplet of fertilizer (0.25 mL) was added, another 300 g of topsoil was added, and the bag was tied shut. The bag was then placed in a 10 cm diameter bucket auger hole, buried, removed after a specified interval, and analyzed for residual ammonium. This method has given us quite precise data on the relative nitrification rates of various solid or liquid fertilizers. Roots and rainfall freely penetrate the bags.

Spring applications were made at normal seeding time for small grains and samples were taken 4 or 8 weeks later, and all sites were seeded to either wheat or barley. Fall applications were made in late September or early October and were not seeded.. The first sampling was taken at fall freeze-up or first spring thaw, and the second sampling was taken about 4 weeks after the spring thaw. Four sites were established for the Spring 1988 applications, three sites for the Fall 1988 applications, and three sites for the Spring 1989 applications.

The results from the spring applications are shown in Figure 1. After 4 weeks only 20% of the added N could be recovered as ammonium when urea alone was applied. The average recovery was increased to above 30% when ATS was added. The effect of ATS was significant at 2 of the 7 sites. Adding 2% of N as DCD also increased recovery of ammonium to over 40%. The average value for the ATS-DCD mixture was about the same as for DCD alone.

The results after 8 weeks were similar to the results obtained after 4 weeks, except the overall levels of ammonium recovery were lower. Only about 5% of the added N could be recovered as ammonium for the solution containing urea alone. The recovery as ammonium was increased to almost 10% with ATS. The effect of ATS was significant at 1 of the 7 sites. About 12% recovery as ammonium was observed for DCD and for the ATS-DCD mixture.

The results of the three fall application sites are shown in Figure 2. The fall of 1988 was dry, so nitrification was slower than normal. About 45% of the added N was recovered as ammonium with urea alone at the first sampling. The recovery was increased to >60% with ATS. The effect of ATS was significant at all three sites. A similar result was obtained with DCD alone. When ATS and DCD were both used, improved recovery of ammonium was observed at one of the three sites.

At the second sampling, the recovery of N as ammonium was quite low (<5%) with urea alone. This was increased to 10% with ATS, being statistically significant at 1 of the 3 sites. Adding DCD increased this value to about 20%, and there was a measurable benefit to using both DCD and ATS at 2 of the 3 sites.

The conclusions of this study are that ATS does seem to be a mild nitrification inhibitor under the conditions tested, but not as effective as DCD. There does seem to be some advantage to using ATS and DCD together, but this advantage is not consistently observed at every location.

The use of ATS as a nitrification inhibitor has been criticized based on laboratory studies showing nitrite accumulation. We analyzed the soil samples from our field studies for nitrite and never found nitrite present, even when significant effects of ATS on ammonium recovery were observed. The soils were dried before analysis, however, which can lower nitrite recovery. It is unlikely that the air-drying process caused a total destruction of nitrite in these alkaline soils.

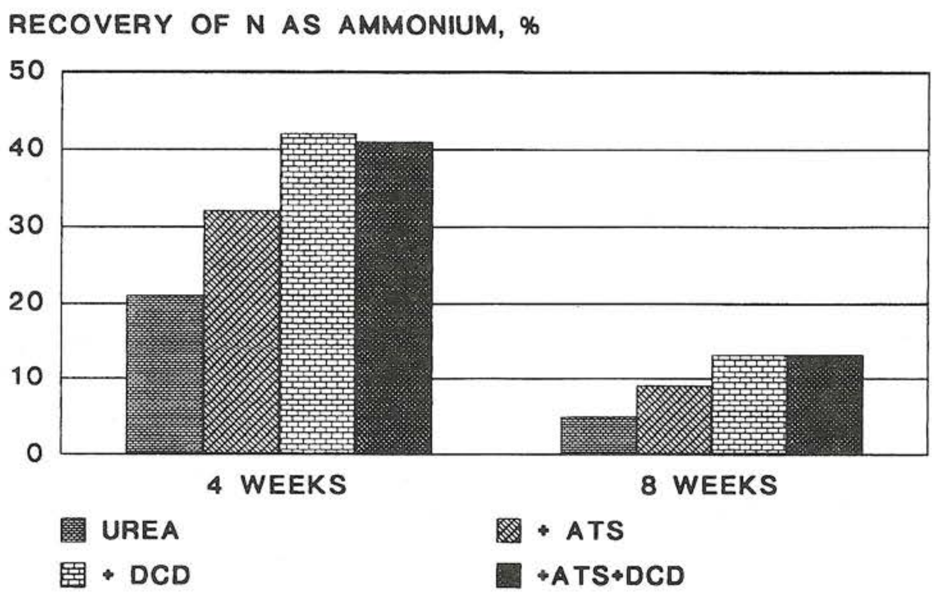

Figure 1. Effect of adding ATS and DCD to solubilized urea on recovery of ammonium from the soil 4 or 8 weeks after application. Seven-site average, spring applications, North Dakota, 1988-1989.

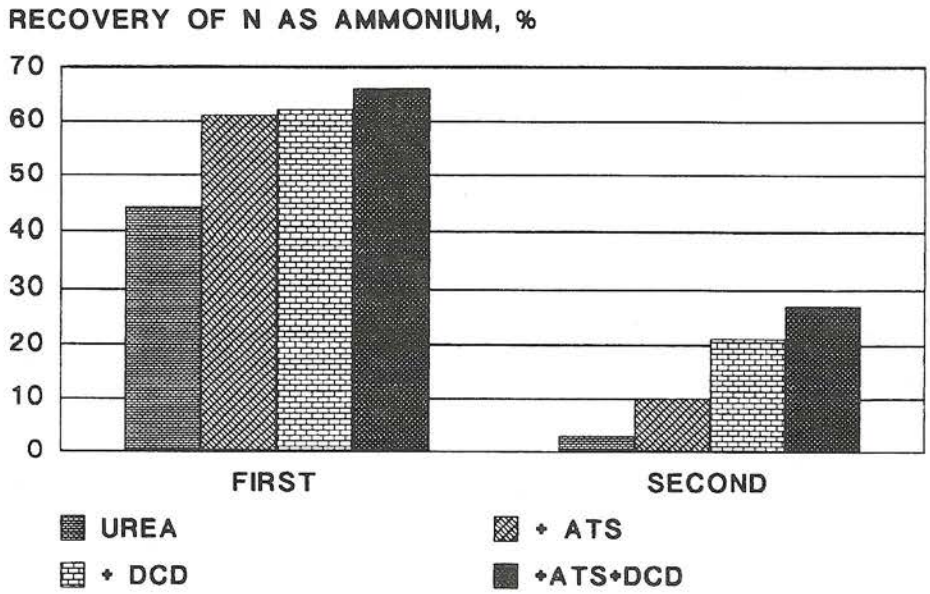

Figure 2. Effect of adding ATS and DCD to solubilized urea on recovery of ammonium from the soil at two sampling times after application. Three-site average, fall applications, North Dakota 1988-1989.

<u>Ammonium thiosulfate as an herbicide extender</u>[1]

We began greenhouse research in 1988 to determine if ATS could slow the degradation of short-lived herbicides in the soil. The results of a typical growth chamber experiment are shown in Figure 3. In this study an Embden fine sandy loam was incubated with 5 ppm of EPTC (Eradicane) and various rates of ATS, incubated for various periods, and then seeded to oats. A reduction in shoot length was used as the index of herbicidal activity. After 35 days of incubation there was strong control of oat shoot growth by EPTC alone, with little opportunity for an effect of adding ATS. After 49 days, however, there was no remaining herbicidal activity at a rate of 0 or 0.10 mL of commercial-grade ATS/kg soil, but there was strong herbicidal activity at all rates tested above 0.10 mL/kg.

We have conducted many other studies in the greenhouse and growth chamber, and have found that ATS can slow the decomposition of a several herbicides from distinct chemical families. Significant extension of herbicidal activity has been observed at 0.10 mL of ATS/kg soil, but usually 0.15 mL/kg is the threshold value. Translating these figures to field conditions is difficult, due to the variable depths of herbicide incorporation and the effect of rainfall on ATS movement.

Our field studies of this concept, conducted in 1989, were encouraging but not definitive. ATS-EPTC and ATS-2,4-D mixtures were sprayed on the soil and tilled in to a depth of 5 cm. Improved long-term weed control was obtained with both chemicals, but the effect was not consistently observed. Further field studies are planned.

[1]U.S. patent applied for.

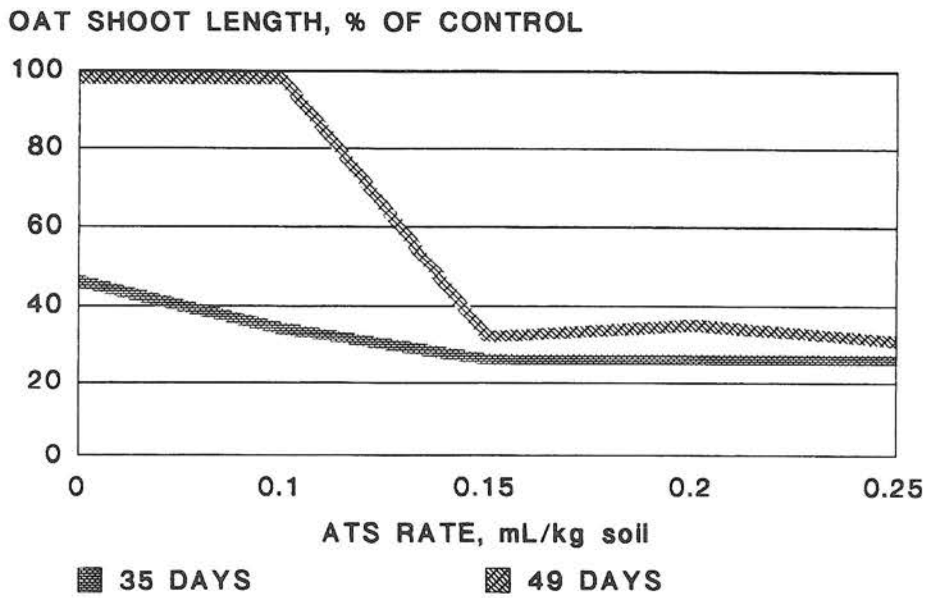

Figure 3. Effect of 5 ppm of EPTC (Eradicane) and various rates of ATS on relative oat shoot length. Bioassays performed after 35 and 49 days of incubation.

A REVIEW OF POINT INJECTION

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INTRODUCTION

Progressive crop production systems involve high nutrient use efficiency and maintain ample residue cover. Considering these characteristics, it is not surprising that point injection (PI) of fertilizer is receiving considerable attention today. Although the first point injector patent dates back to 1953 (Baker et al., 1989), it has taken the demands of today's agriculture to stimulate practical application of the concept.

The advantages claimed for PI fertilizer application include the following:

1. Allows injection of fertilizer in conservation tillage with minimal to no residue covering. This could increase N efficiency through reduction of immobilization, denitrification, and volatilization.
2. Fetilizer may be placed near growing crop plants without significant root pruning.
3. Prevents positional unavailability of N and other nutrients that sometimes occurs with topdressing.
4. Lower fuel and power requirements than conventional injection methods.

Several injection wheel versions are being used by researchers but the most common design is similar to the fourth generation wheel from Iowa State University's Ag Engineering Department (Figure 1). The unit commercially available from CADY Systems, Inc. of Ankeny, IA is patterned after this design. This unit places fertilizer from 3 to 4" deep at an interval of 6 to 7". The rotary valve-hub assembly supplies fertilizer to the down position spokes as the unit rolls through the field. Cady recommends 25 to 40 psi working pressure for proper application (CADY Systems, Inc. Promotional Brochure, 114 N.W. 5th St., Ankeny, IA).

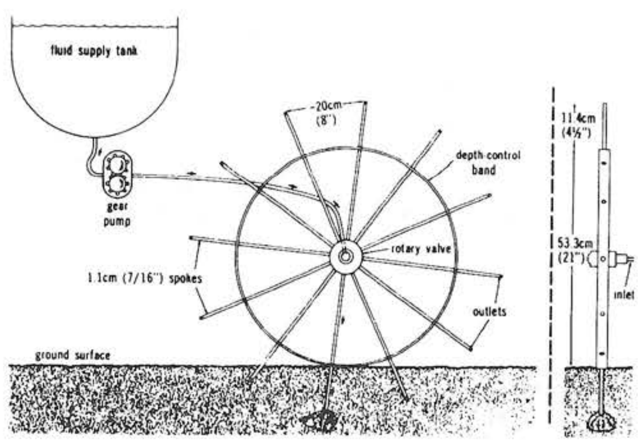

Figure 1. A schematic of the fourth generation wheel developed at Iowa State University (Baker et al., 1989).

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CORN EXPERIMENTS WITH POINT INJECTION

Much of the interest in point injection (PI) application in North America was stimulated by research conducted at Iowa State University in the early 1980's. The concept was tested by point injecting a fertilizer containing N,P,and K by hand near individual corn plants at three times during the growing season. Comparison to single surface application or to knife application over four years resulted in a substantial yield advantage for the split PI treatment regardless of tillage system (Table 1). These data laid the ground work for development of a mechanical means of accomplishing this application method and spurred considerable research on the many aspects of PI.

Later studies in Iowa concentrated on timing of PI and comparison to knifing in no-till systems. Research conducted in 1986-87 showed point injection to be equal to or better than knifed application and showed no benefit from split application (Table 2). The researchers reasoned that the last application of the 3-way split (V15) was possibly too late to be efficient.

Early growth response to the PI treatments was substantial in both years and appeared to exceed the knifed applications which placed bands approximately 5" to the side of the row, apparently too far away for maximum starter effect (Table 3). The 3-way split PI application in 1986 was not as effective at stimulating early growth. Increasing the percentage of fertilizer applied preplant in 1987 corrected the problem. Other data not reported here caused the researchers to believe that most of the early growth response from these applications was due to N rather than P or K.

Point injection has been considered a potential technique for reducing leaching losses of nitrate when rainfall occurs shortly after fertilizer application. Theoretically, macropore leaching would be reduced since the N is concentrated in a localized zone with much of it likely in micropores and protected from loss. Studies at Iowa State University are ongoing that are designed to evaluate this hypothesis. Preliminary data based on one site-year look promising but are not conclusive (Table 4). The N in the fertilizer material used was 100% nitrate to simplify processes but this also likely amplified the leaching losses.

Minnesota ridge till studies on a Webster clay loam have compared point injection of UAN to anhydrous ammonia (AA), surface UAN bands, and broadcast UAN in both continuous corn and corn soybean rotations (Tables 5-6). Continuous corn yields resulting from PI treatments applied preemergence were similar to preplant AA regardless of whether the UAN was injected into the ridge or the valley and slightly better than broadcast UAN in one year. Preemergence application of 30 lbs N/A was insufficient to prevent N deficiency when the remaining N was applied at V8. In a corn soybean rotation, preemegence PI application into the ridge gave the highest 3-year average yield. Split application with either PI of UAN or knifed AA did not increase yields in these studies over single application and may have decreased yield in 1989.

Table 1. Comparison of three fertilizer application techniques to corn in Iowa, average of 1981-84.

Tillage	Check	Surface[1]	Knife[2]	Point injected[3]
	Bu/A			
Conventional	61	94	94	131
Chisel	36	77	89	112
No-till	38	72	96	119
Average	45	81	93	121

Fertilizer rate: 180+50+80 ($N+P_2O_5+K_2O$, lbs/a). [1]Before fall tillage. [2]Before planting. [3]25%, 25%, 50% at 2, 5, and 9 weeks post planting respectively by hand near individual plants. (Baker and Timmons, 1984; Timmons, 1984).

Table 2. Comparison of timing and fertilizer application method for no-till corn in Iowa on a Canisteo soil, average of 1986-87.

Application method	Check	Time of applic. / % of total fertilizer: PP1 100	PP+V6 43+57	PP+V6+V15 1986: 6+63+31 1987:17+55+28
	Bu/A			
Knife[2]	75	177	175	
Point inj.[3]	75	185	185	172

Rate received by all treatments except check: 156+91+107 ($N+P_2O_5+K_2O$, lbs/a). [1]PP = preplant. [2]Knifed 5" from the row. [3]PP applications were injected in the row, V6 & V15 injected 5" from the row. All fertilizer was applied in non-trafficked areas in each plot. (Baker et al., 1988).

Table 3. Growth response at V6 to fertilizer application method and timing for no-till corn in Iowa.

Year	Check	PP PI	PP Kn	2-way PI	2-way Kn	3-way PI
	tons/a					
1986	0.20	0.51	0.37	0.58	0.36	0.31
1987	0.33	0.52	0.44	0.57	0.44	0.50

See Table 2 for treatment descriptions. (Baker et al., 1988)

Table 4. Influence of nitrate fertilizer application method and tillage system on nitrate in drainage water - preliminary data.

Tillage	NO_3-N[1]		Recovery in drainage water[2]	
	Surface	PI	Surface	PI
	-----PPM-----		------%------	
Ridge till	107	100	24	13
Chisel	171	139	14	8

[1]Flow-weighted average concentration. [2]Since N recovered in drainage water contained N from sources other than the applied fertilizer, these values as a percentage of applied N are inflated. A Br tracer supported this assumption. Simulated rainfall of approximately 4" over 3 hours applied the day after fertilizer application. (Kay & Baker, 1989)

Table 5. Comparison of N placement and timing for continuous corn in Minnesota.

N Rate 1986	N Rate 1987	Application [1]Time	Application [2]Placement	Grain Yield 1986	Grain Yield 1987	Grain Yield avg
Lbs/A				--------Bu/A--------		
0	0	Check		55	86	71
150	PP	AA-valley		131	156	144
150	150	PE	SBR	128	156	142
150	150	PE	Broadcast	120	158	139
150	150	PE	PI-ridge	133	154	144
150	150	PE	PI-valley	129	157	143
30/120	60/90	PE/V8	SBR/PI-val.-AA	123	152	138
30/120	60/90	PE/V8	SBR/PI-valley	114	153	134
30/120	60/90	PE/V14	SBR/PI-valley	124	158	141
30/120	60/60	PE/V14	SBR/PI-valley	118	153	136
	BLSD (.05):			10	10	

[1]PP=preplant, PE=preemergence, V8 & V14=leaf stage. [2]N source is UAN except where AA indicates anhydrous ammonia, PI=point injected, SBR=surface band 8 to 10" wide on the ridge. (Randall & Rehm, 1989).

Table 6. Comparison of N placement and timing for a corn-soybean rotation in Minnesota.

N Rate	Application: Time[3]	Application: Placement[4]	Grain Yield: 1986	1987	1989	avg
Lbs/A			------------Bu/A------------			
0	Check		128	127	89	115
100	PP	AA-valley	145	165	154	155
100	PE	SBR	148	156	148	151
100	PE	Broadcast	143	157	135	145
100	PE	PI-ridge	164	167	153	161
100	PE	PI-valley	159	161	146	155
40/60[1]	PE/V8	SBR/PI-val.-AA	152	156	158	155
40/60[1]	PE/V8	SBR/PI-valley	143	158	159	153
40/60[1]	PE/V14	SBR/PI-valley	153	161	146	153
40/40[2]	PE/V14	SBR/PI-valley	144	159	143	149
	BLSD (.05):		13	11		

[1]30/70 in 1986. [2]30/50 in 1986. [3]PP=preplant, PE=preemergence, V8 & V14=leaf stage. [4]N source is UAN except where AA indicates anhydrous ammonia, PI=point injected, SBR=surface band 8 to 10" wide on the ridge. (Randall & Rehm, 1989).

Table 7. Comparison of N placement in no-till continuous corn in Illinois.

Placement[1]	1988[2] Carbon.	1988[2] Belle.	1989[3] Carbon.	1989[3] Belle.	Average
	------------BU/A------------				
Check	34	47	33	34	37
Broadcast Urea	109	107	60a	97 a	93
Dribble UAN	115	107	60a	119b	100
Pt. Inject. UAN	118	129	65a	137c	112
LSD (.05)	12	10			

[1]N applied 4-6 weeks after planting, dribble band was 1" wide placed 4" from the row. [2]N rate = 120 lbs/A. [3]N rate = 150 lbs/A. (Varsa & Leis, 1989; Varsa, 1989).

Illinois no-till continuous corn studies clearly show PI N application to be superior to surface broadcast or dribble treatments (Table 7). The researchers indicated that very limited rainfall following N application likely rendered the surface treatments temporarily positionally unavailable. Where N was injected, corn was taller and more vigorous than where surface treatments had been used.

Studies are ongoing in Maryland with PI in no-till corn. First year data (1989) are preliminary at this writing but suggest similar effectiveness for knife and PI treatments in 3 studies and somewhat lower effectiveness for PI compared to knifed UAN in a fourth (Bandel, 1989). Unusually heavy rainfall in 1989 may make these data atypical for Maryland crop production.

WHEAT EXPERIMENTS WITH POINT INJECTION

Considerable interest exists in PI in the Great Plains as a means of allowing N application nearer the time of plant uptake but without the risk of positional unavailability or immobilization as exists with conventional topdressing. Alberta researchers have conducted detailed investigations of several aspects of PI N application to winter wheat. A summary of 8 site-years of micro-plot experiments in southern Alberta shows that in some situations PI performs substantially better than spring topdressed applications (Table 8). In other situations no differences were found in grain yield, however, in these cases general N response was usually very limited. The percent of N uptake derived from fertilizer as indicated with ^{15}N was substantially higher for PI at several locations (Table 8). The researchers stated that the advantage of PI over broadcast methods is likely to be most pronounced under conditions where post-application precipitation prior to peak demand for N is inadequate to move surface applied N into the soil profile.

Timing of PI and broadcast N application to winter wheat was studied by Janzen et al.(1990b). From their results the researchers concluded that point-injection can significantly enhance fertilizer-use efficiency and that the optimum time of injection is in the early spring just prior to the period of maximum N assimilation by the crop (Figure 2).

In other Alberta experiments optimum PI application parameters were determined at two sites for winter wheat (Janzen & Lindwall, 1990). The researchers concluded that the optimum across row spacing was 16" or two wheat rows which was also the optimum longitudinal spacing within the row. The optimum depth of injection was 4". Grain yield response increased 4 fold when depth increased from 1" to 4" but no advantage was found for increasing depth from 4" to 6".

No-till winter wheat PI comparisons in 1989 were made on one dryland and one irrigated site in northcentral Montana (Table 9). Under dryland conditions PI gave yields similar to preplant knife, spring broadcast, and spring surface band UAN applications. However, at the irrigated site, PI application was 31 bu/a better than preplant knife application and 14 bu/a better than spring broadcast and spring surface band application. The investigators reported several lost treatments due to plugged point

Table 8. Comparison of fertilizer N sources and placement for winter wheat in micro-plot experiments in southern Alberta.

Treatment	CAR85	CAR86	LET86	BOW87	CLA87	FOR87	LET87	SKI87	AVG
	Site								
	Grain yield, bu/a								
Check	13	18	25	30	20	21	21	29	22
Broad. UAN	16	27	28	--	--	--	--	--	--
Broad. Urea	16	23	27	31	17	22	19	29	23
Broad. A. N.	17	27	28	30	19	20	21	28	24
PI UAN	17	40	30	33	18	16	23	28	26
SB UAN	--	--	--	29	18	16	20	27	--
LSD (.05)	NS	11	NS	NS	NS	NS	2	NS	
	N Derived From Fertilizer, %[2]								
Broad. UAN	41	25	26	--	--	--	--	--	--
Broad. Urea	38	19	29	7	4	9	26	16	19
Broad. A.N.	42	38	26	24	5	16	25	22	25
PI UAN	61	58	29	23	11	15	39	24	33
SB UAN	--	--	--	11	3	8	25	13	--

[1]N rate = 53 lbs/A in 1985 & 1986, 36 lbs/A in 1987. Injection was at a 4" depth. SB = surface band midway between alternate rows. [2]Based on ^{15}N. (Janzen et al., 1990a).

Table 9. Comparison of N application methods to no-till winter wheat in northcentral Montana.

Site	Check	Prepl. Knife	At jointing Broad.	At jointing Band	At jointing PI	LSD(.05)
	Bu/A					
Dryland	28	33	40	39	37	6
Irrigated	40	36	52	53	67	11

Dryland N rate = 60 lbs/a, Irrigated = 50 lbs/a. N source = UAN. Band, knife, and injection row spacing = 10". (Kushnak & Gallagher,1989).

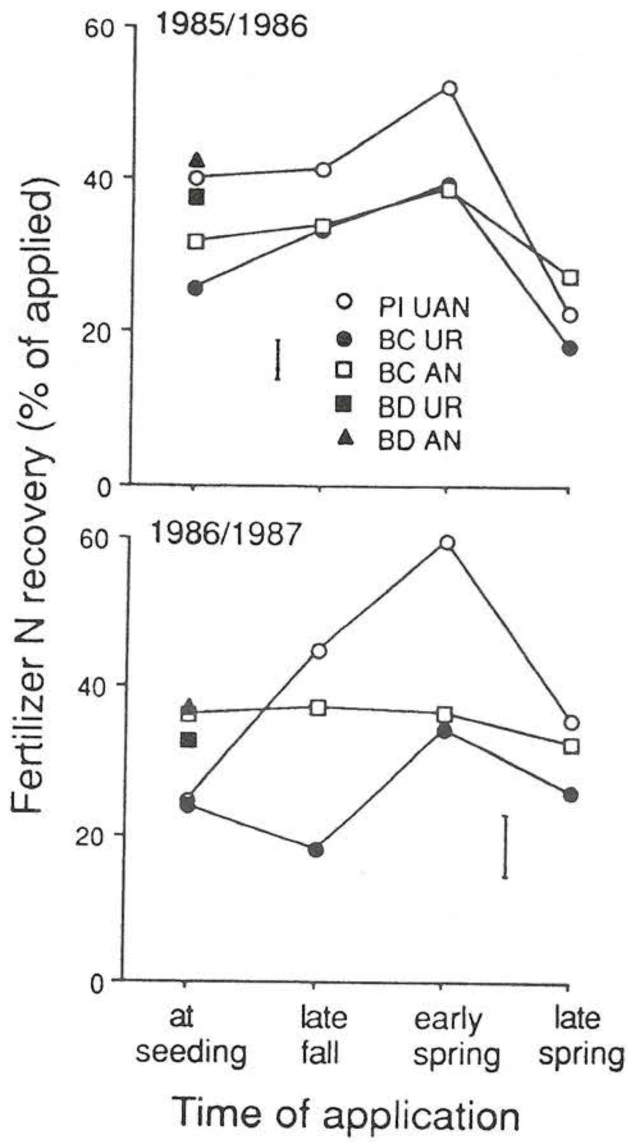

Figure 2. Fertilizer N recovery by winterwheat as influenced by time and method of N application (PI = point injection, BC = broadcast, BD = band, UAN = urea ammonium nitrate, UR = urea, AN = ammonium nitrate; Janzen et al., 1990b).

injector orifices. They felt this may have been caused by unusually wet soil conditions or insufficient pressure to force the fluid through the blockage. Field testing of an experimental point injector built after the ISU design by the NDSU Ag Engineering department also resulted in some plugging problems for wheat (Hofman, 1987).

SUMMARY

Results with PI application to date indicate that this is a promising method of N application. In nearly all cases it has been either the most effective method evaluated or has been equal in effectiveness to the best method. In a few cases PI has been markedly superior to broadcast application.

A major unanswered question is how effective is PI for P and K application. The vast majority of studies conducted have been on N. Soil immobile nutrients need to be tested to determine if a sufficient amount of the root system can contact the discontinuous fertilizer zones formed by the action of the spoked wheel. This is critical in determining if PI has a future as a method of starter fertilization.

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RESEARCH ON GEL-TYPE FERTILIZERS

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ABSTRACT

A research effort was recently initiated to examine the effects of hydrophilic gel-type polymers on nutrient availability from fertilizers. Several greenhouse and laboratory experiments have demonstrated that gelled N fertilizer can delay N leaching losses for several weeks and increase N availability to plants compared with N fertilizer alone. In other experiments, Fe phytoavailability from $FeSO_4$ was increased through use of hydrophilic polymers. Additional research is underway to study the use of polymers with other plant nutrients, to determine if gelled fertilizer is suitable as a starter fertilizer, and to modify the polymer chemistry to enhance its compatibility with fluid fertilizers.

INTRODUCTION

Researchers at the National Fertilizer and Environmental Research Center (NFERC) are continually searching for ways to increase the recovery of applied N fertilizers while minimizing potentially adverse environmental impacts resulting from N fertilization. One way of doing this is through development of new fertilizer products that better meet the nutritional needs of plants. It has been shown that in some circumstances, the use of slow- or delayed-release N fertilizers can improve fertilizer recovery by plants. Because of this, a new research project was recently initiated to evaluate the use of gel-type polymers with fertilizers to increase fertilizer recovery.

The use of hydrophilic gel-type polymers is not new to agriculture. Vegetable growers often plant small-seeded crops in a band of "gel" to enhance germination and increase plant stand uniformity (Orzolek, 1987). Polymers are also commonly added to horticultural potting mixes to improve the physical properties and the water holding capacity of the mix. Research has demonstrated that additions of polymers can improve the physical properties of agricultural soils by improving aggregate stability (Wallace and Wallace, 1986) and reducing surface crusting (Azzam, 1983). The use of polymers can also decrease evaporation losses from soils in some circumstances (Al-Omran et al., 1987)

The chemical and physical properties of hydrophilic polymers vary greatly (Johnson, 1984). The major classes of polymers used in agriculture include starch copolymers, polyvinylalcohols, and polyacrylamides. All of these products (often classed as super-absorbents) have a high water absorption capability and, depending on their original form, swell to form an amorphous gelatinous mass or discrete hydrated gel particles.

The term "gel-type" fertilizers has caused confusion for workers interested in this area of research. "Gelled fertilizer" has been used to describe products such as traditional suspension fertilizers, settling resistant suspensions, emulsions, thickened fertilizers, and polymer + fertilizer mixtures. For the research reported here, gelled fertilizer can be loosely defined as a viscous, fluid-based fertilizer that will retain its physical integrity after addition to soil. The gel fertilizer may have a jelly-like consistency and will not immediately diffuse or solubilize into the soil following application.

The use of gel-type polymers with fluid fertilizers is conceptually attractive for use in agriculture for many reasons. Some of the potential benefits that may come from the use of gelled fertilizers include:

1. Controlled nutrient release from the fertilizer source, resulting in increased plant uptake and reduced fertilizer leaching loss.
2. Reduced NH_3 volatilization loss from applied N fertilizers by providing a physical barrier to gaseous losses.
3. Increased micronutrient fertilizer availability to plants by reducing fertilizer-soil contact and reactions.
4. Improved starter fertilizers by allowing placement close to the seed and improving nutrient availability, yet reducing fertilizer/soil contact and salt damage to seedlings.
5. Potential to control the form of N supplied to plants (NH_4 or NO_3) and thus optimize plant response to applied N.

RESULTS

Although this research project is in its early stages, there have been indications that the use of hydrophilic polymers with fertilizers may enhance plant nutrient recovery. A summary of some selected research projects conducted at NFERC is reported here.

<u>The use of gels to reduce nitrate leaching loss.</u>

Nitrogen fertilizer lost through leaching represents an economic loss of an important agricultural input as well as a potential environmental pollutant. If applied N can be protected from leaching during the early growing season until the crop roots are well established, the potential for N loss is reduced. In soil-filled leaching columns, one polymer was added to urea ammonium nitrate (UAN) and band-applied at a rate equivalent to 100 lb. N/acre. For this particular polymer, N leaching losses were delayed for two to three weeks by addition of polymer compared with N fertilizer alone.

<u>The addition of gels with UAN to reduce N leaching losses.</u>

Although gels may be effective carriers of N fertilizer, their effectiveness may vary amongst different chemical classes of polymers. This greenhouse experiment was conducted to examine leaching losses of fertilizer N added with five gel-type polymers in the presence of growing plants. At the final harvest, plants receiving polymer-amended N fertilizer were as much as 30% larger than UAN-fertilized plants. Nitrogen accumulation was also significantly increased with the addition of some gel polymers. Due to poor soil physical properties, it was not possible to accurately measure N leaching losses.

Decomposition of fertilizer ± gel mixtures as measured by CO_2 evolution.

Previous experiments hinted that the degradation of some N + gel mixtures was rapid in soil. This observation was based on the inspection of residual bands in the soil and the fact that carbon (gel) and nitrogen (fertilizer) are generally the two limiting factors for soil microbial growth. This laboratory experiment demonstrated that the degradation of N + gel mixtures varied greatly depending on the chemical composition of the polymer. Some mixtures were largely degraded within three to four weeks, while others persisted throughout the duration of the experiment.

Use of gels as a carrier for $FeSO_4$ in Fe-deficient soils.

Many soils contain insufficient available Fe to adequately meet crop needs. To alleviate crop Fe deficiencies, growers can use expensive synthetic chelates or apply foliar sprays. When $FeSO_4$ is applied to soil, it reacts chemically and becomes unavailable to plants. This experiment examined the use of gels to increase the plant availability of soil-applied $FeSO_4$, an inexpensive Fe source.

In a greenhouse experiment, several gel + $FeSO_4$ formulations were evaluated for their Fe-supplying capacity to plants grown in Fe-deficient soil. Two polymers were identified that were nearly as effective as Fe-chelate (EDDHA) in supplying Fe to plants. A subsequent experiment showed these two polymers to be persistent in soil and effective in supplying Fe to plants for the duration of the three-month experiment.

Other research regarding the use of gelled fertilizer is currently underway. Areas of immediate interest include the use of gel polymers with P fertilizers, formulations and placement of starter nutrients with gelled fertilizer, chemical modifications to the polymers that would make them more effective in retaining nutrients in the fertilizer band, and the economic feasibility of this technology.

It is not certain that the use of gel-type fertilizers will increase fertilizer recovery by crops in the field and decrease undesirable nutrient losses to the environment in all circumstances. However, this research is an example of the effort needed to provide new fertilizer products that will meet the economic and environmental demands of society.

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WHEAT RESPONSE TO PB-50 (*Penicillium bilaji*), A PHOSPHATE-SOLUBILIZING INOCULANT

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ABSTRACT

Phosphorus is a key plant nutrient which is rapidly precipitated and made unavailable for plant use when added to soil as fertilizer. Every soil contains a number of microorganisms which act to solubilize fixed phosphate making it available for plant uptake. One such microorganism, a fungus called *Penicillium bilaji*, demonstrated superior phosphate solubilizing ability in liquid media. In greenhouse and field trials established in 1985, 1986, and 1987, bran inoculated with *P. bilaji* applied in-furrow consistently increased phosphate availability and uptake by crop plants. *P. bilaji* was subsequently registered in Canada under the trade name PB-50™. Trials were established at 38 locations in 1988 and 1989 to examine the effect of seed inoculated *P. bilaji* on wheat yield over increasing rates of phosphate fertilizer. In general, *P. bilaji* treatments exhibited significant yield increases over the lower check rates of phosphate fertilizer. As phosphate fertilizer rates approached recommended levels, yield differences due to *P. bilaji* tended to decrease.

OVERVIEW

Phosphorus is one of the key nutrients which are essential for plant growth and development. However, the availability of this nutrient for uptake by plants and microorganisms is restricted by its tendency to precipitate with certain cations (e.g., Ca^{++}, Mg^{++}, Fe^{+++}, Al^{+++})(Barber, 1984) or to become tightly bound to or within soil particles (Tisdale and Oades, 1982). These forms of phosphorus are relatively insoluble and unavailable for uptake by plants. Because of their extreme reactivity, plant-available phosphates represent only a small portion of the total phosphorus present in soils (Barber 1984). Consequently, in most agricultural soils, fertilizer phosphate application is required to supplement native soil phosphate in order to supply crop phosphate demands and to produce the required crop yields (Stewart and Sharpley, 1987).

The roles of microorganisms in the release of precipitated phosphates into soluble plant available forms are well documented. Research with fungi and bacteria isolated from soils and root regions indicate that a wide range of microorganisms have the capacity to solubilize precipitated inorganic phosphates (Kucey, et al., 1989). Researchers led by Dr. Reg Kucey at the Agriculture Canada Research Station in Lethbridge, Alberta, isolated from soil a number of fungi and bacteria capable of solubilizing precipitated inorganic phosphate (Kucey, 1983). One of these, an isolate of the fungus

obligat symbiont Fungi

the innoculant is the Resting spore of Penicillium bilaji.

Penicillium bilaji, was unique in the efficiency with which it solubilized rock phosphate in liquid media.

Bran inoculated with P. bilaji applied in-furrow was shown to increase phosphate availability and uptake by wheat and canola in greenhouse and field trials established in 1985, 1986, and 1987.

Under field conditions, wheat yield and P uptake of P. bilaji plus rock phosphate (RP) was equivalent to increases due to the addition of monoammonium phosphate (MAP) at an equivalent rate of P. Yield and P uptake was not affected when RP was applied in the absence of P. bilaji (Kucey, 1987). Wheat dry matter production and total P uptake in turn coincided with a significant increase in phosphate solubilizing fungi in the rhizosphere of inoculated plants (Kucey, 1988). In greenhouse trials, the addition of P at 20 mg/Kg soil as RP plus P. bilaji resulted in P uptake by canola equivalent to that obtained from MAP at the same rate of P. Under field conditions, canola dry matter and P uptake of inoculated plants at half the rate of MAP was equal to that absorbed from the full rate of MAP by uninoculated plants (Kucey and Leggett, 1989).

The efficacy of P. bilaji has been demonstrated on phosphate responsive soils and registered in Canada under the trade name PB-50™ for in-furrow application with wheat and canola. However, the formulation was not practical for large scale field use. Successful liquid fermentation of P. bilaji has enabled the replacement of the in-furrow bran formulation with a water soluble, dry powder, seedcoat formulation.

OBJECTIVES

The objectives of the 1988 and 1989 research program were to determine the efficacy of the P. bilaji seedcoat formulation on wheat over a wide range of soil and climatic conditions. In this paper, we report the results of field trials established with wheat in 1988 and 1989 across the three prairie provinces.

MATERIALS AND METHODS

Trials to assess the efficacy and performance of the P. bilaji seedcoat formulations on wheat were established by Philom Bios, the Saskatchewan Wheat Pool and Westco Fertilizers Limited at 38 locations across the three prairie provinces in 1988 and 1989.

Field trials were arranged in a split-plot experimental design. The bilaji seed treatment, were compared over the mainplot factors, which were rates of phosphate fertilizer application (0, 10, 20, 30 Kg/ha P_2O_5). Prior to seeding, supplemental nitrogen fertilizer was applied over all trial locations as required to ensure adequate nutrient supply and to highlight response to phosphate. Triple-super phosphate (0-45-0) was added in-furrow as the mainplot phosphate treatments. P. bilaji was applied to wheat seed at rates calculated to give 10^3 - 10^4 colony forming units per seed. All trials were seeded with small plot seed drills and harvested with small-plot combines.

Subplot treatment mean yields were separated using multiple location paired-comparison T tests.

RESULTS AND DISCUSSION

Combined location analysis for 38 separate trials is shown in Table 1. Within uninoculated phosphate fertilizer check treatments a mean yield response of 138 Kg/ha occurred with the addition of 10 Kg/ha P_2O_5. As would be expected, incremental yield increases declined with further phosphate additions. Within inoculated P. bilaji treatments, grain yield was increased with the application of 10 Kg/ha P_2O_5. Additional fertilizer applications had no further influence on grain yield.

TABLE 1: Effect of Penicillium bilaji on the yield of wheat. Multiple year data summary for 38 locations.

Phosphate Applied (Kg/ha P_2O_5)	Mean Yield (Kg/ha) PHOSPHATE CHECK	P. bilaji TREATMENT	YIELD DIFFERENCE (P. bilaji minus Phosphate)	[1]Statistical Significance (Prob T >|T|)
0	2771	2827	56	0.01
10	2909	2958	49	0.04
20	2930	2962	32	0.15
30	2962	2948	(14)	0.54

[1] Paired-comparison T-test for P. bilaji response. Values denote the level of significance of the observed differences between PB-50 treatment and phosphate check yields for each rate of applied phosphate.

The addition of P. bilaji alone ($P<0.01$) and with 10 Kg/ha P_2O_5 ($P<0.04$) significantly increased grain yield when compared to uninoculated controls. As the rate of phosphate fertilizer applied increased, the yield response to inoculation decreased. It would appear that at higher rates of fertilization the crop was able to obtain adequate levels of phosphate for optimum plant growth.

The combined site analysis was separated into trials established on low to medium residual phosphate soils (<20 Kg P/ha) and those established on high residual phosphate soils (>20 Kg P/ha).

The combined location analysis for 28 trials established on low to medium phosphate soils (Table 2) indicates that within uninoculated treatments yield continued to increase as the rate of phosphate fertilizer increased. Within inoculated treatments, yield did not increase beyond levels obtained with 10 Kg/ha P_2O_5. Treatments inoculated with P. bilaji increased the mean grain yield of wheat without added phosphate ($P<0.004$) and of plants receiving 10 Kg/ha P_2O_5 ($P<0.04$) and 20 Kg/ha P_2O_5 ($P<0.08$).

TABLE 2: Multiple year data summary. Trials established on low to medium phosphate soils[2] at 28 locations.

Phosphate Applied ($Kg/ha\ P_2O_5$)	Mean Yield (Kg/ha) PHOSPHATE CHECK	P. bilaji TREATMENT	YIELD DIFFERENCE (P. bilaji minus Phosphate)	[1]Statistical Significance (Prob T >|T|)
0	2581	2657	76	0.004
10	2765	2824	59	0.04
20	2797	2841	44	0.08
30	2839	2815	(24)	0.31

[1] Paired-comparison T-test for P. bilaji response. Values denote the level of significance of the observed differences between PB-50 treatment and phosphate check yields for each rate of applied phosphate.

[2] Low to medium phosphate soils: 0 - 20 lb available P/acre.

Results of trials established on high residual phosphate soils are outlined in Table 3. Neither phosphate fertilization nor P. bilaji induced a yield response. It is believed that the high levels of soil phosphate in effect precluded yield responses to phosphate fertilizer and inoculation with P. bilaji. The lack of response to P. bilaji under high soil phosphate conditions is not unexpected. The relative benefits of phosphate solubilizing fungi have been observed to decrease as phosphate availability increases (Ross, 1971).

TABLE 3: Multiple year data summary. Trials established on high phosphate soils[2] at 10 locations.

Phosphate Applied ($Kg/ha\ P_2O_5$)	Mean Yield (Kg/ha) PHOSPHATE CHECK	P. bilaji TREATMENT	YIELD DIFFERENCE (P. bilaji minus Phosphate)	[1]Statistical Significance (Prob T >|T|)
0	3313	3312	(1)	0.97
10	3282	3309	26	0.59
20	3280	3280	ND	1.0
30	3298	3312	16	0.73

[1] Paired-comparison T-test for P. bilaji response. Values denote the level of significance of the observed differences between PB-50 treatment and phosphate check yields for each rate of applied phosphate.

[2] High phosphate soils: >20 lb available P/acre.

On the basis of Tables 1 and 2, it is apparent that the largest yield response to inoculation occurs when phosphate fertilizer is not applied. Presuming this yield response occurs due to increased phosphate availability, it appears P. bilaji is able to solubilize soil phosphate fractions which are unavailable to the uninoculated check. Within inoculated treatments, optimum yield occurred with the addition of 10 Kg/ha P_2O_5; additional fertilization did not induce yield responses. It is hypothesized that with inoculation, yield was sustained through solubilization of soil phosphate and increased solubilization of commercial fertilizer. Previous results indicate that P. bilaji was able to solubilize soil and added phosphate sources (Asea et al., 1988).

The mode of action of P. bilaji is, at present, not fully understood. The fungi is known to be able to solubilize relatively unavailable forms of soil phosphate. It is believed that P. bilaji acts to solubilize inorganic phosphate by acidification of the surrounding media. Acidification occurs through the production of organic acid metabolites (Kucey manuscript in preparation). However, this may not be the sole mechanism of action. Several studies on phosphate solubilizing organisms have demonstrated a lack of correlation between the ability of organisms to solubilize phosphate and a reduction in media pH (Surange, 1989, Gaur et al., 1973). Tracer studies found that P. bilaji was capable of releasing greater amounts of phosphate from rock phosphate than that released by 0.1 N HCl applied to obtain equivalent media pH levels (Asea, et al., 1988). Therefore, it is probable that organic acids produced by P. bilaji are also acting through calcium chelation thereby altering the chemical equilibrium between solid and solution phosphate and shifting reactions to favor the latter.

In summary, field trials established with wheat in 1988 and 1989 have demonstrated that P. bilaji increased phosphate availability and uptake as evidenced by positive yield responses. Although cross-comparison statistical analysis has not yet been completed, it is of interest to note that yields obtained with the P. bilaji treatment at 10 Kg/ha P_2O_5 were equivalent to those obtained with the uninoculated controls at 20 and 30 Kg/ha P_2O_5.

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RESEARCH IN PROGRESS

Additional research underway includes the following:

1. Evaluation of the efficacy of P. bilaji on other crops such as winter

2. Evaluate interactions which may occur between P. bilaji and Rhizobium spp. when applied on pulse crops.

3. Identification of mechanisms pertaining to P. bilaji's mode of action.

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USE OF COMPOSTED MANURE ON IRRIGATED GRAIN SORGHUM

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ABSTRACT

Cattle manure compost was evaluated as a N fertilizer source for irrigated grain sorghum and to determine the effect of annual compost and N fertilizer applications on residual soil nutrient concentrations. Five rates of manure compost (0, 0.9, 1.8, 3.6, and 7.2 ton/acre) and four rates of N fertilizer (0, 55, 110, and 165 lb/acre) were applied annually since 1987 to a Ulysses silt loam in west-central KS. Grain yields were increased 2.5, 7, and 7 bu/acre with each ton of compost applied in 1987, 1988, and 1989, respectively. The average yield response from compost as compared to N fertilizer showed that one ton of compost was equivalent to about 14 lb N fertilizer. Greater grain yields were consistently obtained with combinations of compost and N fertilizer rather than from either applied alone. Compost additions at the lowest rate maintained residual soil P levels and, at higher compost rates, soil P levels were significantly increased. Soil P was decreased by additions of N fertilizer. Soil K and Fe were also increased by applications of compost. Soil Na levels were increased by compost additions but not to toxic levels. Manure compost can be used as a N source for crop production and can increase residual soil P and K levels without excessive accumulation of Na.

OBJECTIVES

Animal manure is a valuable source of plant nutrients. In areas, where manure is available in sufficient quantities, it can supply a significant proportion of crop nutrient requirements. Cattle feeding operations in western Kansas produce approximately 3 billion lb of manure (dry matter) annually which contains approximately 110 million lb N, 30 million lb P, and 70 million lb K, along with considerable amounts of several micronutrients. Although cattle manure is a good nutrient source, there are several problems and concerns associated with its use. The cost of transporting manure is a concern since fresh manure is primarily water (> 80%) with a relatively low nutrient content. Nutrients in manure can be lost to the atmosphere and in runoff of surface water during manure storage and distribution causing concern for environmental contamination. Improper manure storage and handling can cause increases in odor and pest problems. There is the concern that excess nitrogen from manure applications may leach through the soil and into the groundwater. Manure contains Na and other soluble salts which can create a soil salinity problem. However, despite these potential problems, the fact remains that large quantities of manure are produced (an estimated 6 million ton of animal manure are produced daily in the U.S.) and the most appropriate use for manure is as a plant nutrient source. With proper management, manure can be effectively, safely, and efficiently used for crop production.

The objectives of this study were to determine the amount of crop N requirements that can be supplied by composted cattle manure, determine the effect of composted manure applications on residual soil chemical concentrations, and determine the effect of composted manure on nitrate accumulation and movement in the soil profile.

MATERIALS AND METHODS

Cattle manure compost and N fertilizer were applied annually from 1987 to 1989 on a Ulysses silt loam (Aridic Haplustoll). The experiment was conducted at the Tribune Unit, Southwest Kansas Research-Extension Center, Tribune, KS. Chemical properties of the surface soil (0-6 in) were pH of 7.7, 13 ppm P (Bray-1), 730 ppm exchangeable K, and 56 ppm exchangeable Na. The experimental design was a complete factorial of five manure compost rates (0, 0.9, 1.8, 3.6, and 7.2 ton/acre) and four N fertilizer rates (0, 55, 110, and 165 lb/acre) replicated four times.

The manure compost contained approximately 1.4% N, 0.9% P, 2.1% K, 0.6% Na, and 0.9% Fe. Composted manure has a more uniform texture and can be more uniformly applied than fresh manure. Composting is biological decomposition of an organic material. Composting manure greatly reduces the volume, moisture content, weed seed viability (Wiese, et al., 1977), and odor of fresh manure. Nitrogen fertilizer was applied as ammonium nitrate. Plot size was 20 by 60 ft. All treatments were broadcast applied and incorporated prior to planting of grain sorghum. Planting dates were 6 June 1987, 9 June 1988, and 25 May 1989. Residual herbicides were broadcast after planting to control weeds.

The study area was furrow irrigated in 1987 on 14 June, 2 August, and 27 August; in 1988 on 13 June, 25 July, 17 August, and 3 September; and in 1989 on 25 April, 7 July, 25 July, and 11 September. Growing season precipitation was 7.81 inches in 1987, 8.42 inches in 1988, and 10.69 inches in 1989.

Leaf samples (at boot stage) were collected, dried, ground, and analyzed for total N. After physiological maturity, a measured length of the center two rows of each plot were machine harvested. Harvest dates were 4 Nov. 1987, 4 Nov. 1988, and 1 Nov. 1989. Grain yield was adjusted to 12.5% moisture. Grain samples were dried, ground, and analyzed for total N.

Soil samples (0-6 in depth) were collected after harvest in 1989, dried, ground, and analyzed for P (Bray-1), exchangeable K, DTPA extractable Fe, and exchangeable Na. Soil samples to a depth of 10 ft were taken after harvest in 1988 and analyzed for NO_3-N and NH_4-N.

RESULTS AND DISCUSSION

Grain yields were increased by N fertilizer and composted manure applications (Table 1). Nitrogen fertilizer alone increased yields up to

Table 1. Effect of manure compost and nitrogen fertilizer on grain yield of irrigated grain sorghum, Tribune, KS, 1987-1989.

Compost	Nitrogen rate	1987	Grain yield 1988	1989
ton/a	lb/a		bu/a	
0	0	69.3	58.2	40.1
	55	71.8	99.9	79.2
	110	79.3	100.5	82.2
	165	76.6	113.3	90.0
0.9	0	69.2	64.4	50.7
	55	85.7	107.1	85.6
	110	85.0	111.1	98.0
	165	78.0	112.5	97.4
1.8	0	71.9	70.2	57.5
	55	80.7	111.6	87.5
	110	90.4	117.8	102.7
	165	84.3	107.8	96.0
3.6	0	72.3	87.3	60.4
	55	83.4	117.6	97.4
	110	85.8	125.0	98.2
	165	88.7	117.0	107.2
7.2	0	87.3	107.8	88.9
	55	95.0	121.7	106.9
	110	95.7	133.8	109.9
	165	84.9	126.6	103.6
$LSD_{.05}$		15.0	15.8	12.2
ANOVA				
Compost		**	**	**
Nitrogen		**	**	**
Compost * Nitrogen		ns	ns	*
MEANS				
Compost				
0 ton/a		74.2c †	93.0d	72.9d
0.9		79.5bc	98.8cd	82.9c
1.8		81.8b	101.8c	85.9bc
3.6		82.6b	111.7b	90.8b
7.2		90.7a	122.5a	102.3a
$LSD_{.05}$		7.5	7.9	6.1
Nitrogen				
	0 lb/a	74.0b	77.6b	59.5c
	55	83.3a	111.6a	91.3b
	110	87.3a	117.6a	98.2a
	165	82.5a	115.4a	98.8a
$LSD_{.05}$		6.7	7.1	5.5

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

† For a given column, means followed by the same letter are not significantly different at the 0.05 level.

Composted manure analysis

27-39-55-12-18-.05

N P K Na Fe Zn

10 bu/acre in 1987, 55 bu/acre in 1988, and 50 bu/acre in 1989. Composted manure alone increased grain yields up to 18, 50, and 49 bu/acre in 1987, 1988, and 1989, respectively. At the highest compost rate, each ton of composted manure increased grain yields 2.5 bu/acre in 1987 and about 7 bu/acre in 1988 and 1989. Based on yield increases from compost alone averaged across rates and years, one ton of compost was equivalent to about 14 lb N fertilizer. However, greater grain yields were obtained each year with combinations of composted manure and N fertilizer. Sorghum yields were 8, 20, and 20 bu/acre greater in 1987, 1988, and 1989, respectively, with a treatment combining both composted manure and N fertilizer than from either alone. This additional yield from a combination of compost and N fertilizer may be partially attributed to the P content of the compost. However, leaf P content was sufficient (above 0.3%, data not shown) at all compost rates, although greatest yields were obtained at higher compost rates. A similar yield increase from a combination of manure and N fertilizer was reported in an earlier study (Herron and Erhart, 1965).

Leaf N increased with increased rates of both compost and N fertilizer (Table 2). In 1988, leaf N was below 2.5% N with all rates of compost without N and above 2.5% N when nitrogen fertilizer was applied. In 1989, leaf N was 2.5% or below for all treatments and was increased more by applications of N fertilizer than compost. Grain N was increased by N fertilizer but not by compost. The total amount of N contained in the grain (% grain N * grain yield) increased with increased compost and N rates. Apparent fertilizer use efficiency [(grain N_i - grain N_j)/ N $rate_{i-j}$] for the first increment of N was 43% averaged over 1988 and 1989. As N rate increased, efficiency decreased to 18% and 13% for the second and third increment of N, respectively. Nitrogen recovery in grain from compost alone averaged 3.5 lb N/ton of compost applied when averaged across compost rates and years. The apparent N efficiency from compost was 13% (the compost contained 1.4% N or 28 lb N/ton).

Soil P levels were increased from an initial level of 13 ppm Bray-1 P (medium range) up to 77 ppm P (very high range) after three years of compost applications (Table 3). [KSU Soil Testing Laboratory designations for soil P are very low (<5 ppm), low (5-12.5 ppm), medium (13-25 ppm), high (25-50 ppm), and very high (>50 ppm)]. Nitrogen fertilizer decreased soil P. Soil P levels with N alone were in the low range and may have restricted grain yields. Phosphorus deficiency should not have been a problem with treatments receiving compost since soil P levels were maintained or increased by all compost rates.

Soil K levels were increased by compost applications. Although K fertilization is not necessary for this site due to inherently high soil K levels, compost would be a good K source. Compost applications increased extractable soil Fe by 1 ppm. Iron deficiency is sometimes a problem on high pH soils, however, in this study all treatments had soil Fe levels above the approximated critical level of 4.5 ppm (Lindsay and Norvell, 1978).

Manure compost increased exchangeable Na by up to 35 ppm after three years of application. Although salinity problems can be created by manure

Table 2. Effect of manure compost and nitrogen fertilizer on leaf N and grain N of irrigated grain sorghum, Tribune, KS, 1988-89.

Compost	Nitrogen	Leaf N		Grain N			
		1988	1989	1988	1989	1988	1989
ton/a	lb/a	- - - - - - - - - % - - - - - - - -				- - lb/a - -	
0	0	1.83	1.48	0.92	1.02	26	20
	55	2.56	1.90	1.00	1.13	49	44
	110	2.73	2.15	1.28	1.26	63	50
	165	2.90	2.23	1.21	1.37	67	60
0.9	0	2.10	1.51	0.94	1.02	30	25
	55	2.60	1.88	0.97	1.00	51	42
	110	2.76	2.24	1.21	1.34	66	64
	165	2.93	2.29	1.22	1.36	67	65
1.8	0	2.08	1.49	0.93	0.98	32	27
	55	2.48	1.76	0.96	1.01	52	43
	110	2.84	2.22	1.14	1.29	66	65
	165	2.92	2.45	1.22	1.37	64	64
3.6	0	2.24	1.53	0.96	1.00	41	29
	55	2.84	2.15	1.02	1.10	59	52
	110	2.85	2.50	1.13	1.38	70	69
	165	2.80	2.40	1.24	1.33	71	70
7.2	0	2.35	1.73	1.00	0.98	53	42
	55	2.83	2.03	1.07	1.26	64	66
	110	2.93	2.32	1.17	1.34	77	72
	165	2.99	2.39	1.19	1.42	74	72
$LSD_{.05}$		0.30	0.16	0.08	0.10	10	7
ANOVA							
Compost		**	**	ns	**	**	**
Nitrogen		**	**	**	**	**	**
Compost*Nitrogen		ns	*	*	**	ns	*
MEANS							
Compost (ton/a)							
	0	2.50c†	1.94b	1.10a	1.19b	51c	43d
	0.9	2.59bc	1.98b	1.08ab	1.18b	53c	49c
	1.8	2.58bc	1.98b	1.06b	1.16b	54c	50c
	3.6	2.68ab	2.08a	1.09ab	1.19b	60b	54b
	7.2	2.77a	2.12a	1.10a	1.25a	67a	63a
$LSD_{.05}$		0.15	0.08	0.04	0.05	5	4
Nitrogen (lb/a)							
	0	2.12c	1.55d	0.95c	1.00d	36c	29c
	55	2.66b	1.94c	1.00b	1.10c	55b	49b
	110	2.82a	2.24b	1.19a	1.31b	68a	63a
	165	2.90a	2.35a	1.22a	1.37a	69a	66a
$LSD_{.05}$		0.14	0.07	0.04	0.04	4	3

14% Recovery

43% Recovery

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

† For a given column, means followed by the same letter are not significantly different at the 0.05 level.

Table 3. Soil chemical concentrations following three years of manure compost and nitrogen fertilizer applications, Tribune, KS, 1989.

Compost	Nitrogen	Bray-1 P	Exch. K	DTPA Fe	Exch. Na
ton/a	lb/a	ppm			
0	0	12	690	7	56
	55	10	660	7	53
	110	9	660	6	52
	165	9	630	6	49
0.9	0	16	690	6	57
	55	20	720	7	57
	110	12	690	6	53
	165	12	690	7	55
1.8	0	34	730	7	63
	55	24	700	7	64
	110	19	730	7	60
	165	24	680	7	54
3.6	0	32	780	7	65
	55	41	790	7	71
	110	31	770	7	71
	165	31	740	7	59
7.2	0	77	890	8	90
	55	66	880	8	88
	110	64	880	7	84
	165	61	880	7	91
$LSD_{.05}$		10	45	1	13
ANOVA					
Compost		**	**	**	**
Nitrogen		**	*	ns	ns
Compost*Nitrogen		ns	ns	ns	ns
MEANS					
Compost					
0 ton/a		10e †	660d	6.4c	52d
0.9		15d	700c	6.4c	56cd
1.8		25c	710c	7.2ab	60bc
3.6		34b	770b	6.8bc	66b
7.2		67a	880a	7.4a	88a
$LSD_{.05}$		5	23	0.6	7
Nitrogen					
0 lb/a		34a	760a	7.1a	67a
55		32a	750a	6.8a	66a
110		27b	740ab	6.8a	64a
165		27b	730b	6.8a	62a
$LSD_{.05}$		4	20	0.5	6

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

† For a given column, means followed by the same letter are not significantly different at the 0.05 level.

applications, the levels of exchangeable Na attained in this study would not be detrimental to crop production. This increase in exchangeable Na does, however, demonstrate the need to monitor soil Na when making repeated manure applications.

Soil inorganic nitrogen levels to a depth of 10 ft were measured in 1988 with no appreciable accumulation of nitrate in the lower portion of the soil profile from either compost or N fertilizer (data not shown).

Cattle manure compost is a good source of nutrients for crop production. Grain sorghum yields were increased up to 7 bu/acre by each ton of compost. When compared with yield increases from N fertilizer, one ton of compost was equivalent to about 14 lb of N fertilizer. However, greater grain yields were observed with combinations of compost and N fertilizer than from either alone. Three annual applications of compost increased residual soil P, K, and Fe levels. Soil Na levels were increased by compost additions but not to damaging levels.

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SOIL FERTILITY RESEARCH PROJECTS
SOUTHWEST KANSAS RESEARCH-EXTENSION CENTER

Macronutrient fertilization of irrigated corn and grain sorghum. Long term studies (initiated 1961) evaluating the effect of N, P, and K fertilization on grain production, nutrient uptake, and soil nutrient concentrations. Alan Schlegel.

Fertilizer management of ridge till corn. Evaluating various N sources, N rates, times of application and an urease inhibitor for production of irrigated ridge till corn. Alan Schlegel.

Use of an urease inhibitor to reduce urea phytotoxicity. Evaluate the effect of an urease inhibitor and fertilizer placement on reducing the phytotoxic effects of urea containing fertilizers on seedling emergence and plant growth. Alan Schlegel.

Residue management of irrigated grain sorghum and wheat. Long term studies evaluating the effect of residue management practices (burning, physical removal, and incorporation) and N fertilization on grain production, nutrient uptake, and soil properties of irrigated grain sorghum and winter wheat. Alan Schlegel.

Nitrogen and irrigation management of winter wheat. Evaluate N rates and time of applications on sprinkler irrigated wheat and the interaction of N fertility and irrigation management. James Schaffer, Alan Schlegel, and Bill Spurgeon, SWKREC.

Nutrient dynamics in a dryland cropping system. Evaluate the effects of residue management and N fertilization on soil nutrients, crop water use, and grain production in a dryland cropping system. Alan Schlegel and John Havlin, KSU Agronomy.

Tillage systems and nitrogen management for a dryland wheat-sorghum-fallow cropping system. Evaluate various tillage systems and N management on water use and crop production in a dryland WSF system. Alan Schlegel and Herb Sunderman, Northwest Kansas Research-Extension Center.

CHARACTERIZATION AND BIOAVAILABILITY OF IMPURITY COMPOUNDS IN COMMERCIAL PHOSPHATE FERTILIZERS

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ABSTRACT

The effect impurity compounds have on P availability in commercial triple superphosphate (CSP) and monoammonium phosphate (MAP) fertilizers was studied in a variety of field, greenhouse, and laboratory studies. The levels of impurity compounds currently in CSP and MAP fertilizers did not have a detrimental effect on P availability. The impurity compounds isolated as water-insoluble fractions of the fertilizers did have lower P availabilities than soluble reagent grade (chemically pure) P sources and there were differences among the fertilizer sources. A study using mixtures of water-insoluble fractions of MAP and reagent-grade MAP indicated that the level of impurity compounds can increase to a level resulting in 60% water-soluble P and create only an 11% decrease in plant growth. The water-insoluble fractions of CSP are believed to include metal-P compounds and unreacted phosphate rock (PR). Water-insoluble compounds identified in MAP were $AlNH_4HPO_4F_2$, $FeNH_4(HPO_4)_2$, and $MgAl(NH_4)_2H(PO_4)_2F_2$. Determined equilibria constants for the impurity compounds in the water-insoluble fractions of MAP indicated the compounds would be more soluble in soil compared to variscite, strengite, and dicalcium phosphate. All field, greenhouse, and laboratory studies imply the increasing use of impure phosphate rock in P fertilizer production is currently not a major agronomic problem.

OBJECTIVES

Increasingly impure PR is utilized in the production of commercial MAP and CSP fertilizers. Major impurity elements in PR consist of Al, Fe, Ca, Mg, and F. There is concern that impurity elements in the PR may result in impurity compounds in commercial P fertilizers that have low solubility, thus reducing P availability to plants. Also, impurities may have potential impact on US fertilizers competing with foreign P fertilizers in the European community because of a stringent European regulation requiring P fertilizers to have 93% of the declared citrate-soluble P soluble in water (1). This report contains a summary of several field, greenhouse, and laboratory experiments conducted to determine the effects of the impurity compounds on plant growth.

MATERIALS AND METHODS

Several CSP and MAP sources were used which were produced from Florida (FL), North Carolina (NC), Idaho (ID), or Moroccan (MR) PR. The water-insoluble fractions of the CSP and MAP fertilizers were collected by modifying the Association of Official Analytical Chemist (AOAC) method for water-soluble P (2) by using larger fertilizer sample size and collecting the water-insoluble fraction. The water-insoluble fractions were approximately 13 to 17% of each total fertilizer by weight. The fertilizers were analyzed for water-soluble and citrate-insoluble P following AOAC methods (2).

In the field and greenhouse studies, sorghum-sudangrass (Sorghum bicolor), pearl millet (Pennisetum typhoides), and potato (Solanum tuberosum L.) were used as test crops. The soils were fertilized with macro- and micronutrients so the only limiting plant nutrient was P. Soils were limed to pH levels between 6 and 7. A range of P rates was used in the crop growth studies where P response was the greatest. Only one P rate is reported in tables of this report for sake of brevity.

Laboratory studies involved the measurement of P dissolution from the water-insoluble fractions of selected MAP fertilizers. One g of the water-insoluble fraction was mixed with 40 ml of 3 mM $Ca(NO_3)_2$ and mixed for time periods of 0.1 to 64 hours for the kinetic study. The samples were filtered with 2 μm millipore filter and the filtrate was analyzed for pH, P, and all other elements that existed in the water-insoluble fraction.

RESULTS AND DISCUSSION

Agronomic evaluation of commercial fertilizers

Commercial CSP and MAP fertilizers were tested for their ability to provide P to plants in field and greenhouse environments. The chemical analyses of the fertilizers are shown in Table 1. The AOAC-available P soluble in water ranged from 80 to 93% in the CSP fertilizers and from 81 to 97% in the MAP fertilizers.

Table 1. Chemical analyses of CSP and MAP fertilizers used in field and greenhouse experiments.

Fert-ilizer	PR SOURCE	Total P	Total N	citrate insol-uble P	AOAC "avail" P [a] soluble in H_2O	Al	Fe	Ca	Mg	F
		%								
CSP										
CSP1	FL	19.2	-	0.59	80	0.92	1.4	14	0.47	2.4
CSP2	FL	20.8	-	0.78	86	0.75	1.4	15	0.40	2.3
CSP3	FL	20.7	-	0.99	83	0.99	1.5	14	0.47	2.1
CSP4	NC	20.7	-	0.78	87	0.28	1.1	15	1.09	1.7
CSP5	ID	19.7	-	0.02	92	0.82	0.6	15	1.02	1.3
CSP6	MR	21.2	-	0.75	92	0.19	0.2	17	0.71	2.4
NSP1 [b]	MR	7.9	-	0.20	93	0.20	0.1	20	0.17	1.6
MAP										
MAP1	FL	22.7	11.5	0.01	93	0.78	1.5	0.33	0.45	1.8
MAP2	FL	22.6	11.3	0.22	91	0.97	1.5	0.35	0.50	1.6
MAP3	FL	22.1	10.6	0.53	93	0.93	1.5	0.62	0.64	2.1
MAP4	FL	21.4	9.9	0.09	83	1.11	3.4	0.58	0.66	2.2
MAP5	FL	21.6	10.0	0.05	81	1.20	3.1	0.49	0.62	2.1
MAP6	FL	22.3	10.3	1.34	86	1.15	2.7	0.67	0.71	2.2
MAP7	FL	22.7	11.0	0.05	93	0.84	1.6	0.29	0.48	2.0
MAP8	NC	22.8	11.5	0.01	97	0.27	0.7	0.42	0.86	1.0
MAP9	ID	22.6	11.2	0.21	92	0.96	0.6	0.80	0.62	2.0

[a] AOAC "available" P = water+citrate soluble P.
[b] NSP = Normal superphosphate.

There were no significant differences in dry matter weight of sorghum-sudangrass in a greenhouse experiment when fertilized with the one NSP and six CSP fertilizers identified in Table 1 (3). There was also no difference in potato yields in a field experiment utilizing CSP fertilizers CSP1, CSP2, CSP4, and CSP6 at two locations (4). A field evaluation of the nine commercial MAP sources identified in Table 1 indicated no major differences in dry matter weight of pearl millet (5).

The agronomic results indicated that the levels of impurity compounds that are presently in the commercial fertilizers had no observable impact on the availability of P to plants. The lowest level of AOAC "available" P soluble in water was 80% for the CSP fertilizers and 81% for the MAP fertilizers. The data reemphasizes conclusions of previous research that at least 60% water-soluble P is adequate for crop growth (6) and that there is no significant gain in crop response with >80% of AOAC "available" P soluble in water (7). Therefore, the stringent European regulation that 93% of citrate-soluble P must be water-soluble is not justified agronomically.

P availability of water-insoluble fractions of fertilizers

Results from the studies using the commercial fertilizers indicated no detrimental effect of impurity compounds on crop growth. However, the studies did not address the issues of availability of P in impurity compounds themselves, the level of impurity compounds that can be tolerated in fertilizer without decreasing yields, and the identification of individual impurity compounds that may be highly unavailable as residual P in soil. To help answer questions that these issues pose, water-insoluble fractions were collected from commercial MAP and CSP fertilizers and studied.

The P availability of the water-insoluble fractions of several CSP fertilizers was studied in a greenhouse experiment using sorghum-sudangrass as a test crop (8). The P availabilities of the water-insoluble fractions were less than that from reagent grade monocalcium phosphate and there were differences among the different sources (Table 2). The highest P availability occurred with the water-insoluble CSP produced from NC PR (WI-CSP4). The lowest P availabilities occurred with the water-insoluble CSPs produced from ID (WI-CSP5) and MR (WI-CSP6) PR. The water-insoluble compounds of the CSP fertilizers are believed to consist of unreacted PR

Table 2. Dry matter weight and P uptake of sorghum-sudangrass in a greenhouse study with water-insoluble CSP fractions (WI-CSPx) as P sources (8).

Fert-ilizer	PR Source	Dry matter weight [a]	P uptake
		g per pot	mg per pot
RG-MCP [b]		18.1	20.0
WI-CSP1	FL	11.8	9.7
WI-CSP2	FL	11.8	9.3
WI-CSP4	NC	14.7	13.0
WI-CSP5	ID	5.0	3.4
WI-CSP6	MR	5.1	3.3

[a] Total dry matter weight and P uptake of 2 harvests at 21 and 42 days after harvest.
[b] RG-MCP = Reagent grade monocalcium phosphate (chemically pure).

PR and metal-P salts formed during acidulation. The AOAC determined "available" P levels (2) were greater than the actual P availabilities of the compounds in the water-insoluble CSP fractions (8).

The P availabilities of the water-insoluble fractions of all MAP fertilizers in Table 1, excluding MAP4 and MAP5, have been determined in greenhouse experiments using sorghum-sudangrass as a test crop (9,10). As with the water-insoluble fractions of CSP, the MAP water-insoluble fractions provided less P for plant growth than reagent grade MAP and there were differences among the sources (Table 3). The P of the water-insoluble MAP from NC PR (WI-MAP8) was most available and that from a FL (WI-MAP6) and ID (WI-MAP9) PR was the least available to the test crop.

Table 3. Dry matter weight and P uptake of sorghum-sudangrass in greenhouse studies with water-insoluble MAP fractions (WI-MAPx) as P sources.

Fertilizer	PR Source	Dry matter weight [a]	P uptake [a]
		g per pot	mg per pot
	EXPERIMENT 1 (Ref. 9)		
RG-MAP [b]		17.7	31.5
WI-MAP1	FL	11.4	11.4
WI-MAP2	FL	8.5	7.2
WI-MAP3	FL	7.2	5.5
WI-MAP6	FL	3.3	2.3
WI-MAP7	FL	10.8	10.8
WI-MAP8	NC	16.1	21.4
WI-MAP9	ID	5.8	4.3
	EXPERIMENT 2 (Ref. 10)		
RG-MAP [b]		8.3	11.2
WI-MAP1	FL	6.0	6.0
WI-MAP8	NC	8.1	10.1
WI-MAP9	ID	3.0	2.6

[a] Total dry matter weight and P uptake of four harvests taken 30, 60, 90, and 120 days after planting for Experiment 1. Total dry matter weight and P uptake of two harvests taken 33 and 40 days after planting for Experiment 2.

[b] RG-MAP = Reagent grade MAP (chemically pure).

The impurity compounds in the water-insoluble fractions of MAP were found to be metal-N-P compounds formed during the ammoniation of phosphoric acid (10). Three common P impurity compounds found in WI-MAP1, WI-MAP8, and WI-MAP9 were $AlNH_4HPO_4F_2$, $FeNH_4(HPO_4)_2$, and $MgAl(NH_4)_2H(PO_4)_2F_2$. A good negative correlation existed between P availability and % P present in the water-insoluble fractions as $MgAl(NH_4)_2H(PO_4)_2F_2$, which suggested this compound has a low solubility or rate of P dissolution in soil. Another factor that appeared to control P availability was crystallinity of the impurity compounds. In addition to having the highest level of P present in $MgAl(NH_4)_2H(PO_4)_2F_2$, the high crystallinity of the compounds in WI-MAP9 may have contributed to the low P availability of this source.

In studying the P availability of the water-insoluble fractions, the water-insoluble fractions were collected as a powder and pressed under high pressure to form fertilizer pellets for soil application. Due to the amorphous nature of the compounds, the resultant pellets were very hard and some pellets did not dissolve completely in the soil of the greenhouse studies. By pelleting the water-insoluble fractions, the best simulation of how the water-insoluble fraction may exist in soil may not have been realized. The water-insoluble fractions are most likely present in soil as small particles after the soluble MAP dissolves from fertilizer granules. A greenhouse study was conducted to concentrate on the placement and particle size of the water-insoluble fractions and the effects on P availability.

Broadcasting the water-insoluble fraction as a powder two inches below the soil surface resulted in the greatest P availability (Table 4). The broadcasted water-insoluble fraction fertilized a greater proportion of the soil and resulted in greater solubilization of the P and greater root contact. A soluble P source would not be expected to have done as well broadcast at such a low particle size due to reaction with the soil to form insoluble P compounds (11). Placement of the water-insoluble fertilizer powder in the same number of sites as the hard granules resulted in a greater P availability compared with the hard granules which may be due to a greater kinetic rate of P dissolution from the powder due to the much higher surface area. The actual P availability from the water-insoluble MAP impurity compounds may be somewhere between the broadcast and specific site treatment of the powder because of the diffuse distribution of impurity compounds accompanying MAP granules. Hard pellets of the water-insoluble fertilizer fractions used in previous greenhouse experiments (Tables 2 and 3) may have underestimated the actual P availability of the impurity compounds in fertilizer granules.

Table 4. Effect of placement of water-insoluble MAP fractions (WI-MAPx) on dry matter weight and P uptake of sorghum-sudangrass.

Fert-ilizer	PR Source	Broadcast Powder	site-placement of powder	site-placement of granules
		Dry Matter Weight (g per pot) [a]		
WI-MAP1	FL	13.2	12.6	9.7
WI-MAP6	FL	4.7	3.0	2.4
WI-MAP9	ID	11.0	4.8	3.1
		P Uptake (mg per pot) [a]		
WI-MAP1	FL	11.7	13.2	9.5
WI-MAP6	FL	3.3	1.9	1.6
WI-MAP9	ID	8.3	4.1	2.3

[a] Data from one harvest taken 30 days after planting.

Impurity compounds apparently were not at a high enough concentration in the whole fertilizers to result in decreased P availability. However, when the water-insoluble fractions were used as P sources, lower P availabilities were observed, as compared with soluble reagent grade P sources (Table 2 and 3). Greenhouse studies were conducted to determine the level of impurity compounds in commercial fertilizers that could be tolerated by plants before decreased yields would result. The P sources for the study were obtained by mixing reagent grade MAP with water-insoluble MAP fractions in various proportions.

The data for dry matter weight of sorghum-sudangrass was plotted vs. per cent water-soluble P in the mixtures and the quadratic model for the relationships was $Y = 10.3 + 0.22\ X - 0.001\ X^2$, $R^2=0.73$ (12). From this model, a mixture containing 60% water-soluble P would decrease growth by only 11%. Because of the different solubilities of the MAP water-insoluble fractions, the level of water-insoluble fraction that would be present to decrease water-soluble P to 60% would depend on the source of the P rock used to produce the P fertilizer. The quadratic model gives an estimate on how crop yields might be affected by higher levels of impurity compounds that would decrease water-soluble P in MAP. Work also is being conducted to determine the plant vs. water-soluble P relationship for mixtures of water-insoluble CSP fractions and reagent-grade monocalcium phosphate.

Kinetics and equilibrium of P dissolution in impurity compounds

Laboratory experiments have been conducted to better define the kinetics of P dissolution and solubility products of the impurity compounds in the water-insoluble fraction of MAP fertilizers. The rate of P release from the water-insoluble fractions was not modeled well by using a first-order rate equation because of a heterogeneous solid phase and variable solution composition upon dissolution (13). The rate of P dissolution was described well with the Elovich equation, $dP/dt = \alpha\ \exp(\beta P)$. The β constant in the Elovich equation was a good predictor of P availability in a greenhouse experiment with low β associated with high P availability (13). The good relationship between β and P availability does not indisputably prove that the rate of P dissolution is important in P availability since a relationship exists between β and the equilibrium P concentration (P_{eq}). At equilibrium, $dP/dt=0$ and $P_{eq} = 1/\beta\ \ln \alpha$. Further work is needed to determine the relevance of P dissolution kinetics to bioavailability of P in soil.

The solubility products of impurity compounds in water-insoluble MAP fertilizer fractions were calculated from the total concentrations of chemical species found in the solution phase in contact with the water-insoluble fraction at an equilibrium time of 64 hours. A chemical speciation computer program, MINEQL (14), was used to calculate the activity of the chemical species and thus the ion activity product, or solubility product, of the three impurity compounds, $AlNH_4HPO_4F_2$, $FeNH_4(HPO_4)_2$, and $MgAl(NH_4)_2H(PO_4)_2F_2$, found in the water-insoluble MAP fractions (Table 5). With an estimate of the solubility products, the equilibrium concentration of P from the compounds was calculated in soil and compared to equilibrium P concentrations from other P compounds believed to occur in soil (Table 5).

At pH 5.0 the impurity compounds are more soluble than variscite and strengite and have similar solubility to that of dicalcium phosphate (Table 5). At pH 6.5, the impurity compounds are more soluble than dicalcium phosphate, variscite, and strengite. The higher solubility of the impurity compounds compared with the P compounds that are believed to precipitate in soil indicates the impurity compounds do not become residual P in soil that is highly insoluble and unavailable to plants.

The impurity compound, $MgAl(NH_4)_2H(PO_4)_2F_2$, was the least soluble in soil among the three impurity compounds at pH 6.5 and is consistent with the negative correlation between sorghum-sudangrass growth (Table 3, Exp. 2) and the % P present as $MgAl(NH_4)_2H(PO_4)_2F_2$ in the water-insoluble fractions (10).

Table 5. Solubility products for $AlNH_4HPO_4F_2$, $FeNH_4(HPO_4)_2$, and $MgAl(NH_4)_2H(PO_4)_2F_2$ and their solubility in soil compared to variscite, strengite, and dicalcium phosphate.

Compound	log K^o [a]	log $[P_T]$ [b] at pH 5.0	log $[P_T]$ [b] at pH 6.5
$AlNH_4HPO_4F_2$	-15.92 ± 0.57	-1.6	+1.2
$FeNH_4(HPO_4)_2$	-8.75 ± 0.20	-1.7	-0.9
$MgAl(NH_4)_2H(PO_4)_2F_2$	-13.61 ± 0.96	-1.6	-1.6
Variscite		-4.2	-2.7
Strengite		-4.5	-3.0
Dicalcium Phosphate		-2.2	-4.5

[a] Log K^o describes dissolution equilibria with the production of $H_2PO_4^-$. For example, 1, 2, and 3 protons reacts with $AlNH_4HPO_4F_2$, $FeNH_4(HPO_4)_2$, and $MgAl(NH_4)_2H(PO_4)_2F_2$, respectively.

[b] Al and Fe activity assumed to be controlled by gibbsite and $Fe(OH)_3$(soil), respectively. F activity assumed to be controlled by fluorite. Ca activity = $10^{-2.5}$ M. Mg and NH_4 activity = 10^{-3} M. P_T = Total P concentration at equilibrium.

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CHLORIDE EFFECTS ON WHEAT GROWTH AND DEVELOPMENT

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ABSTRACT

Kernel weights are frequently higher and heading date advanced as a result of Cl fertilization. The objective of the study was to examine the effects of KCl fertilization on the reproductive development of wheat growing on high K-test soils. Spike formation was examined for two rates of KCl fertilization and on two wheat varieties. Culm length at the time of rapid culm elongation was used as an easily measured parameter to verify development differences due to the chloride ion. The initiation, rate, and duration of grain fill was studied in the 1989 field season. The beginning of spikelet primordia formation, defined as the appearance of a double ridge on the apical meristem, was advanced by Cl. Advanced reproductive development was observed on the Cl plots through anthesis. Culm elongation commenced earlier on Cl fertilized plots. KCl and $CaCl_2$ treated plots were similarly advanced relative to check plots. Anthesis occurred one day earlier on Cl fertilized plots. There were no differences between Cl treatments for the date of physiological maturity or rate of grain fill. There was an increase in grain fill duration for the variety Marshall resulting in higher kernel weights.

OBJECTIVES

Wheat yield response to KCl on very high K-testing soils is related in part to the chloride ion. Soil and plant Cl concentrations were previously related to yield responses in South Dakota (Fixen et. al. 1986a). Results of field experiments demonstrate that foliar disease suppression is a major contributing factor to the yield response. However, yield responses have also been observed at sites with little or no detectable disease (Fixen et.al. 1986a). Wheat response to chloride frequently includes an increase in kernel weight and earlier dates of heading and culm elongation. This relationship suggests an effect of Cl on the reproductive development of wheat. The objectives of this research were to: 1. determine the effects of chloride on the reproductive development of spring wheat; and 2. examine the relationship of chloride to kernel growth.

MATERIAL AND METHODS

Measurements were made on spike development for two years (1988 and 1989) on experimental plots designed to examine the effects of chloride on crop production (Kooiman, 1989). Each experiment included two cultivars (Marshall and Guard), and two KCl application rates (0 and 120 lbs/a). Marshall generally responds while Guard does not respond to Cl fertilization on soils testing low in Cl (Fixen et.al. 1986b). The fungicide Tilt, 1-[2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl] methyl]- 1H-1,2,4,-triazole, was applied over the study area to reduce the effects of foliar disease. Soil chloride tested in the responsive category at 19, and 21 lbs/a in the top two feet. Soil potassium levels in the top six inches tested at 390, and 460 lbs/a for the two study years.

Plants were sampled at the 3.5 leaf stage (Haun scale) (1973) until the beginning of grain fill at intervals of 2 to 4 days. Five main stems per plot (thirty plants per treatment) were removed from each plot for spike evaluation. Spike differentiation was described using the 12 stage scale of George (1982) and descriptions by Kirby (1981) for stages 13 to 16. Linear regression was used to determine the critical points of double ridge formation and terminal spikelet formation based on data from the linear phase of spike development (Stern and Kirby, 1979). Culm lengths were measured during the period of culm elongation after heading. Culm length measurements were also made on an adjacent Cl source study to verify Cl ion effects on development at the time of heading. The Cl source study included check, KCl,and $CaCl_2$ treatments.

The period of grain fill was analyzed in 1989 for initiation, rate and duration of kernel growth. Spikes from the main stem were tagged when extruded anthers first appeared from the central florets (Bruckner and Frohberg, 1987). Samples of five tagged spikes were taken from each plot at 3-4 day intervals until after harvest maturity. Samples were dried in a forced air oven at 80 C. Kernel number and dry weight were used to determine physiological maturity. Physiological maturity was defined as the date when maximum kernel weight is attained (Copeland and Crookston, 1985).

RESULTS AND DISCUSSION

Spike formation.

Spikelet primordia development was advanced by KCl fertilization on most sampling dates for the variety Marshall (Table 1). Formation of the double ridge (stage 6) and terminal spikelet (stage 13) occurred 2 days earlier on KCl treated Marshall plots in 1988 and 1 day earlier in 1989. The effects of KCl fertilization on spikelet primordia development was less pronounced in the variety Guard. The appearance of a double ridge on the growing apex represents the beginning of the reproductive phase of development. The terminal spikelet stage marks the end of spikelet primordia development. The total number of spikelet primordia was not affected by KCl fertilization for either variety (14 in 1988 and 12 in 1989).

Culm Elongation.

Culm lengths after heading and during anthesis are easily measured and a good visual indicator of reproductive development. There was a consistent effect of Cl on heading and subsequent culm elongation. Culm elongation started earlier on Cl treated plots independent of the source of Cl (Table 2). The effect was most pronounced in both years on the variety Marshall. There was no effect of Cl treatment on the rate of culm elongation. Final culm lengths were similar between Cl treatments in 1988 but not in 1989. The ultimate height of plants were reduced on Marshall KCl treated plots. The effect could be explained by the interaction of culm elongation with a precipitation event. Precipitation of 1.8 inches occurred near the end of the culm elongation phase of development in the KCl treated plots. The control plots during this time were in the middle of culm elongation. Control culm lengths increased after the precipitation event. A similar response was observed in a related chloride source study for both KCl and $CaCl_2$.

Table 1. The effect of KCl on spike stage of development.

	1988				1989			
	Marshall KCl		Guard KCl		Marshall KCl		Guard KCl	
DAP	0	120	0	120	0	120	0	120
26	-	-	-	-	4.4	5.9	6.3	7.0
29	-	-	-	-	7.6	9.3^{+}	12.2	11.5
32	1.6	2.6	2.0	2.6	12.1	12.9^{+}	14.5	14.7
34	3.5	5.0^{*}	4.0	5.6^{*}	14.0	14.6^{+}	15.0	15.0
36	4.6	5.3^{*}	6.5	8.1^{*}	-	-	-	-
39	4.7	7.1^{**}	10.8	10.5	-	-	-	-
41	7.8	8.5	11.6	12.1	-	-	-	-
43	7.9	10.5^{*}	12.8	12.8	-	-	-	-
48	12.8	13.2^{*}	13.3	14.0^{*}	-	-	-	-
50	13.0	13.3	14.0	14.7^{*}	-	-	-	-
53	13.5	14.5^{*}	14.5	15.0	-	-	-	-

$^{+}$, *, ** represents significance of the F statistic for mean comparison within year and variety at the .10, .05, .01 levels of probability, respectively.

Table 2. Relative* culm lengths during the period of culm elongation following heading.

Treatment	Source Study Marshall 1988	Source Study Marshall 1989	Development Study Marshall 1988	Development Study Marshall 1989	Development Study Guard 1988	Development Study Guard 1989
	-----%-----		-----%-----		-----%-----	
Check	25	9	10	18	84	44
KCl	80	28	37	50	89	81
$CaCl_2$	65	30	-	-	-	-
KNO_3	30	-	-	-	-	-
$LSD_{.05}$	18	10	12	18	NS	15

* Culm lengths are expressed as a percentage of final length.

Grain Fill.

The date of anthesis , measured as the extrusion of anthers in the central florets of the main tiller, was consistently advanced by 1 day across all KCl treated plots (Table 3). Physiological maturity was measured as the point of maximum dry matter accumulation of kernels on the main tiller. Although the date of anthesis was advanced by one day, the point of physiological maturity occurred at the same day for both KCl and control treatments in Marshall. There was a tendency for Guard to reach the end point of dry matter accumulation earlier on the KCl treated plots relative to the control. A similar finding was found for the date of 95% maximum kernel weight. The maximum kernel weight at physiological maturity was significantly greater for the KCl treatment with the variety Marshall but not Guard. Rate of grain fill during the linear phase of kernel growth was not affected by KCl treatment. The duration of grain fill (anthesis to physiological maturity) was increased by 1.5 days in Marshall but not in Guard. The increased grain fill duration corresponds closely to the maximum kernel weight at physiological maturity. This suggests that the increased kernel weights from KCl application were a result of the lengthening of the grain fill period and not due to an effect on the rate of grain fill. Final kernel weights at harvest were similarly increased. However, grain yield for both 1988 and 1989 were reduced due to both temperature and water stress. As a result there was little effect of KCl fertilization on overall grain yield (Table 4). The effects of increased kernel weight on grain yield are more likely to be observed in a higher yield environment.

Table 3. Effects of KCl on grain fill.

Variety	KCl	AT	PM	95% KWT	KWT PM	Rate G.F.*	Duration G.F.**
		--------DAP-------			mg	mg/day	days
Marshall	0	58	88.2	81.9	30.3	1.81	30.2
	120	57	88.7	81.7	31.5	1.83	31.7
P > F		0.001	NS	NS	0.003	NS	0.03
Guard	0	55	85.1	78.5	31.7	2.00	30.2
	120	54	84.2	77.6	31.9	2.02	30.2
P > F		0.001	NS	0.17	NS	NS	NS

AT = Anthesis; PM = Physiological Maturity; KWT = Kernel Weight
G.F. = Grain Fill
* Rate of grain fill during the linear phase.
** Duration of grain fill - Anthesis to PM.

Table 4. Influence of KCl on yield and yield components .

		1988			1989		
Parameter	KCl	Marshall	Guard	LSD.10	Marshall	Guard	LSD.10
Grain Yield bu/a	0	19.8	21.9	NS	19.6	20.1	0.7
	120	19.9	22.2		19.2	20.8	
Kernel Weight mg/kernel	0	21.1	21.6	NS	27.8	29.8	0.6
	120	22.2	22.3		29.0	30.1	
Spikes/meter	0	515	551	NS	418	368	14
	120	518	597		424	400	
Kernels/ spike*	0	20.9	15.7	NS	19.4	20.9	NS
	120	22.0	17.1		19.2	20.8	

* Main spike.

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A COMPARISON OF MEASURED AND PREDICTED N MINERALIZED USING MINIMO, A SUBROUTINE OF CERES-MAIZE

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The amount of mineralized N recovered by double cropped sorghum and wheat from ^{15}N labeled sorghum residues was compared to the amount of predicted N mineralized by MINIMO a subroutine of CERES-MAIZE. In its present form the simulation model over predicted between 2 and 9 times the amount of N mineralized measured 110 days after residue incorporation. An improved agreement between measured and model predicted N mineralized was achieved by reducing the rate constants of all three plant carbon pools, refitting the C/N function to the measured data, and decreasing the microbial requirement for microbial decay.

OBJECTIVE

Most Laboratories recommending N fertilizer either ignore or simply guess at the amount of N mineralized or immobilized during the decomposition of a previous years crop residue. This is understandable since presently there isn't a laboratory method available for accurately predicting the amount of N that will mineralize or immobilize in a given season. The problem lies in the complexity of organic N turnover which is affected by both characteristics of the residue, and soil and variable soil temperature and moisture conditions from year to year.

Simulation models which mimic the processes of N turnover allow for the integration of various soil, residue and environmental factors. An objective of this study was to determine if a simulation model could be used to predict the amount of N mineralized from ^{15}N-labeled sorghum residues, of variable N content, decomposing under field conditions.

MATERIALS AND METHODS

On June first of 1985 ^{15}N-labeled Sorghum residues, of variable N content, were incorporated into the surface 4 inches of field microplots, on a Smolan silt loam, at the North farm agronomic research center in Manhattan, Kansas. Just prior to residue incorporation, the soil was sampled to a depth of 26 inches at four depth increments of: 0-4, 4-10, 10-18, and 18-26 inches. The soil samples taken were analyzed for total and inorganic N. Soil water content was also gravimetricaly determined at this time at each depths. Just after residue incorporation, sorghum was sown into the microplots. On September 19th the plants in each microplot were harvested. Whole plants were oven dried, weighed, and ground. Total N and ^{15}N abundance was determined using the method of Bremner (1982), and of Smith et al. (1963) respectively. On the same day plants were harvested the soil was again sampled to the same depths increments described previously for inorganic N, total N, and soil water content determinations.

Wheat was planted on 18 October 1985 and harvested on 31 May 1986. At harvest soil and plant samples were again taken as described for sorghum. On 26 June 1986 sorghum was planted in each microplot and harvested in mid October 1986. A second wheat crop was planted in October 18 1986. The double cropped sorghum-wheat rotation was continued for a third year for a total of 6 crops. The accumulated amount of residue N recovered in the harvested plants during the three year period was summed and expressed as a ratio of the recovered tagged N over the initial amount of N applied in the residue.

The MINIMO model was used to simulate the amounts of N mineralized from the various crop residues incorporated. To run the simulation daily soil temperature and daily soil water contents were read from an external data file. Soil temperatures were measured using Omni-data temperature recorders. The soil water contents read into the model were generated using the soil water balance model described by Ritchie et al. (1986). A weather station located approximately 500 m away from the site was used to obtain climatic data for the soil water balance model.

RESULTS AND DISCUSSION

Some chemical characteristics of the residues used are given in Table 1. Generally, as the C/N ratio increased less mineralized residue N was recovered (Fig. 1). For C/N ratios of 30, 37, and 44 only 9.5, 8.8 and 4.5% respectively, of the residue N was recovered by the first sorghum crop 110 days after residue incorporation (Fig. 1). In microplots where C/N ratios of 20, 25, and 27 were applied 22, 23 and 25% of the residue N was recovered by the first sorghum crop, respectively. The N recovered by the first sorghum crop constituted 56 to 77% of the total N recovered during the three year period. Since only small amounts of inorganic N were extracted with 2 M KCI (particularly NO_3-N) at each of the six harvests the amount of residue-mineralized-N recovered was assumed to be equal to the net N mineralized.

The results of the simulation are given in Table 2. In all cases the amount of mineralized N predicted using MINIMO was 2 to 9 times greater than that measured. In MINIMO there are three rate constants used to calculate the gross rate of decomposition of a crop residue. These rate constants of 0.8, 0.5, and 0.0095 day $^{-1}$ represent the decomposition rates for residue carbohydrate-like, cellulose-like, and lignin-like fractions of a crops residue respectively. To bring MINIMO simulated values closer to those measured with the ^{15}N-labeled residues the rate constants for residue carbohydrate-like, cellulose-like, and lignin-like fractions of a crop residue were decreased to 0.05, 0.00425, and 0.0009 day $^{-1}$ respectively.

MINIMO also contains an equation that adjusts the various rate constants based on the C/N ratio of the mixture of freshly incorporated organic matter (FOM) and soil this equation in its original form is:

$$CNRF = e^{-0.693((CNR - CNMAX)/CNMAX)}$$

where CNRF is the adjusting C/N ratio factor for the decomposition rate

Table 1 selected chemical properties of the crop residues used in the ^{15}N labeled experiment.

Residue description	C/N	Atom % ^{15}N	-----Total----- N	C	Lignin
		———————	%	———————	
stage 2 sorghum plants	20	1.51	2.10	41.1	5.1
stage 3 sorghum plants	25	1.10	1.71	41.9	5.1
post harvest sorghum leaves	30	1.70	1.33	40.4	7.1
post harvest sorghum leaves	37	2.44	1.10	40.7	5.7
stage 4 sorghum stems	27	1.30	1.53	41.1	5.7
post harvest sorghum stems	44	2.29	0.92	40.8	7.4

Table 2. Measured and predicted mineralized N recovered 110 days after incorporation from ^{15}N labeled sorghum residues of various C/N ratios.

C/N	Measured	original	adjusted
	———————	%	———————
20	22.3	63.0	25.3
25	23.0	56.7	20.2
27	24.8	56.5	18.9
30	9.5	55.0	16.6
37	8.8	46.3	9.5
44	4.5	38.8	3.9
RSS		212400.0	209.0

Values are the amount of mineralized N expressed as a percent of the amount of N applied in the residue.
RSS is the residual sum of squares.

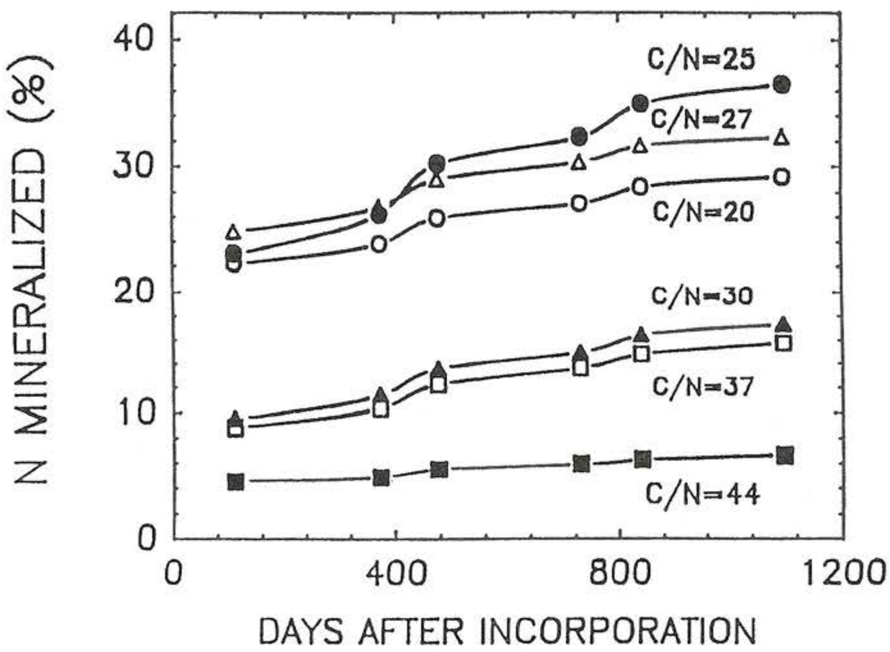

Fig. 1. Accumulated mineralized-N-recovered by double cropped sorghum and wheat over a three year period from 15-N labeled sorghum residues.

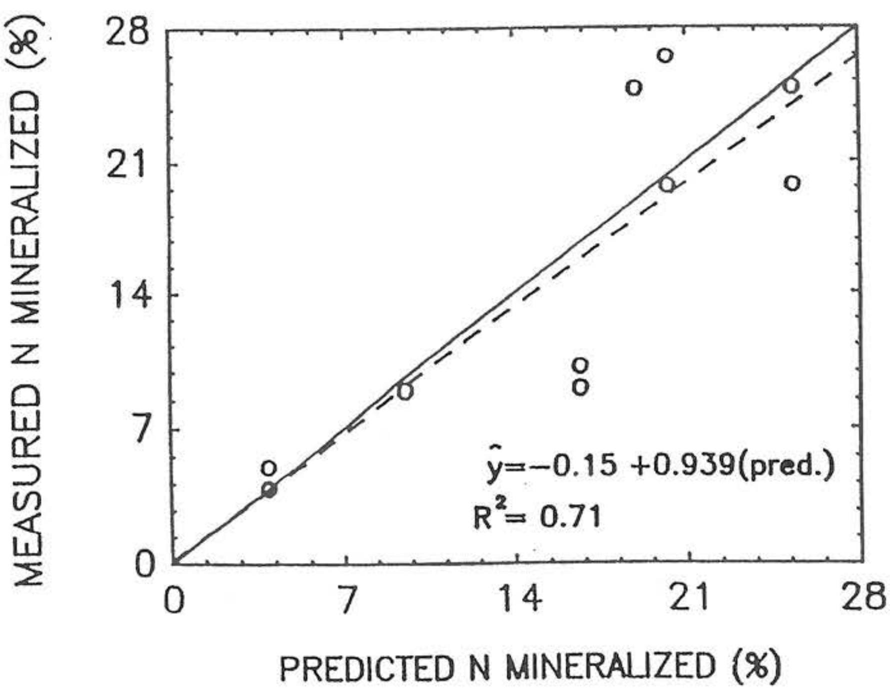

Fig. 2. A comparison between measured and predicted mineralized-N-recovered by day 110 using the MINIMO model after adjustment of rate constants and other model parameters (see text).

constant, CNR is a C/N ratio determined by dividing the C in FOM by the sum of the N in FOM and the soil inorganic N, and CNMAX is the C/N ratio where no decrease in the decomposition rate constant is calculated. For our residue experiment CNMAX was set equal to 13. A final adjustment was made to the model to increase the amount of mineralization from residues with the narrower C/N ratios by decreasing the N requirement for microbial decay from 0.02 to 0.0165. These changes allowed MINIMO to more accurately predict the amount of N mineralized. A linear fit between predicted and measured N recovered is shown in Fig 2. The slope and intercept of the linear fit between measured and predicted N mineralized was not significantly different than 1 and 0 indicating a reasonable simulation.

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EFFECTS OF TILLAGE, CROPS, AND CROP SEQUENCES ON SOIL N STATUS

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ABSTRACT

Soil NO_3^--N accumulation during fallow and soil NO_3^--N levels on no-till (NT) and stubble mulch (SM) tillage were measured under continuous wheat (CW) continuous grain sorghum (CS) and in a wheat- sorghum-fallow sequence (WSF) on Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls). Average annual N uptake was similar under NT and SM in all cropping sequences. It was higher under CS than under CW and WSF and similar in the two latter sequences. Nitrate N accumulation during fallow on NT CS and SM CS averaged 23 and 20 lbs/ac respectively. Respective average accumulations under NT CW and SM CW were 17 and 32 lbs/ac. Between wheat and sorghum on WSF accumulation on NT and SM averaged 34 and 50 lbs/ac respectively. Respective accumulations between sorghum and wheat were 23 and 36 lbs/ac. NO_3^--N removal exceeded mineralization with both tillage systems under CS, but under CW, NO_3^--N levels were maintained. On WSF, sorghum on NT plots removed most of the NO_3^--N to 6 ft and on SM plots to 4 ft. Removal by sorghum was greater than by wheat. Sorghum responded to N fertilizer under NT and SM CS and NT WSF. Wheat did not respond to N fertilizer.

OBJECTIVES

No-tillage (NT), mulch tillage and other conservation tillage practices have been shown to reduce soil loss by wind and water erosion. Under NT, a greater proportion of precipitation is stored as soil water but the supply of available nitrogen (N) is decreased through surface management of residues. When under stubble-mulch tillage (SM), Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) and other fine-textured soils of the Southern High Plains have been shown to contain sufficient plant nutrients for as high yields as the precipitation allows. However, under NT, the additional soil water storage increases the yield potential and the yields may be limited by the supply of available N. The objectives of the study were, (1) to determine the comparative effects of NT and SM on N supplying capacity of soil in a wheat (*Triticum aestivum* L.) - sorghum [*Sorghum bicolor* (L.) Moench] - fallow sequence (WSF), and under continuous wheat (CW) and continuous grain sorghum (CS), and, (2) to determine fertilizer needs for wheat and grain sorghum grown under NT and SM in WSF sequences and in continuous cropping systems.

METHODS AND MATERIALS

The site was on leveled minibenches (Jones, 1981) on a 1.5% slope (before benching) on Pullman clay loam at the USDA-ARS Conservation and Production Research Laboratory, Bushland, Texas. The 50-yr average annual precipitation at Bushland is 18.64 inches, 78% falling during the 6-month period, May through October. Average evaporation during the 6-month period, April through September is 69.01 inches.

Tillage treatments were NT and SM tillage. On NT, weeds were controlled with chemicals and the only soil disturbance involved seeding the crops. On SM, tillage was performed with a sweep plow with large (72-inch) V-shaped blades. The first tillage after harvest loosened the soil to a 5 inch depth. Succeeding operations were at shallower depths, usually just deep enough to operate the equipment for weed control. Three tillage operations were usually required between continuous crops; five were required during fallow periods in the WSF sequence. The first tillage was performed as soon after harvest as necessary to control weeds. The first tillage following grain sorghum was in April.

Cropping systems studied were CW, CS, and a WSF sequence. In the WSF sequence, each crop is followed by an approximate 11-month fallow period, allowing two crops in 3 years.

Individual plots were 33 x 470 ft "minibenches", leveled areas enclosed with borders to prevent runoff. The experimental design was a randomized block with 3 replications. In March 1988, 50 lbs/ac of N was applied on the CW plots and at planting, a like amount was applied on CS plots. At wheat planting in 1988 and at sorghum planting in 1989, 50 lbs N/ac was applied on all plots planted. Two check strips, 50-ft wide, were left unfertilized on each plot.

We measured soil NO_3^--N and soil water to 6 ft at beginnings and ends of growing seasons and to 1 ft at 2-3 week intervals during growing seasons; grain yields, forage yields, and N uptake.

RESULTS

The study was conducted during a series of years when climatic conditions were generally favorable for crop production. Yields were much higher than longtime averages. Average annual yields in this study and longtime average yields at Bushland (both under SM) were as follows: CW, 1128 and 618 lbs/ac; CS, 3490 and 1107 lbs/ac; wheat in WSF, 1304 and 942 lbs/ac; and sorghum in WSF, 4357 and 1687 lbs/ac.

Low soil NO_3^--N levels and deficiency symptoms prompted N applications in 1988 and 1989. Applied N increased sorghum yields but did not affect wheat yields. Unless indicated otherwise, data presented here are from unfertilized areas in plots.

Nitrogen Uptake

Average annual N uptake was similar under NT and SM in all cropping sequences, however, there were trends toward higher uptake under NT in the CW and WSF sequences and a trend toward higher uptake under SM in the CS sequence (Table 1). Nitrogen uptake was greater in the CS sequence than in the CW and WSF sequences and similar in the two latter sequences.

Table 1. Average annual nitrogen uptake*, 1986-1988.

Cropping sequence and tillage	N uptake
	lbs/ac
Continuous wheat	
No-till	58
Stubble Mulch	54
Continuous sorghum	
No-till	71
Stubble Mulch	78
Wheat-sorghum-fallow	
No-till	63
Conventional	59

* N in above-ground plant parts

Nitrate N Accumulation During Fallow

Nitrate nitrogen levels in the soil at beginnings of fallow periods and increases during fallow are presented in Table 2. Data are for the surface 4 ft of soil because most of the accumulation was in that soil depth.

Table 2. Nitrate nitrogen in soil (0-4 ft) at initiation of fallow and increases during fallow as affected by cropping systems and tillage methods.

	No-till		Stubble-Mulch	
	Initial	Increase	Initial	Increase
	--lbs/ac--		--lbs/ac--	
Continuous sorghum				
11/18/86 - 6/24/87	4	24	10	18
11/19/87 - 6/30/88	7	31	6	23
11/10/88 - 6/20/89	3	15	2	20
Continuous wheat				
6/2/87 - 10/8/87	3	29	13	50
6/10/88 - 10/19/88	13	15	33	7
6/20/89 - 10/12/89	32	8	35	38
Wheat-sorghum-fallow				
Wheat to sorghum				
6/2/87 - 6/10/88	4	39	7	49
6/10/88 - 6/20/89	8	28	10	51
Sorghum to wheat				
11/19/87 - 11/10/88	4	17	4	36
11/10/88 - 11/13/89	2	29	4	42

Continuous Sorghum

Under NT CS accumulation of NO_3^--N between harvest and planting ranged from 15 to 31 and averaged 23 lbs/ac. Under SM the range was from 18 to 23 and averaged 20 lbs/ac. Average accumulation between harvest and deep sampling in April was only 2 lbs/ac, (data not shown) thus most of the accumulation occurred between mid-April and mid-to-late June. Although the soil is usually dry at harvest, in both 1986 and 1987, the surface foot of soil contained adequate water for microbial activity. Thus, mineralization was apparently limited by low soil temperatures.

Continuous Wheat

Under CW, NO_3^--N accumulation during the fallow period averaged 17 lbs/ac with NT and 32 lbs/ac with SM. There was considerably more accumulation in 1987 than in 1988. The difference was probably due to differences in soil water contents during the fallow period. The surface 3 inches of soil was dry for much of the fallow period in 1988 (June-mid August) while it remained wet for most of the fallow period in 1987. The crop was destroyed by hail on 16 May 1989 and was not harvested. Soil water contents were favorable for mineralization throughout the fallow period but less NO_3^--N accumulated under NT in 1989 than in 1988. Under SM, however, there was more accumulation in 1989 than in 1988 and almost as much as in 1987. Apparently, some condition other than soil water limited NO_3^--N accumulation on NT in 1989.

Wheat-Sorghum-Fallow Sequence

During the fallow period between wheat and sorghum, accumulation on NT averaged 34 lbs/ac while that on SM averaged 50 lbs/ac. Between sorghum and wheat, accumulation on NT averaged 23 lbs/ac and that on SM was 36 lbs/ac. The averages indicate that more N became available in the fallow period after wheat than during the period following sorghum, however, on NT during the 1988-89 fallow periods, N accumu- lation was similar after both crops. The difference in N accumulation after wheat and after sorghum is not attributable to amounts of residue returned. Further research may be necessary to determine whether residues from these two crops have differential effects on NO_3^--N accumulation.

Tillage Effects

The NO_3^--N accumulation data show that, with CS, as much or more NO_3^--N accumulated on NT as on SM while, with CW and in the WSF sequence, more NO_3^--N accumulated under SM. Lamb, et al. (1985) studied N accumulation in NT, SM, and moldboard plowed soil. They found greater NO_3^--N accumulation in moldboard plowed than in NT during the first several years of tillage but differences narrowed with time. They indicated that the NT and SM soils moved towards a new steady state which allows N accumulation to occur at a rate similar to that in plowed soil. If our soil reacts like theirs, we can expect the differences between tillages to decrease with time.

Soil Nitrate Nitrogen Levels

Soil NO_3^--N levels to 1, 4, and 6 ft depths are shown in Figure 1. Although most of the N removal was from the 0-4 ft depth, data from the 4 to 6 ft depth are included because there was differential use from that depth. On the WSF sequence, the crops were grown on different plots in each of the 3 years, thus, the data can be used to measure NO_3^--N removal within years but differences between harvest-time NO_3^--N levels in one year and planting time levels the following year do not represent over-winter NO_3^--N accumulation.

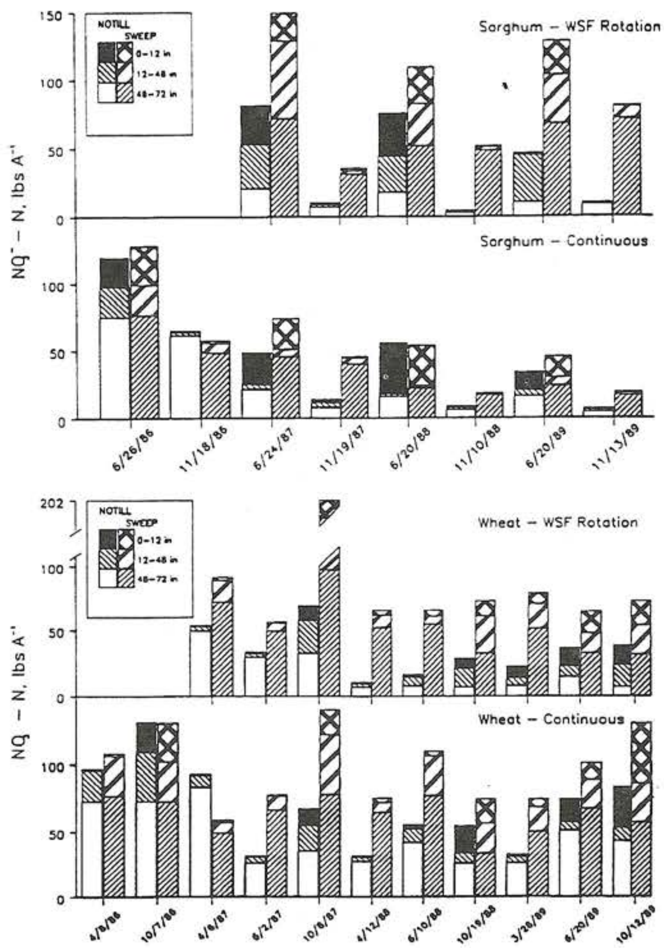

Figure 1. NO_3^--N in soil at planting and at harvest (sorghum) or at planting, in spring, and at harvest (wheat) under continuous cropping and WSF. Upper: sorghum, Lower: wheat.

Continuous Grain Sorghum

Under CS N removal exceeded mineralization resulting in a decline in soil NO_3^--N with time. Nitrate N was removed from the 4 to 6 ft depth under both NT and SM but more was removed under NT than under SM. In 1987 and 1988, the 4 to 6 ft soil depths on NT contained more water at planting than those on SM. There was water depletion from the 4 to 5 ft depth on NT, indicating root activity at that depth.

Continuous Wheat

Plots under CW maintained higher NO_3^--N levels than those under CS. Soil NO_3^--N levels on SM plots remained constant during the study period, indicating that nitrification was about equal to crop removal. There were some fluctuations in NO_3^--N levels in the 4 to 6 ft depth but there was no substantial decline as was evident with CS. On the NT plots, NO_3^--N was maintained at lower levels than on SM plots. As was true with CS, there was more removal from the 4 to 6 ft depth on NT and although not as well defined as with sorghum, this was also related to water content in that soil depth.

Wheat-Sorghum-Fallow Sequence

In the WSF sequence, tillage effects were similar to those under CW and CS. The SM plots contained more NO_3^--N than the NT plots and much of it was in the 4 to 6 ft depth. Comparison of sorghum planting and harvest time NO_3^--N levels on CS and WSF shows that the WSF plots con- tained much more NO_3^--N at planting than the CS plots but at harvest, NO_3^--N levels were similar to 6 ft on the NT plots and to 4 ft on the SM plots. Practically all of the NO_3^--N had been removed from the surface 6 ft under NT and from the surface 4 ft under SM. At wheat planting and harvest, however, differences in NO_3^--N levels between CW and WSF plots were not as marked as those in the sorghum comparison. On SM plots, levels under CW were usually similar to or slightly higher than those under WSF. Under NT, levels were higher under CW due to the higher levels in the 4 to 6 ft soil depth. The lower levels in the 4 to 6 ft depths under WSF resulted from removal by the sorghum crop.

Tillage Effects

Nitrate N levels were lower under NT than under SM in all three cropping sequences. This is logical for the CW and WSF plots where NO_3^--N accumulation during fallow was greater under SM. Under CS, NO_3^--N accumulation was similar under the two tillage methods and differences in residual N levels were attributed to differences in plant removal possibly due to deeper soil wetting. Deeper soil wetting probably contributed to the differences under continuous wheat too but, in the WSF sequence, the soil profile was wetted to 6 ft under both tillages but much more NO_3^--N was removed from the 4 to 6 ft depth under NT than under SM tillage. Soil water measurements at harvest indicated water depletion to 6 ft under both tillages. Crop yields were similar under the two tillages so crop removal of NO_3^--N would be expected to be similar. Part of the increased removal of

N from the 4 to 6 ft depth may logically be attributed to plant uptake since the 0 to 4 ft depth contained less NO_3^--N than on the SM plots, however it is doubtful plant uptake would account for all of the increased removal. It is possible that some NO_3^--N may have been leached from the 4 to 6 ft zone by additional water moving through that zone or some NO_3^--N may have been lost by denitrification. Broder, et al., (1984) found lower nitrifier populations in NT than in plowed soil and that soil denitrifier populations tended to increase with less tillage. The higher soil water content and lower temperatures under NT favored the denitrifiers. Rice and Smith (1982) also indicated that the generally higher soil moisture contents in NT soils, rather than tillage per se, are primarily responsible for higher denitrifying activity. They stated that "Enhanced denitrification may account, in part, for the lower soil NO_3^--N concentrations and higher N fertilizer requirements some- times reported for no-till soils."

Fertilizer Needs

In 1988, 50 lbs N/ac increased sorghum yield 54% (from 2320 to 3480 lbs/ac) on SM CS and 61% (from 2400 to 3850 lbs/ac) on NT CS. In 1989, N fertilizer increased yields 18% (from 3410 to 4035 lbs/ac) on SM CS and 96% (from 2410 to 4715 lbs/ac) on NT CS. No N was applied on sorghum in the WSF sequence in 1988, but in a separate study, grain sorghum did not respond to applied N in a NT WSF sequence. In 1989, applied N did not affect sorghum yields on SM WSF (avg. yld, 5515 lbs/ac) but increased yields 18% (from 5280 to 6205 lbs/ac) on NT WSF.

In Spring, 1988, N deficiency was observed on both NT and SM CW but applied N did not affect yields. Apparently, the soil supplied N for as high yields as the water supply allowed. In 1989, the wheat crop was destroyed by hail on 16 May and no yields were taken.

The soil NO_3^--N data show that cropping to CS has removed the residual NO_3^--N from both the NT and SM plots and that the residual NO_3^--N has been removed from the NT plots in the WSF sequence. Thus, without fertilizer N, the N supply for crops is limited to that mineralized in the soil during fallow and during the growth of the crop. On NT CS, grain yields were limited to 2400 lbs/ac in both 1988 and 1989. On SM CS, they were limited to 2320 lbs/ac in 1988 and to 3410 lbs/ac in 1989. Since these yields were produced in years when N, rather than water limited yields, it can be concluded that the soil will supply N for these yield levels. If soil water and precipitation are favorable for higher yields, N response will be realized. On NT WSF, 1988 and 1989 yield levels were 3790 and 5280 lbs/ac respectively. The N supply for sorghum is affected by the intervening wheat crop as well as by mineralization of N, thus is less predictable than that in CS. Considering that longtime sorghum yields in a WSF sequence are about 1700 lbs/ac, one would expect N response in the WSF sequence only under exceptional conditions.

Soil NO_3^--N levels appear to be adequate on all treatments for as high wheat yields as soil water conditions will allow.

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FERTILIZER REQUIREMENTS OF CANOLA

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Introduction

Rapeseed has been produced in western Canada since the early 1940's when oil from rapeseed was required as a lubricant for marine engines during the second world war. Two types of rapeseed, Brassica Napus (Argentine) and Brassica Campestris (polish) were dominant at the time. Early attempts at breeding concentrated on improving agronomic characteristics and increasing oil content. The result was the first variety. Golden, being licensed in Saskatoon in 1854.

Attempts at improving the quality of rapeseed oil and meal resulted in the development of what is now called canola. Canola describes rapeseed varieties with low erucic acid oil and low glucosinolate meal. The development of these varieties marked the introduction of a high quality oil for human consumption and a highly Palatable meal for livestock.

Argentine and Polish types of canola display somewhat different characteristics. Westar, the most common argentine variety, requires an average of 99 days to mature and performs well under good moisture and frost-free conditions. Tobin, the most common polish variety, requires an average of ten fewer days to mature but will generally yield 15 to 20% less with good growing conditions.

Fertilizer Requirements

Canola is regarded as being highly responsive to inputs of fertilizer but very sensitive to management Practices. The development of an environment that favors crop establishment leads to high yielding canola. Seedlings develop slowly and are vulnerable to competition and disease during the early growth states. A firm, well packed seedbed ensures adequate seed-soil contact and the development of a vigorous stand. Shallow seeding into a moist seedbed also favors the development of a viable canola crop. Excess tillage does not favor the development of these types of seedbeds and does not favor high yielding canola.

Studies in western Canada have shown that satisfactory and profitable yields can be produced on nonfallow land with adequate fertilizer and weed control. With favorable moisture conditions. a dryland yield of 35 bu ac^{-1} is realistic. Yields of over 50 bu ac^{-1} have been recorded under dryland conditions with high fertility and high management (Penney and Solberg;

1988). Under irrigated conditions, yields of 50 to 80 bu ac^{-1} are common. In southern Alberta irrigated yields of canola have gone as high as 70 bu ac^{-1}.

Nitrogen

Canola has a similar requirement for nitrogen (Table 1) as do cereals at equivalent yields. A canola crop of 35 bu ac^{-1} removes, on average, 105 lbs ac^{-1} of nitrogen. The majority of N taken up by canola is removed with the seed at harvest with the straw containing somewhat more N than cereals which contributes to the rapid mineralization of canola straw.

Table 1: Nutrient removal by comparative yields of canola, wheat and barley.

Crop	Yield		Nutrients Removed			
			N	P_2O_5	K_2O	S
	bu ac^{-1}		lb ac^{-1}			
Canola	**35**	**Seed**	**66**	**32**	**16**	**12**
		Straw	**39**	**14**	**67**	**9**
		Total	**105**	**46**	**83**	**21**
Wheat	50	Seed	75	30	20	5
		Straw	31	6	60	8
		Total	106	36	80	13
Barley	70	Seed	70	26	23	6
		Straw	35	9	78	8
		Total	105	35	101	14

Adapted from Alberta Agriculture ASANL yield increase tables.

When soils are initially low in available nitrogen, canola responds well to the addition of nitrogen fertilizer and moisture. This is reflected in the recommendations for nitrogen applications made by each of the Provincial soil testing facilities in western Canada.

In southern Manitoba. the response of Tower canola to applications of nitrogen fertilizer was examined (Marantz. 1989). Seed yield response generally increased as rate of nitrogen fertilizer increased on soils that were low in available nitrogen. Seed yield of canola increased up to 90 lbs ac^{-1} of applied nitrogen. Little or no increase in seed yield was reported beyond 125 lbs ac^{-1}. General recommendations for nitrogen fertilizer for dryland canola in central and northern Saskatchewan suggest applications of between 50 and 90 lbs ac^{-1} depending on soil test nitrogen and moisture at seeding.

Slower maturing Argentine varieties have a 15 to 20% yield advantage over Polish varieties and the yield differences between varieties may depend on the level of nitrogen fertilizer applied. Harapiak and Flore (1985) reported that the consequences of under fertilizing higher yielding Argentine varieties were more detrimental than under fertilizing the Polish types. Nitrogen response curves for polish varieties were reported to reach a maximum before Argentine varieties.

The maximum rate of seedrow placed N is much lower for canola than recommended for cereals. Canola is small seeded and therefore extremely sensitive to seed placed fertilizers especially when soil moisture is low. Excessive amounts of seed placed N (Table 2); and P_2O_5; greatly reduces germination and extends the time required for emergence. A survey of 392 Alberta canola growers (Alberta Agriculture, 1884) indicated that the highest yields were obtained when there was uniform crop emergence 5 to 7 days after seeding. Thus every effort should be made to ensure rapid, uniform emergence.

Late fall banding to a depth of 3 to 4 inches is the most effective way to apply N as it greatly reduces potential N losses and places the N in an area where fertilizer N will not become stranded by dry soil conditions. Care must be taken when spring banding to maintain a firm and moist seedbed that will allow seeding to a 1 inch depth.

Table 2: Effect of seed row placed N fertilizer on canola germination and emergence under 2 moisture regimes.

Rate of N	Percent Germination Available Soil Moisture		Days to Emerge Available Soil Moisture	
lb ac^{-1}	30%	50%	30%	50%
0	100	100	6	6
5	83	90	15	12
10	22	40	23	19
20	0	0	--	--

Canola has a higher sulphur requirement than cereals (Table 1) because of its higher protein content. Janzen (1986) determined that the optimum ratio of available N to available S for canola production is 7:1. Nyborg et al. (1974) showed that by applying high rates of N fertilizers to soils low in S, the N to S ratios may be excessively raised to intensify S deficiency in crops (Table 3). The application of high rates of N without S to canola grown on S deficient soils generally produces little yield increase and may reduce yields below check levels.

Sulphur deficiency symptoms are very characteristic and if moisture conditions are good corrective application of surface broadcast sulfate (Table 4) can be effective up to 42 days after seeding (Ukrainetz. 1982).

Table 3: Response of canola to N and S fertilizer.

Fertilizer Applied	Yield: North West Saskatchewan	Yield: Northern Alberta
	bu ac^{-1}	
Check	13	7
NPK	12	2
PKS	18	10
$NPKS_1$	32	32
$NPKS_2$	34	35

N, P_2O_5, K_2O, S_1 and S_2 were applied at 100, 70, 46, 25 and 50 lb ac^{-1} respectively.

Table 4: Effect of time of broadcasting granular sulfate sulfur fertilizer on canola (average of 2 years).

Cultivar	Time of SO_4S Application	Yield Increase	% Oil
		bu ac^{-1}	
Regent	at seeding	7.1	44.1
B. napus	7 days after seeding	8.4	44.3
	14 days after seeding	6.7	43.6
	28 days after seeding	7.1	43.6
	42 days after seeding	5.6	43.4
Candle	at seeding	5.8	41.7
B. campestris	7 days after seeding	5.7	42.6
	14 days after seeding	6.1	43.2
	28 days after seeding	5.4	42.7
	42 days after seeding	3.7	43.0

Phosphorous

Three factors are important for determining the phosphorous (P) fertilizer requirements of canola:

1). the amount of P removed in the seed and straw
2). response to applied P
3). the method of application or placement

The phosphorous requirement of canola is higher than for comparable yields of wheat and barley (Table 1). Most of the difference is due to the higher p content of canola straw compared to cereals. If crop residues are retained, P removal is similar for equivalent yields.

The higher total P requirement of canola is not reflected as response to higher rates of applied P. Maximum P response generally occurs at a lower rate for canola than for barley (Fig. 1). Response comparisons (Fig. 1) are based on 70 field experiments with canola and 111 with barley (Thomas, 1884). The lack of response of canola to higher rates of p has been attributed to improper placement (high rates of p in the seed row causing seedling injury). However, in 12 paired experiments; with canola and barley; using split applications to avoid seedling injury, barley responded to higher rates of P than canola (Fig. 2). Barley responded up to the highest rate of P investigated (90 lb P_2O_5 ac^{-1}) while canola showed only a moderate response to rates above 15 lb ac^{-1}, Ukrainetz et al. (1975) observed that when P_2O_5 fertilizers are banded with or near the seed, rapeseed and mustard are able to utilize fertilizer P more efficiently than cereals. The# concluded that maximum canola responses are generally obtained at somewhat lower rates of applied P than for wheat and barley. However when the value of the crops is considered, maximum net returns from applied p on canola generally occurs at a similar rate as cereal crops. The net returns from applied P for canola and barley (Fig. 4) were calculated from the response data (Fig. 3) using $6.00 (canola) and $2.00 (barley) per bushel and $0.26 lb^{-1} P_2O_5. Net returns from applied P are higher for canola than for barley but maximum net returns occur at 45 lb ac^{-1} for both crops.

The rate of phosphate fertilizer required to achieve maximum net returns per acre from canola grown on p deficient soils is often higher than can be safely placed in the seed row. The maximum rate that can be safely placed in the seed row when a double disc or narrow hoe opener is used, is 20 to 25 lb P_2O_5 ac^{-1}. Since equipment for side banding fertilizer is generally not used by farmers in the Plains Region of Canada, rates of application above 20 lb ac^{-1} are usually banded prior to seeding.

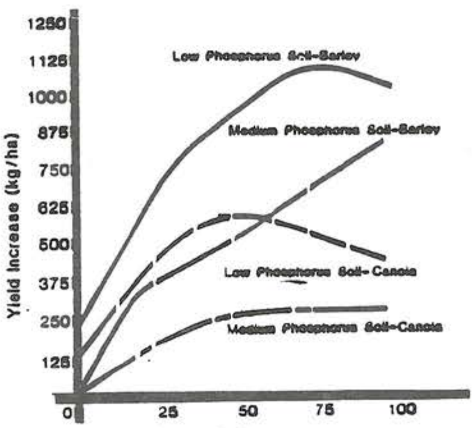

Fig. 1: Yield Response to P_2O_5.

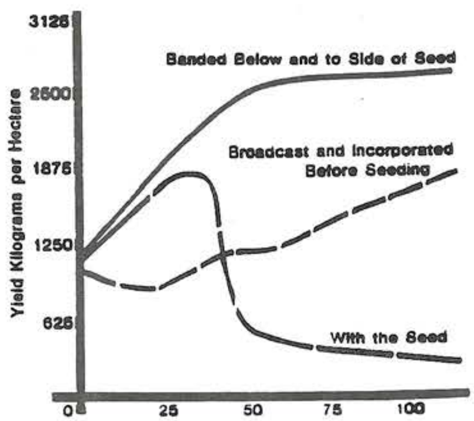

Fig. 4: P_2O_5 Placement Effects on Canola.

(adapted from the Canola Growers Manual. Canola Council of Canada. 1984)

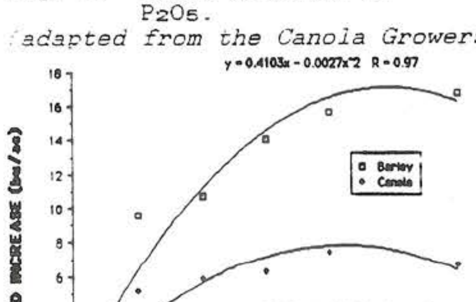

Fig. 2: Response of Barley and Canola to Applied P_2O_5 (paired experiments at 12 sites)

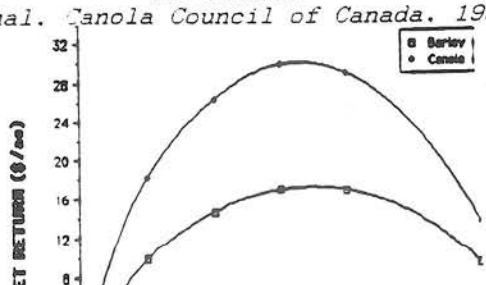

Fig. 3: Net Return of Applied P_2O_5 for Barley and Canola.

A comparison of broadcast, banded and drill-in N and P are shown in Table 5 (Harapiak and Flore, 1985). Banding N and P is more effective than broadcast. Banded N and P plus starter drill-in P gave better results than banding N alone and drilling all of the P with the seed.

Table 5: Response of canola to different placements of N and P_2O_5 fertilizers.

Placement	Yield
	bu ac^{-1}
Check	13.4
N + P broadcast	22.0
N broadcast + drill-in P	24.4
N banded + drill-in P	34.8
N + P banded	34.0
N + 2/3 P banded + drill-in 1/3 P	37.4

N - 90 lb ac^{-1}; P_2O_5 - 34 lb ac^{-1}

Potassium

The Potassium requirements of canola are similar to wheat but lower than barley at comparable yields (Table 1). The amount of potassium removed in the harvested seed is lower than for cereals. Research conducted by Walker (1979) in Central Alberta showed that barley was more responsive to K fertilization than canola (Table 6). At all soil test levels the Percentage yield increase from applied K was greater for barley than for canola.

Table 6: A comparison of yield response of canola and barley to K fertilizer at various levels of soil test K (1 N NH_4OAc extractable)

Soil Test K_2O	Canola			Barley		
	No. Of Tests	% of Tests Responsive	% Yield Increase	No. of Tests	% of Tests Responsive	% Yield Increase
lb/ac						
< 50	--	--	--	4	100	1000
51-100	6	50	39	17	75	242
101-150	11	19	28	22	66	47
151-200	13	6	25	25	24	30
201-250	9	0	--	12	18	34
> 250	9	0	--	35	3	11

The rate of K fertilization that can be safely placed in the seed row of canola is highly variable depending on soil type and moisture (Ukrainetz et al., 1975). Walker (1979) compared seed placed and banded applications of K to canola and barley (Table 7). At the lowest rate (15 lb K_2O ac^{-1}) K with the seed was superior to banded applications for both crops. At the 30 lb

K_2O ac^{-1} rate; placement with the seed was superior to banding for barley but not for canola. Although it was not reported in the study, delayed and reduced emergence could have limited response to the 30 lb K_2O ac^{-1} placed with the seed.

Table 7: Effect of KCl fertilizer placement on yield of barley and canola.

		Canola		Barley	
Rate of Application	Method of Application	No. of Tests	Yield	No. of Tests	Yield
lb K_2O ac^{-1}			lb ac^{-1}		lb ac^{-1}
15	Banded	6	246	19	492
	With Seed	6	285	19	788
30	Banded	4	247	19	678
	With Seed	4	247	19	889

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Soil Fertility Research In Alberta

Fertilizer requirements of irrigated and dryland crops in southern Alta. J. Carefoot and H. Janzen, Ag. Canada; R. McKenzie, Alta Ag.

ICM systems for wheat, barley and canola under irrigation and dryland. D. Penney, R. McKenzie, E. Solberg and J. Helm; Alta Ag.

Pre and post application of N Fertilizer. R. McKenzie, E. Solberg, D. Penney; Alta Ag.; J. Ashworth, Norwest Labs, Edmonton.

Soil P cycling and laboratory P soil test development. R. McKenzie.

Crop responses to lime, phosphogypsum and ripping of acid, luvisolic and solonetzic soils. J. Lickacz, Alta Ag.

Nutrient requirements, liming and deep plowing of organic soils. R. Sherstabetoff, Alta Ag.

Comparison of acid and dry P fertilizer. E. Solberg, Alta Ag.; D. Beever, Sheritt Gordon, Edmonton.

Nitrogen management for maximizing bromegrass production. S.S. Mahli, Ag. Canada; E. Solberg, Alta Ag.; M. Nyborg, U of A, Edmonton.

Effect of zero-till, N source and placement of efficiency of N applied to barley. S. Mahli, Ag. Canada; M. Nyborg, U of A; E. Solberg

Spring and fall spoke injection of N in minimum tillage systems. M. Nyborg, U of A; E. Solberg, Alta Ag.

N dynamics of mature straw tillage systems. M. Nyborg, U of A; E. Solberg and D. Heaney; Alta Ag.

Fertilizer and other management inputs for MEY.

Identification and correction of cooper deficient soils in Alberta. D. Penney, E. Solberg, D. Heaney and L. Kryzanowski; Alta Ag.

LONG-TERM SOIL-CROP MANAGEMENT RESEARCH FOR THE 21ST CENTURY

by

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ABSTRACT

Long-term field plot research in the USA was basically discarded in the 1950's except for a few classical experiments. As we face the 21st century we have questions regarding the impact of long-term management of agricultural systems on the environment, economics and society. Questions regarding the impact of: (1) continuous use of fertilizers and pesticides on ground and surface water quality; (2) cropping systems on soil organic matter, erosion, and water conservation; (3) tillage systems on soil physical characteristics, particularly structure and pore size distribution; (4) sustainability of production systems; cannot be answered with short term experiments. Existing data bases are often outdated in terms of newer practices. Models improve our ability to answer these questions, but models need verification with adequate data sets. The value of new long-term research will be illustrated with examples from a management experiment established in 1985 in Eastern Colorado.

INTRODUCTION

Historically agronomists have recognized the need to conduct long-term field research, especially with questions relating to soil properties that change slowly with time and/or where climatic influence is expected. Prior to 1920 almost all field research was conducted with a long-term perspective. Examples of long-term experiments that continue to the present day are the Broadbalk plots at Rothamstead, the Morrow plots in Illinois and Sanborn Field in Missouri; all of these are over 100 years old.

There was an abrupt change in the amount of long-term work conducted by agronomists in about 1950 (Fig.1). There were several reasons for the termination of so many long-term experiments which include:

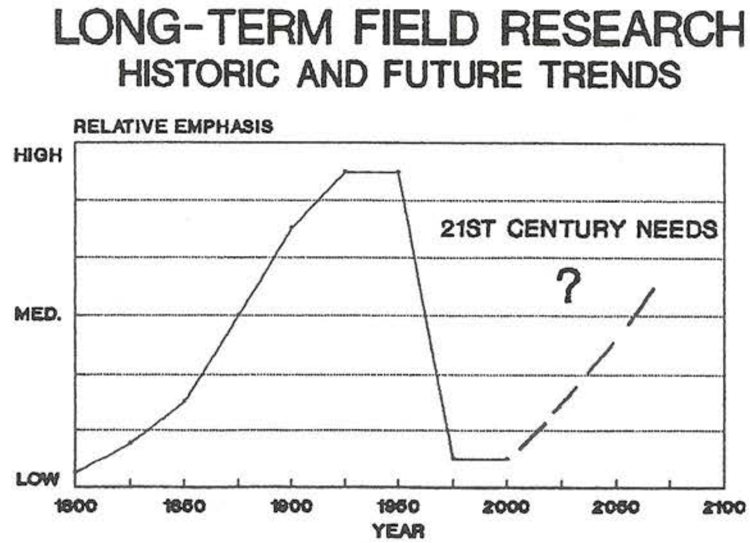
(1) Recognition of the need for replication and measurement of interactions, and the impossibility of modifying the original experiments to accommodate these changes.

(2) Failure to address modern problems.

It is apparent from Fig.1 that very few newly designed long-term experiments were initiated to address modern day questions with modern designs. Why was this the case? Possible reasons are:

(1) Agronomists placed more emphasis on specific treatments with less focus on systems.
(2) New statistical techniques that encouraged fewer variables and measurement of interactions were in vogue.
(3) Increased administrative emphasis on shorter publication time and greater numbers of publications.
(4) Increased administrative emphasis on projects with completion dates of 5 or less years.

Figure 1.



Agronomic science at the end of the 20th century is realizing the necessity of evaluating entire management units or systems and not just the individual parts. New long-term field research is needed because: (1) There is a demand for "systems" information that assembles information into useful packages not presently existent; (2) Interaction of management practices with climate and soil environments is not understood ; and (3) Producers need to know "how and why" drastic changes in inputs such as tillage, fertilizers, pesticides, growth regulators will impact soil-crop systems.

Integration of our detailed knowledge into system level units also is important for improved technology transfer. Synthesis of existing knowledge can be done with modeling, but these models must be verified under field conditions. A new long-term management study has been initiated in Colorado, which can serve as a model approach for systems experiments.

EXAMPLE OF NEW LONG-TERM RESEARCH

Research Problem:

Problems that face Central Great Plains agriculture require the long-term approach advocated above. Traditional wheat-fallow systems have many negative aspects, such as high erosion potential, low water use efficiency, and enhanced soil organic matter loss due to fallowing. However, we lack knowledge regarding the fit of modern techniques such as no-till and extended rotations to specific soil and climate situations. The new long-term project addresses these problems.

Example Hypotheses:

(1) Wheat-fallow, traditionally practiced in areas with 200-500 mm/year precipitation, can now be limited to areas with precipitation of 200-500 mm/year.

Because: No till management improves water conservation allowing intensive cropping systems.

(2) Intensively managed no-till cropping systems with fewer fallow periods will increase soil organic matter contents more rapidly than perennial grasses.

Because: Crop residue (C) additions are greater with cultivated crops than with perennial grasses.

(3) Deep percolation of water and leaching of nitrates will decrease with fewer fallow periods in the rotation.

Because: Increased plant water use by more intensive cropping decreases potential percolation and leaching.

Methods:

Sites were chosen along a transect in eastern Colorado to represent three climate regimes (Fig.2). All have equal annual average precipitation (16 in.), but potential evapotranspiration (PET) increases north to south. At each site management treatments (crop rotations) have been placed over a soil catena (Fig.3) that represents soils typical of that climatic area. Crop rotations being studied have decreasing amounts of summer fallow time (Fig.3). Complete climatic measurements are made at each site so precipitation and potential evapotranspiration balances can be calculated. The following measurements are made annually by rotation by soil by site: Grain and straw yield, Crop residue (prelant and preharvest), N and P removal, Soil nitrate at planting, and Soil water at planting and harvest. The following are measured periodically: Total soil C & N, Water infiltration rate, Bulk density, and Aggregate size distribution.

Figure 2.

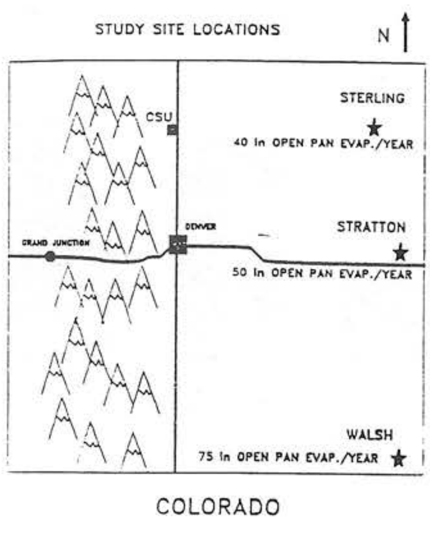
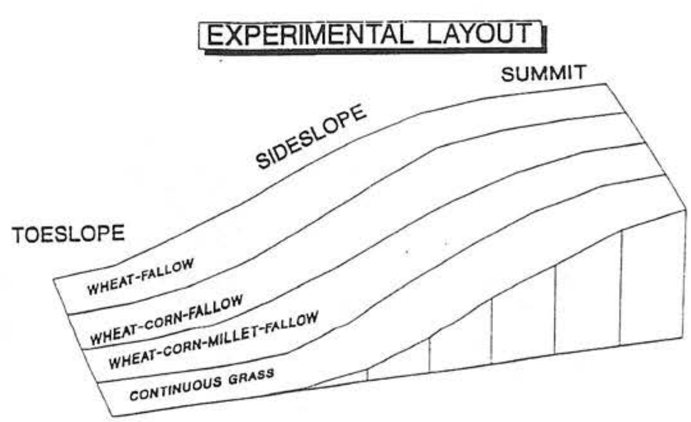


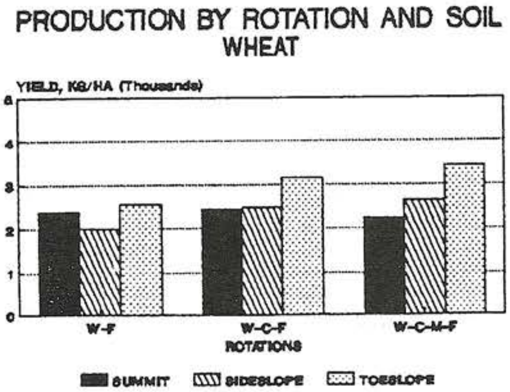
Figure 3.

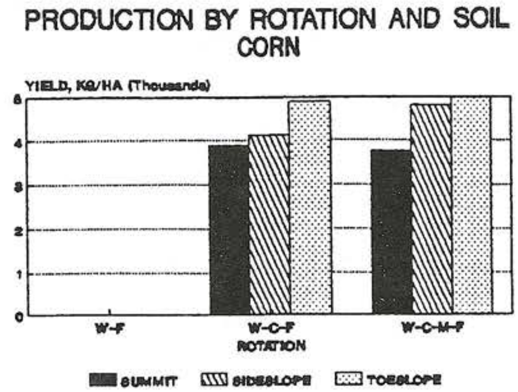


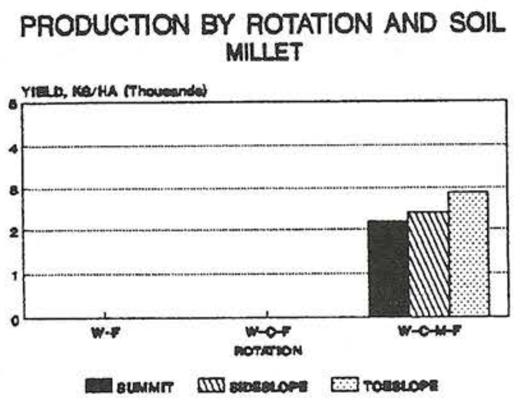
Preliminary Results:

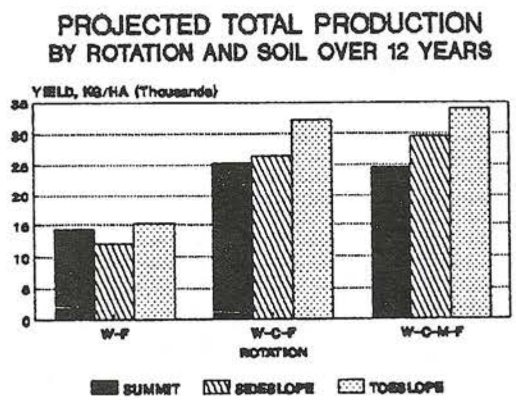
Data for the 1988-89 season for the Sterling site are presented in Figures 3-6 as an example of the type of information to be gained from the project.

Figures 3-6.









Total grain yields for a 12 year period were projected using 1988-89 yield results from the Sterling site to illustrate the interesting questions that arise on a long-term basis. Rotations with two crops in three years, such as wheat-corn-fallow have a projected production of 2X that of wheat-fallow (Fig.7). This means a doubling of yield on the same amount of water (Fig.8) or a doubling of water use efficiency.

Figure 7.

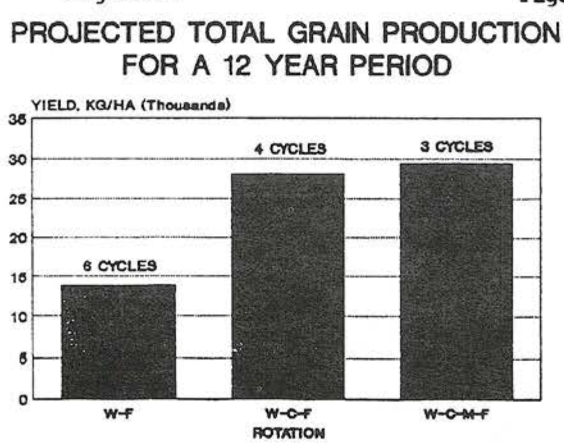
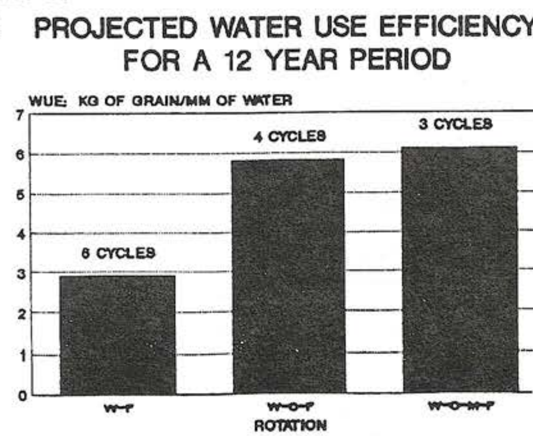


Figure 8.



After only four years, the wheat-corn-millet-fallow rotation has increased soil C on the sideslope and toeslope soils compared to wheat-fallow (Fig. 9). Increased crop residue additions in the wheat-corn-millet-fallow rotation compared to wheat-fallow are responsible for the increased soil C (Fig 10). Soil C has responded to the management changes much more rapidly than was expected.

Figure 9.

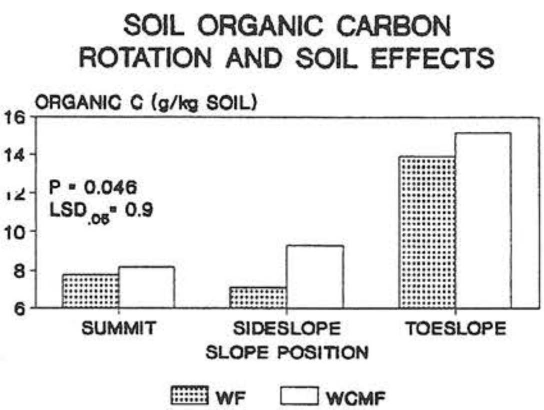
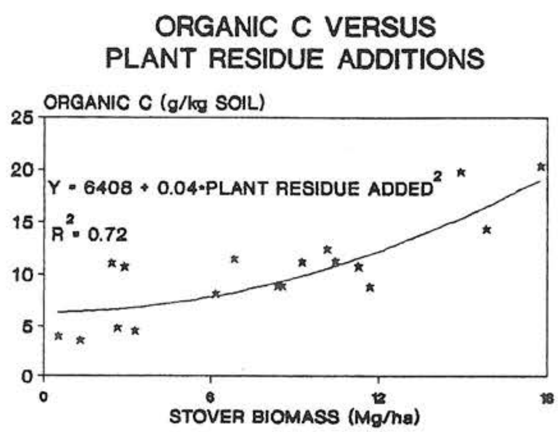


Figure 10.



CONCLUSIONS

Long-term research for the 21st century is important to the sustainability of agriculture in the world and to the long-term well being of societies in general. Never before have agriculturists been able to create such wide and rapid swings in positive and negative changes with their management techniques. We need modern long-term field research to answer questions regarding the safety of some management practices and questions regarding sustainablity of others.

Example Questions:

What are the impacts of

(1) Continuous use of fertilizers and pesticides on ground and surface water quality?
(2) Cropping systems on soil organic matter, erosion and water conservation?
(3) Tillage systems on soil physical characteristics, particularly structure and pore size?
(4) Modern farming practices on economic sustainability?

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Peterson, G.A., D.G. Westfall, C.W. Wood, L. Sherrod and E. McGee. 1989. Crop and soil management in dryland agroecosystems. Tech. Bull. TB89-3. Agr. Exp. Stn. Colorado State University. Fort Collins, CO.

NITROGEN DYNAMICS IN CONVENTIONAL TILL vs NO-TILL

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ABSTRACT

High residue systems may affect microbial activity which in turn partially controls nutrient dynamics, particularly the availability of nitrogen. The objective of this study is to evaluate the change in surface inorganic and organic nitrogen levels in a wheat - sorghum - sorghum - fallow rotation under no-till and clean till conditions. The dryland field study was conducted during 1988 and 1989 at the Agricultural Science Center, Clovis NM. Surface soil samples were taken throughout 1988 and 1989 and analyzed for NH_4-N, NO_3-N, and organic nitrogen and carbon. Inorganic nitrogen (inorganic N = NH_4-N + NO_3-N) availability was higher in the clean till than no-till in both the fertilized and unfertilized treatments. There were no significant differences in organic nitrogen or carbon between no-till and clean till. Results indicate that farmers should expect to apply slightly more fertilizer N to no-till than to clean till when initially converting to no-till.

OBJECTIVES

Several factors including soil and water conservation, greater fuel costs, and government policy have lead to increased use of high residue farming systems. The benefits of a high residue farming system are influenced by how successful farmers are at understanding and using this system. Those farmers who have successfully switched to a high residue system have had to change their fertility management strategy.

High residue systems, which eliminate or reduce tillage, will have a profound effect on the nutrient dynamics of soil. In the Pacific Northwest, Rasmussen and Rhodes (1988) showed that organic nitrogen and carbon in the top 3.0 in of soil were higher in a stubble mulch than in conventional clean tillage. Doran (1980) reported the numbers of soil micro organisms and their metabolic activity were increased by the presence of crop residue. However, an increase in surface crop residue will also influence soil temperature and moisture content, this may or may not be beneficial to metabolic activity. In a dry period increased soil moisture may result in higher microbial activity in high residue systems than in conventional systems. During wet periods the cooler and wetter soils in high residue systems may limit metabolic activity. Thus high residue systems affect microbial activity which in turn partially controls nutrient dynamics, particularly the availability of nitrogen.

The objective of this study is to evaluate the change in surface inorganic and organic nitrogen levels in a wheat - sorghum - sorghum - fallow rotation under no-till and high surface residue conventional clean till conditions.

MATERIALS AND METHODS

The dryland field study was conducted during 1988 and 1989 at the NMSU Agricultural Science Center, Clovis NM on a Pullman sandy clay loam. The Clovis area has a semiarid climate with an annual precipitation of 16 inches and a frost free growing season of approximately 180 days.

The experiment was arranged in a split-plot design with three replications. Main plots consisted of the two tillage variables, no-till and clean till, and sub-plots (53 x 180 feet) consisted of the fertilized or unfertilized variables.

Cultural practices and the specific dates they were performed are listed in Table 1. Clean till and no-till plots were planted with a medium maturity grain sorghum hybrid in both years. Planting rates were 6 and 6.4 lbs/acre in 1988 and 1989 respectively. In May 16, 1988 sorghum was planted into wheat residue. Due to heavy rainfall and soil crust formation that impeded plant emergence the sorghum had to be replanted on June 13, 1988. The fertilizer used was 50 lbs/acre nitrogen (urea-ammonium-nitrate, 32-0-0) and 25 lbs/acre of phosphate using monoammonium phosphate (10-34-0). Fertilizer was placed 5 cm below the surface and 5 cm to the side of the seed at planting.

Table 1. Tillage type and date used in the conventional clean till treatments.

Date	Tillage	Date	Tillage
July 7, 1987	Harvest wheat*	June 17, 1988	Rotary hoe*
Sept. 9, 1987	Apply Roundup 1 qt/acre*	Nov. 11, 1988	Harvest sorg.*
Nov. 6, 1987	Moldboard plow and disk	March 7, 1989	Disk
March 18, 1988	Disk	May 15, 1989	Chisel & disk
May 8, 1988	Disk and harrow	May 16, 1989	Plant sorghum*
May 16, 1988	Plant sorghum*	June 16, 1989	Cultivate*
June 11, 1988	Apply gramoxone (3 pt/a) & milogard (1.33 lbs/a)*	Oct. 17, 1989	Harvest sorg.*
June 13, 1988	Replant (no fertilizer)*		

*Cultural practices occurring in the no-till and clean till treatments.

Sorghum was planted into sorghum residue on May 16, 1989 using the same hybrid, fertilizer, and planting methods. On June 16, 1989 the entire study was cultivated to control weeds and volunteer sorghum.

Surface soil samples (0-6 in) were taken within the row on 11 dates in 1988 and 12 dates in 1989 at intervals ranging from 2 weeks to a month. Soil

NH_4-N and NO_3-N were extracted with a 2N KCl solution immediately after sampling and determined colormetrically (Keeney and Nelson, 1982) with a technicon autoanalyzer. Inorganic nitrogen was calculated by adding NH_4-N and NO_3-N. Total (Kjeldahl) nitrogen was determined by the procedure of Bremner and Mulvaney (1982) with a technicon autoanalyzer. Organic N was obtained by subtracting NH_4-N from total-N. Soil organic carbon was analyzed by dry combustion (Nelson and Sommers, 1982).

Analysis of variance was used to analyze soil parameters at each date. When F-values were significant an LSD value was calculated to make mean separations.

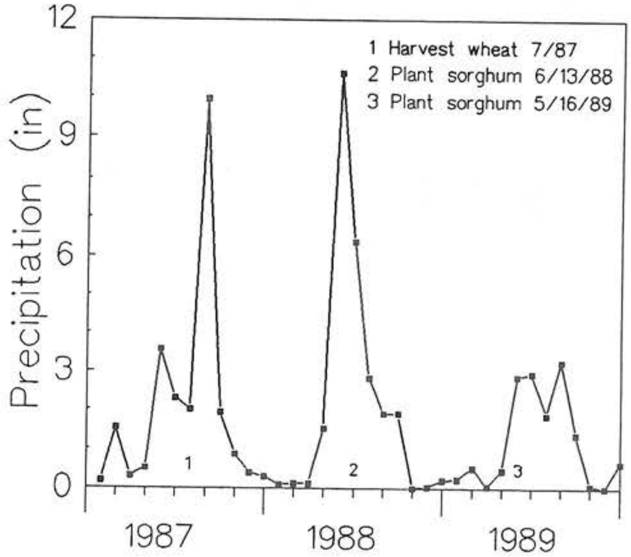
RESULTS AND DISCUSSION

Figure 1 summarizes precipitation occurring from January 1987 through December 1989. The 10 month fallow period occurring from July 1987 to May 1988 received 15.5 inches of rainfall and the first growing season received 24.1 inches. The yields during 1988 (Table 2) are representative of this above normal precipitation. The 6 month fallow period from October 1988 through May 1989 received 1.4 inches of moisture, while the growing season received 12.9 inches. The yields in 1989 are much lower due to the lack of soil moisture. Surface soil moisture (Figure 2) was generally higher in no-till than clean till in both years, although not statistically significant. Expressing soil water on a volume basis might have produced significant differences.

Table 2. Grain sorghum yield, 1988 and 1989

Treatment	1988	1989
	--lbs/acre--	
Clean till fertilized	4658	643
Clean till no fertilizer	4105	1225
No-till fertilized	4730	1795
No-till no fertilizer	3722	1535
LSD(0.1)[1]	1006	ns
LSD(0.1)[2]	1574	ns

[1]Compares fertilizer within tillage
[2]Compares tillage irrespective of fertilizer



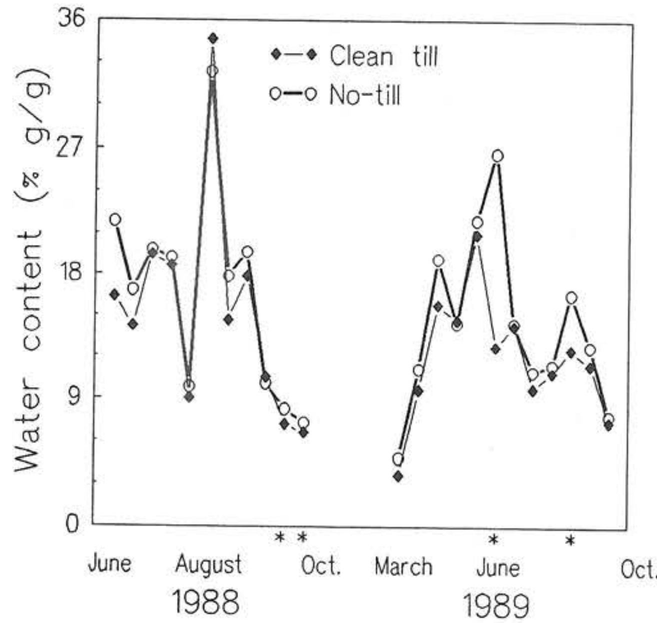


Figure 1. Clovis NM precipitation January 1987 through December 1989.

Figure 2. Surface soil moisture content, asterisks indicate treatment differences.

Inorganic nitrogen (Inorganic N = NH_4-N + NO_3-N) availability was higher in the clean till than no-till in both the fertilized and unfertilized treatments particularly during the early part of the growing season. The differences in inorganic N between the two tillage systems were the result of differences in NO_3-N. NH_4-N concentrations were similar in both no-till and clean till. The lower inorganic N levels in the no-till as compared to the clean till were probably the result of more denitrification in no-till, although higher mineralization rates in clean till could have occurred.

There were no significant differences in organic nitrogen or carbon between no-till and clean till. However, there was a trend toward higher organic C and N levels in the between row area of no-till as compared to clean till. With time differences will probably become significant as a result of organic matter accumulation in no-till.

Yields were significantly different at the p=0.051 level in 1988 but not significantly different in 1989 (Table 2). Plant stands in 1989 were extremely variable due to lack of early moisture, thus the yield data is unreliable. As expected, nitrogen fertilization tended to increase yields in 1988, regardless of tillage treatment. Clean till tended to have higher yields than no-till, regardless of fertilization treatment.

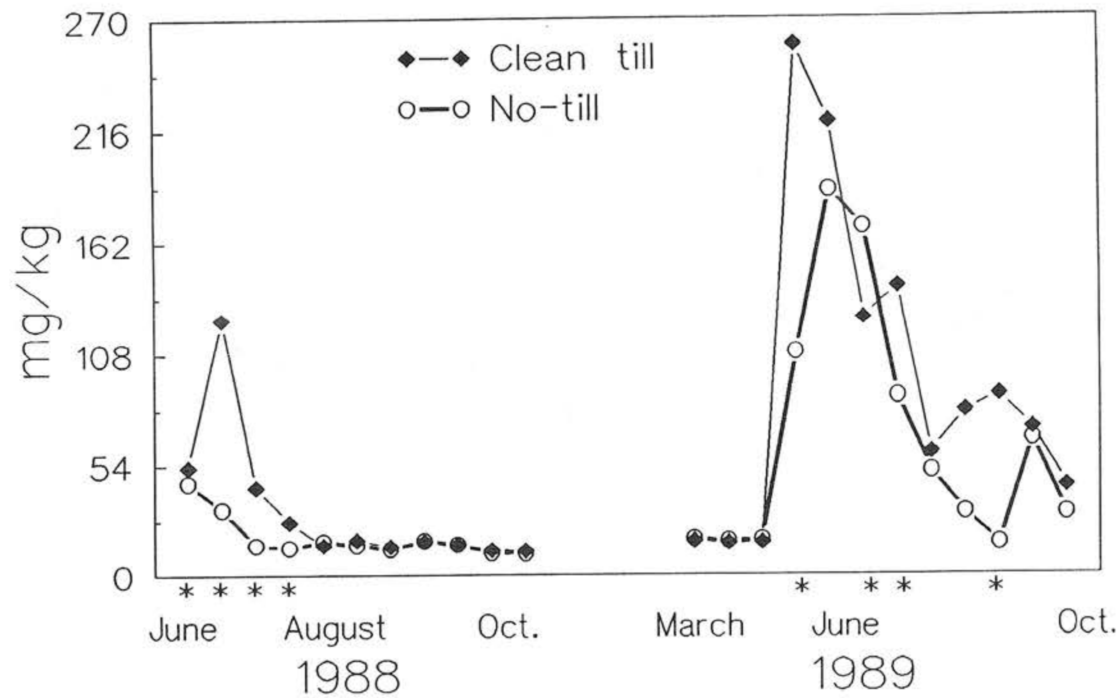


Figure 3. Surface (0-6") soil inorganic nitrogen in the fertilized treatments, asterisks indicate significant (P=0.05) treatment diferences.

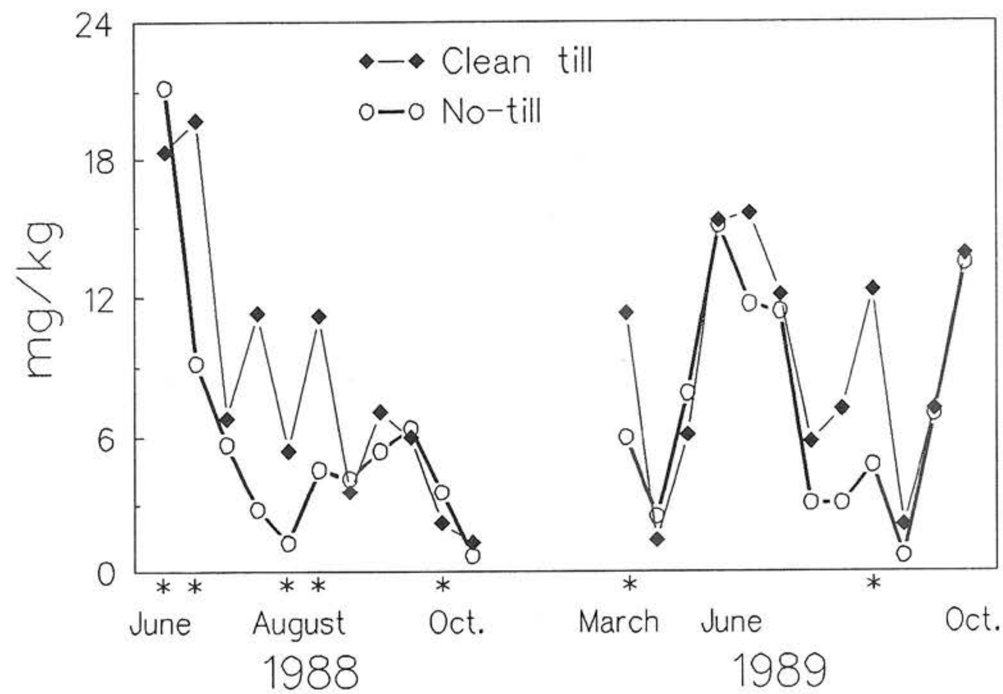


Figure 4. Surface (0-6") soil inorganic nitrogen in the unfertilized treatments, asterisks indicate significant (p=0.05) treatment diferences.

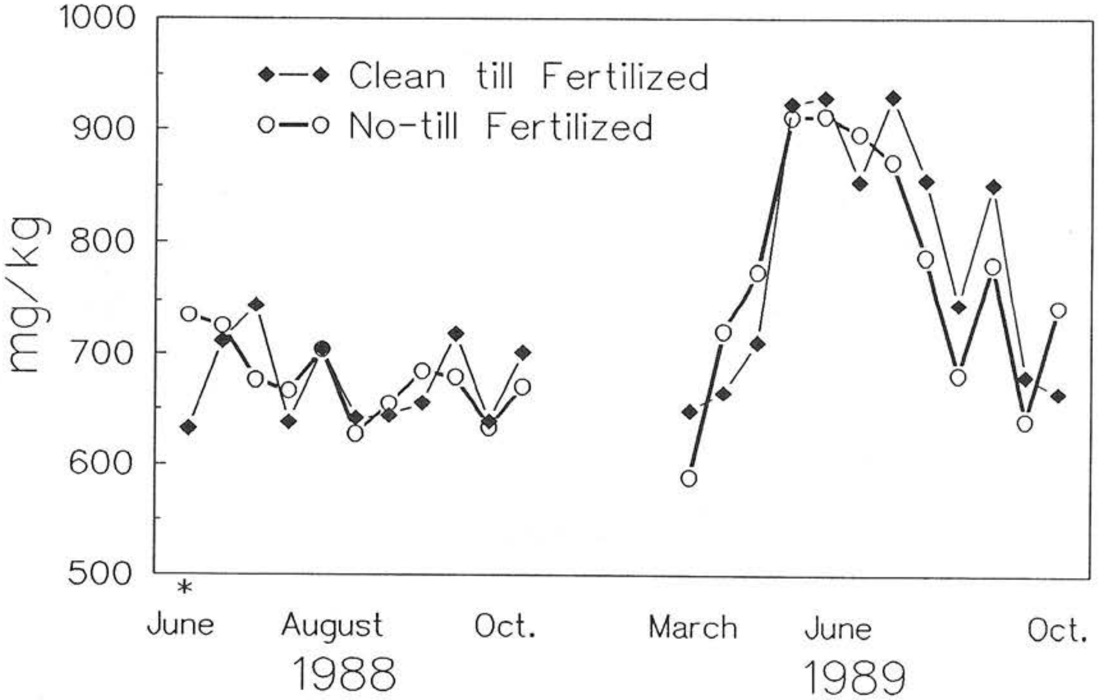


Figure 5. Surface (0-6") soil organic nitrogen in the fertilized treatments, asterisks indicate significant (P=0.05) treatment diferences.

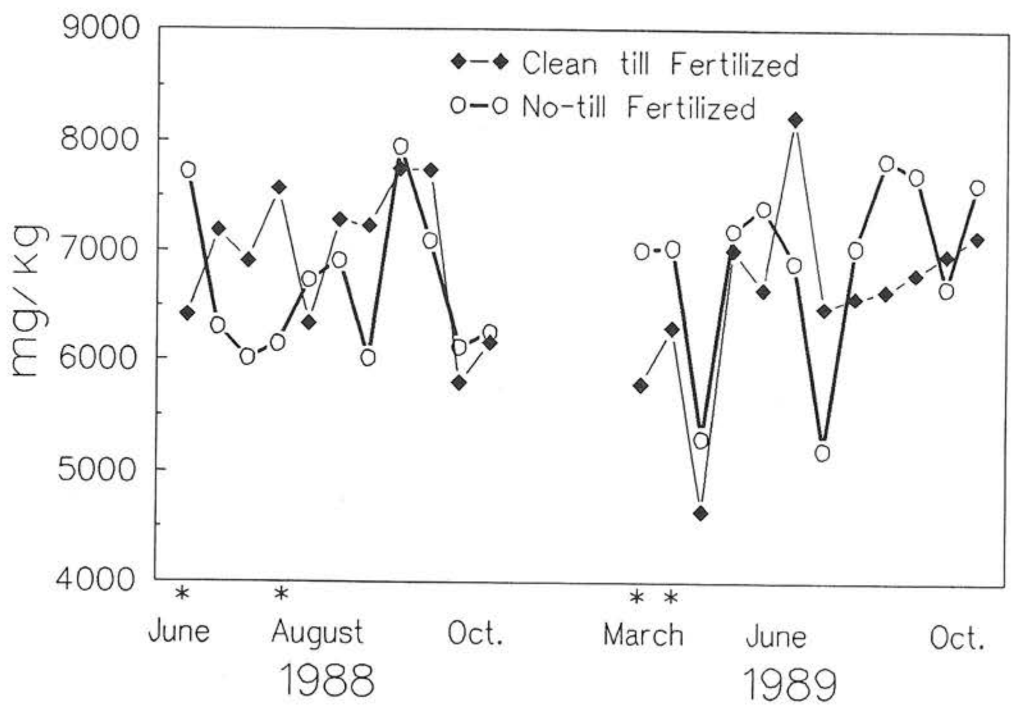


Figure 6. Surface (0-6") soil organic carbon in the unfertilized treatments, asterisks indicate significant (p=0.05) treatment diferences.

This data shows that no-till results in more moisture accumulation but less available nitrogen accumulation than clean till in the first two seasons after conversion to no-till. Farmers should expect to apply slightly more fertilizer N to no-till than to clean till when initially converting to no-till. With time, organic carbon and nitrogen levels may significantly increase in the no-till system resulting in more dramatic effects on soil moisture retention. However, differences in soil inorganic nitrogen levels between no-till and clean till should decrease as the reservoir of organic nitrogen increases in no-till.

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Rasmussen P.E. and C.R. Rohde. 1988. Long-term tillage and nitrogen fertilization effects on organic nitrogen and carbon in a semiarid soil. Soil Sci. Soc. Am. J. 52:1114-1117.

OTHER FERTILITY RELATED RESEARCH PROJECTS AT NEW MEXICO STATE UNIVERSITY

A. Cooperative project between B.D. McCaslin and Bill Melton, NMSU Agronomy and Horticulture Dept. Box 30003, Las Cruces NM 88003. Breeding alfalfa for increased phosphorus concentration in the forage. The project objective is to determine if breeding procedures can produce alfalfa populations with increased phosphorus concentrations in the forage at any given levels of soil phosphorus.

B. Projects being conducted by Greg Weiler, NMSU Agricultural Science Center, P.O. Box 1018, Farmington NM 87401.

1. Foliar application of nutrients to pinto beans. This study will evaluate foliar applications of N,P,K, and chelate versus sulfate forms of foliar applied Zn,Fe,Cu, and Mn.
2. Potassium and magnesium applications to Russet Burbank potatoes, four winter wheat varieties, one barley and one alfalfa. This study will determine if there is a yield response to these nutrients since they are found in low levels towards the end of the growing season.

3. Fertigation of grain corn using N-Hib Calcium, Liquid Thiosul and Liquid Nitrogen at various rates.

4. Spring versus fall applications of nitrogen to "Luna" pubescent wheatgrass and "Hycress" crested wheatgrass.

C. William C. Lindemann, NMSU Agronomy and Horticulture Dept. Box 30003, Las Cruces NM 88003. Study the effectiveness of sulfur oxidation in New Mexican soils and determine if siderophores are involved in the ability of sludge to supply iron to plants.

D. Cooperative project between Neal Christensen and William Lindemann. Study the nitrogen dynamics in no-till farming systems. Neal Christensen is also investigating the yield response of peanuts to micronutrients in high calcareous soils.

NLEAP MODEL FOR NITROGEN LEACHING

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ABSTRACT

The Nitrate Leaching and Economic Analysis Package (NLEAP) model was developed to provide farmers, extension personnel, and action agencies with a rapid, efficient method for estimating potential nitrate-N leaching from agricultural lands and to estimate potential impacts on the quality of underlying ground water. NLEAP was applied to data from dryland (fertilized) and irrigated (fertilized and non-fertilized) corn production plots located in eastern Colorado. Model results compared favorably with field observations of residual soil nitrate-N measured at the end of the 1988 growing season (R^2 value = 0.90). Indices of potential nitrate-N leaching into underlying aquifers were computed for each treatment. The annual leaching risk potential index (ALRP) indicated a low risk of aquifer contamination with the non-fertilized, irrigated corn plots, a moderate risk with the fertilized, irrigated plots, and a very low risk with the dryland corn plots.

OBJECTIVES

Leaching of nitrate-N from agricultural lands has received increased attention in the midwestern corn belt, in the eastern and southern coastal plains, and in irrigated areas of the Great Plains and western U.S. where higher levels of nitrate-N are being observed in associated shallow ground water aquifers. Rapid and efficient methods are needed to assess the potential for nitrate-N leaching under a range of soil, climate, and management conditions so that potential "hot-spots" can be identified and improved management techniques developed to minimize nitrate-N leaching to ground water.

The objective of this paper is to outline the structure and capabilities of the Nitrate Leaching and Economics Analysis Package (NLEAP) model, and show how this new tool can be used to assess the potential for nitrate-N leaching from agriculture and to provide information to help mitigate nitrate-N leaching in the Great Plains and elsewhere.

MATERIALS AND METHODS

The NLEAP model

NLEAP was developed in 1987-1990 as part of a national team effort to consolidate existing knowledge concerning nitrogen management, transformations, and movement in agricultural systems. A book published by the Soil Science Society of America entitled Managing Nitrogen for Ground Water Quality and Farm Profitability, Follett, et al. (1990) summarizes the results of this major effort. The last two chapters, Pierce et al. (1990) and Shaffer et al. (1990), describe in some detail the methods and procedures being used in the NLEAP model.

NLEAP is a user oriented model designed for use by farmers, extension personnel, and action agencies. The model computes nitrate-N leaching and aquifer risk indices, nitrogen use efficiencies, and water and nitrogen budgets. This information is presented in both tables and graphs, and as part of a written summary which also includes suggestions for better N management. Model inputs include on-farm management practices, soil and climate data, and economic information. The model contains regional data bases for the soil, climate, and economic inputs, or the user can supply his own information for some or all of these inputs. NLEAP uses this information in a set of mechanistic equations to project water and nitrogen budgets, potential for nitrate-N leaching below the root zone, potential impacts on ground water quality, and economic impacts of current or alternative N management practices.

The model is controlled from a MAIN MENU (Fig. 1), and uses a three-phase approach to the problem. The screening analysis technique, menu item (2), uses a simplified annual water and N budget approach described in Pierce, et al. (1990). This method produces rough estimates for the leaching index (LI), nitrate-N available for leaching (NAL), nitrate-N leached (NL), and annual leaching risk potential index (ALRP). More detailed analyses are available by selecting menu items (3) or (4) for monthly and event-by-event time steps, respectively. The monthly analysis uses management and climate inputs on a monthly basis along with monthly time steps to compute the water and nitrogen budgets. The event-by-event analysis uses daily precipitation and irrigation together with specific dates for planting, harvest, fertilizer applications, and tillage. Both the monthly and event based methods calculate annual values for NAL, NL, ALRP, and movement risk index (MRI), while the event based method also computes values for the aquifer risk index (ARI), and an economic summary. The user should start with the screening analysis, but move to the more detailed approaches if significant nitrate-N leaching is projected, or if a domestic water supply is involved.

Selecting MAIN MENU item (1) allows the user to enter the State, County, soil survey area (SSA), computer session identification, farm or owner identification, and farm field name. This information is used to identify the study site location and to provide correct access to regional climate and soils data bases. Item (5) gives access to a set of instructions for model operation and use. Instructions specific to each screen can also be obtained by pressing the F5 function hot-key from the screen of interest. Item (6) allows the user to save or load a specific user data file. This file contains an image of the latest computer memory slots as they appeared when the file was last saved or overwritten. Item (7) prints selected tables of monthly output data and the latest summary report of comments and suggestions. Item (8) exits the NLEAP computer session and returns to the operating system (DOS).

NLEAP has been tested using both lysimeter leachate data from Coshocton, Ohio, and tile drain discharge data from Boone County, Iowa. Details of these model validation analyses can be found in Shaffer, et al. (1990). The R^2 values for predicted versus observed mass of nitrate-N leached ranged from 0.82 for the lysimeter data (27 data pairs) to 0.94 for the tile drain data (4 data pairs). Model validation is continuing in various parts of the country.

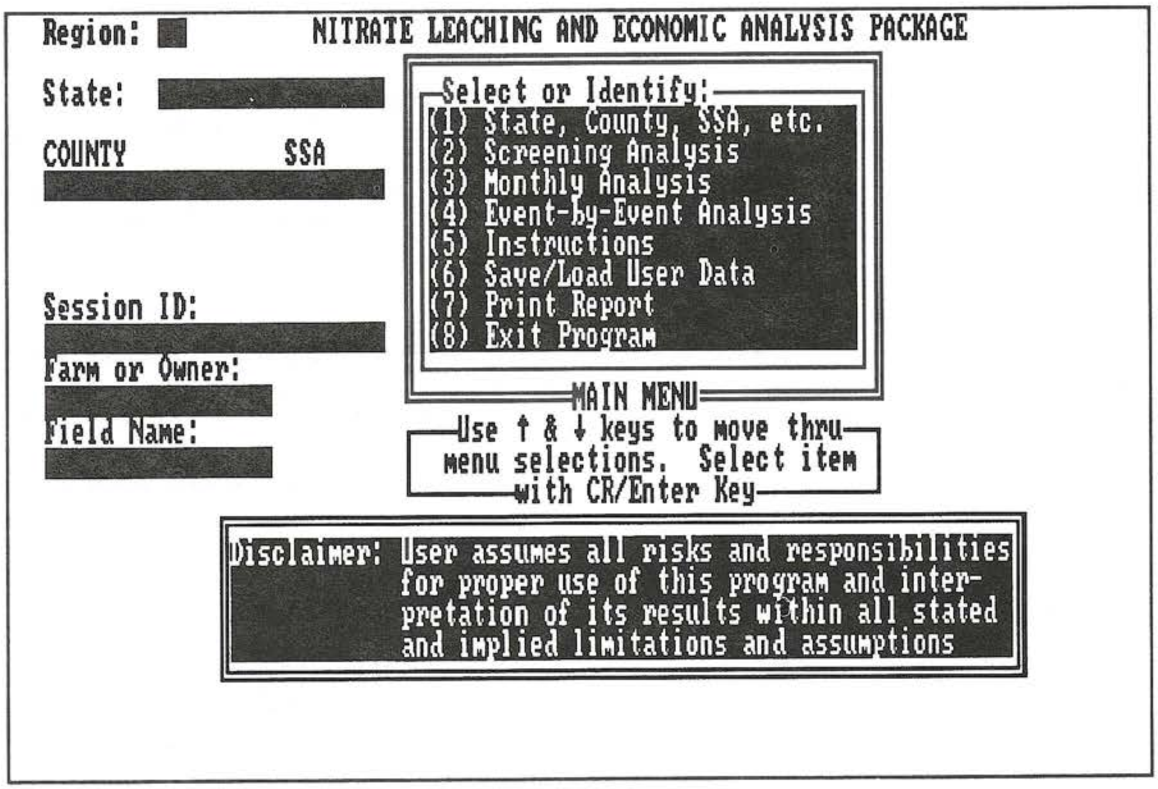

Fig. 1. MAIN MENU computer terminal image for operation of the NLEAP model.

The model is designed to run on IBM AT or 100 percent compatible machines with DOS 2.1 or higher, a hard disk drive, and 640 kbytes of memory. Software copies are available from the Soil Science of America in conjunction with the associated book, Follett, et al. (1990).

Application to field sites in the Great Plains

NLEAP can provide the user with fast and efficient methods to assess the potential for nitrate-N leaching at specific locations. As an example, simulated and observed residual soil nitrate-N and simulated potential leaching of water and nitrate-N were obtained from a two year irrigated and dryland corn study located on the Colorado State University (CSU) South farm in Fort Collins, CO. A Nunn clay loam soil (fine, montmorillonitic, mesic Aridic Argiustoll) was sampled in 1 foot increments from the surface down to 5 feet in October 1988 after corn harvest and analyzed for soil nitrate-N concentrations. The two-year study was initiated in 1987 and consisted of irrigated and dryland continuous corn monocultures. Irrigated corn treatments received either 200 or 0 lb urea-N/ac/year, and all dryland corn plots received 200 lb urea-N/ac/year. Treatments were replicated three times. In 1988, observed corn yields averaged from zero grain production on the dryland plots to 85 bu/ac for all irrigated plots regardless of fertilization treatment. Grain yields for all treatments were negatively affected in 1988 due to corn root worm injury and hail damage.

NLEAP was used to run event based computer simulations of this site for the time period October 1987 through September 1988. Model inputs included weather records obtained from on-site measurements and from the Fort Collins climate station, soils data obtained from the NLEAP soils data base and from on-site measurements, and management data collected on-site.

RESULTS AND DISCUSSION

Figures 2a and 2b show a comparison of simulated and observed residual soil nitrate-N contents at the end of the study period in October, 1988. The R^2 value of 0.90 indicates that 90 percent of the variability in the observed residual soil nitrate-N was accounted for by the model. The highest residual nitrate-N values occurred in the dryland treatment where excessive buildup of nitrates occurred due to heavy applications of fertilizer (200 lb N/ac/year) and crop failure in 1988. Note that significant residual nitrate-N was present in the lower part of the soil profile in non-fertilized plots even after two years of zero applied nitrogen.

Plots of predicted annual leachate volume, nitrate-N available for leaching (NAL), and nitrate-N moving from the crop root zone (NL) are shown in Figure 3. Note that for dryland corn, no water and hence no nitrate-N was predicted to move below the root zone (5 feet). The irrigated plots had nitrate-N leached (NL) values of 21 and 49 lb/ac from the non-fertilized and fertilized treatments, respectively. Annual values for nitrate-N available for leaching (NAL) were 116, 284, and 503 lbs N/ac for the non-fertilized irrigated, fertilized irrigated, and fertilized dryland treatments, respectively. As with the residual nitrate-N, the dryland case showed the highest value for the three treatments. Note that even with the unfertilized treatment, a significant amount of nitrate-N was available for leaching during 1988. To reduce potential leaching of nitrate-N from this soil and management, both residual nitrate-N in the soil profile and mineralization of soil organic matter must be considered.

Table 1 shows the MRI and ALRP index values for each treatment. Based only on water movement, MRI values estimate the fraction of soluble constituents such as nitrate-N likely to leach below the root zone. In this case, nineteen percent of the nitrate-N would be expected to leach from the irrigated treatments and 0 percent from the dryland case.

Table 1. Annual Leaching Indices.

	Irrigated Non-fertilized	Irrigated Fertilized	Dryland Fertilized
MRI	0.19	0.19	0.00
ALRP	Low	Moderate	Very Low

ALRP estimates the potential impact of nitrate-N leaching on underlying aquifers. Nitrate-N leached, position of the aquifer, vulnerability of the aquifer, and travel time to the aquifer are all considered in computing the index. Details can be found in Pierce, et al. (1990). For the Fort Collins case, we computed values for ALRP based on short to intermediate term considerations.

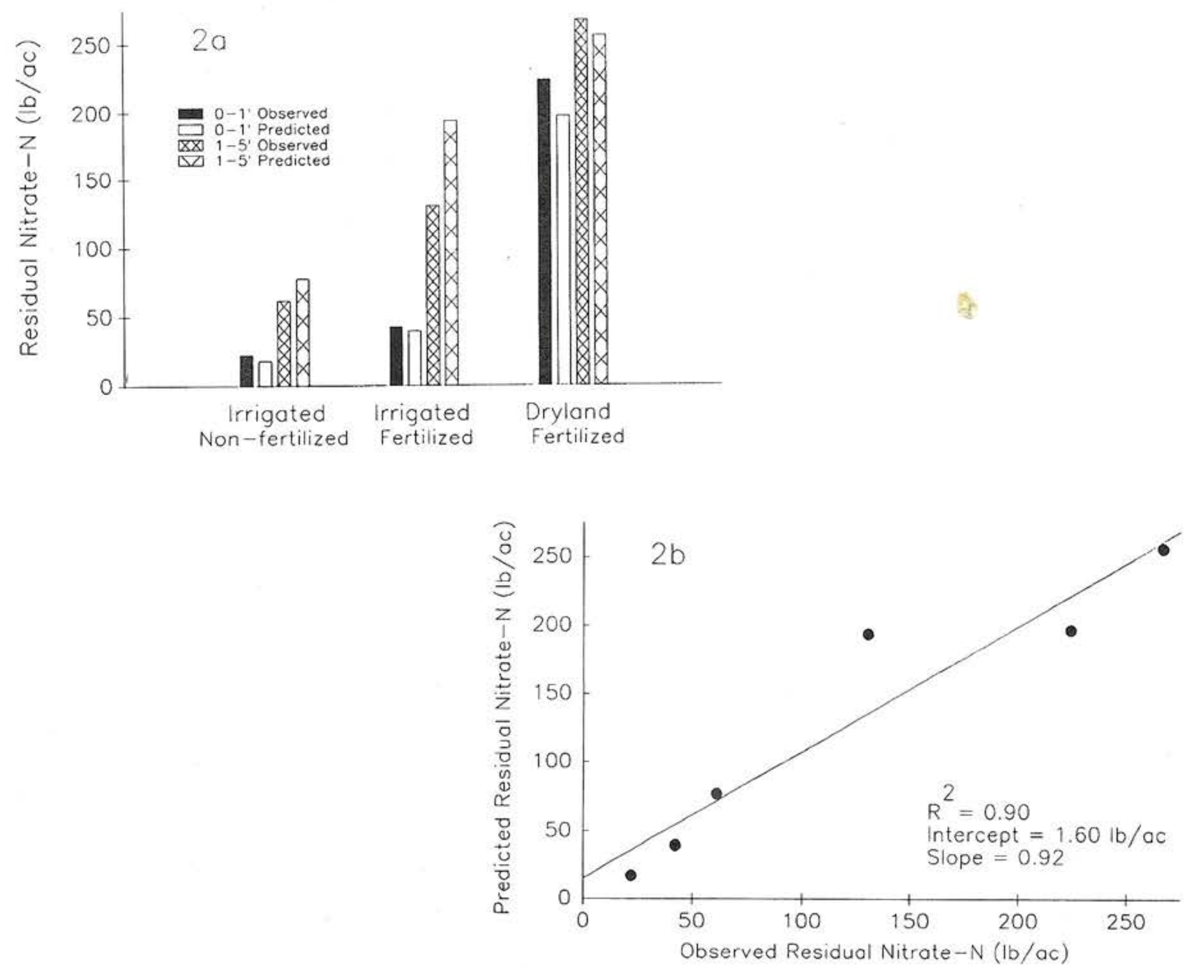

Fig. 2. a) Simulated and observed residual soil nitrate-N concentrations from three corn treatments at Ft. Collins, CO. 1988. b) Regression of predicted-vs-observed residual soil nitrate-N at Ft. Collins, CO and associated R^2 value.

Accordingly, position of the aquifer was assigned a rating of moderate, vulnerability of the aquifer was considered to be moderate (EPA Class IIb), and travel time to the aquifer was moderate except for the dryland treatment where travel time to the aquifer was considered long. Nitrate-N leached from the root zone (NL) was rated low for the irrigated non-fertilized and dryland treatments and moderate for the irrigated fertilized case. The ALRP ratings of Low, Moderate, and Very Low shown in Table 1 reflect the combined effects of the rating criteria.

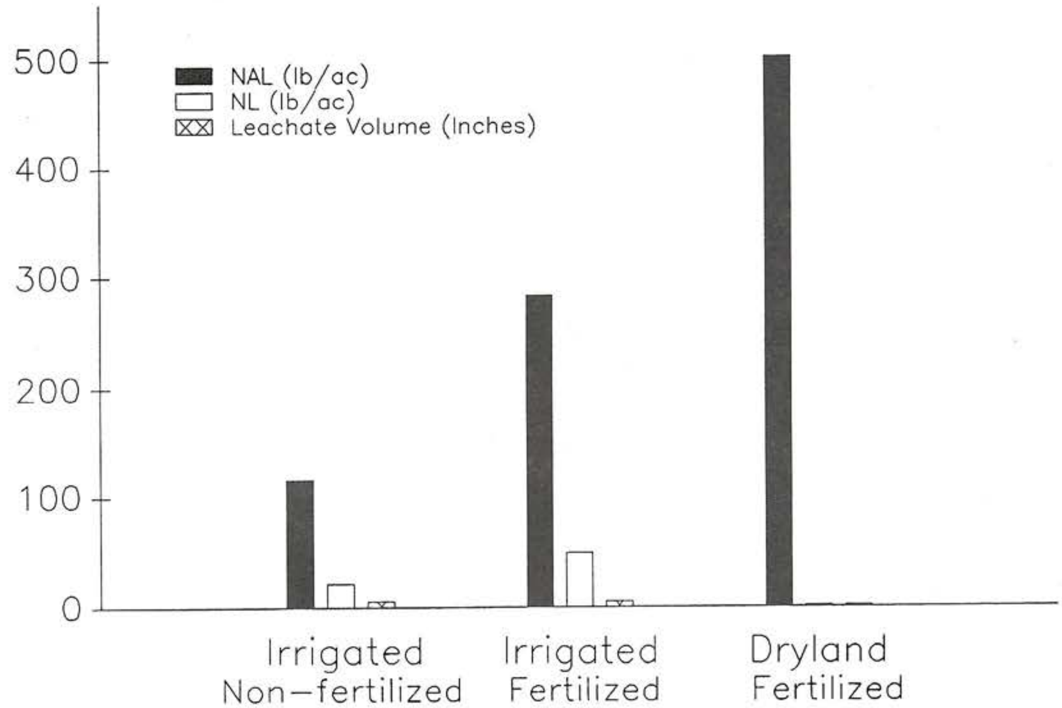

Fig. 3. Predicted annual leachate volume, nitrate-N available for leaching and nitrate-N moving from the root zone computed by NLEAP for Ft. Collins, CO., 1988.

ADDITIONAL RESEARCH ACTIVITIES

In addition to the NLEAP modeling activities discussed here, other soil fertility research efforts are underway by USDA-ARS scientists in the Great Plains Systems Research unit in Ft. Collins, CO. R.A. Bowman, Soil Scientist, is currently conducting field and laboratory studies to evaluate distributions and changes in soil inorganic and organic P in calcareous soils of the Great Plains, Bowman (1988), Bowman and Savory (1989). Bowman also is conducting studies to evaluate changes in soil organic C, N, and P due to crop management practices and duration of cultivation on Great Plains soils. Comparisons between native sod (no cultivation) and fields that have been cultivated for 3, 20 and over 50 years are being made. In a related study, organic matter and nutrient changes in the conversion of marginal cropland into permanent grassland are being examined. Comparisons between continued wheat-fallow cropping systems, native grassland and reestablished grassland on marginal cropland are being made.

C.V. Cole, Soil Scientist, is evaluating and modeling crop management systems in the Great Plains and their effect on organic C, N and P storage and loss, Parton et al. (1989), Burke et al. (1989). In particular, he is interested in the impact of no-till dryland production systems on N and P cycling and loss.

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NUTRIENT CONTENT AND WATER-USE EFFICIENCY OF SPRING WHEAT AS AFFECTED BY FERTILIZER RATE AND PLACEMENT

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ABSTRACT

Precipitation frequency, distribution, and amounts are quite variable in the Great Plains and can lead to inefficient fertilizer use. A study was conducted in 1987 and 1988 7 mi. NW of Sidney, MT on a Williams loam to determine the influence of banded and broadcast N and P fertilizer on spring wheat N and P concentration and content at two plant development stages (Feekes plant development stage 5-6 (tillering) and 11.4 (harvest)), on water-use efficiency and on spring wheat production parameters. Neither water use nor grain and dry matter water-use efficiencies at harvest (Feeks 11.4) were significantly influenced by fertilizer rate or N and P placement method because of dry climatic conditions during the grain fill period (July). Dry matter production and N and P contents were significantly greater for banded vs. broadcast fertilizer placement during tillering (Feekes stage 5-6) each year. Increased dry matter production and N and P content for banded fertilizer did not significantly enhance grain or straw production, but the N content for grain plus straw was greater for fertilized when compared to nonfertilized wheat.

OBJECTIVES

Potential environmental contamination from pesticides and fertilizer has increased interest in efficient use of fertilizer and water. In the Great Plains, production is limited by low and variable precipitation in terms of frequency, distribution, and amounts. During dry years, broadcast fertilizer can result in poor fertilizer recovery for barley and wheat as growing season precipitation amounts decrease (Kucey, 1986; Hartman and Nuborg, 1989).

Objectives of this study were to determine the influences of banded and broadcast N and P fertilizer, with supplemental K and S applied, on spring wheat N and P concentration and content at predetermined plant development stages and on water-use efficiency and spring wheat production parameters.

MATERIALS AND METHODS

A study was conducted in 1987 and 1988 7 mi. NW of Sidney, MT on a Williams loam (fine-loamy, mixed Typic Argiboroll). Soil NO_3 -N was 56 and 74 lb/ac, respectively, for 1987 and 1988 in the 0- to 2-ft. depth while

$NaHCO_3$ - extractable P was 17 ppm for both years in the 0- to 6-in. depth. Spring wheat, cultivar 'Len', was seeded at 65 lb/ac on 13 April 1987 and 20 April 1988 on land previously summer fallowed with stubble-mulch methods. In 1987, wheat was seeded with a deep furrow drill in paired-rows 3 in. apart and 9 in. between row pairs. In 1988, wheat was seeded with a double disk drill in paired-rows 6 in. apart and 14 in. between row pairs. Banded fertilizer was placed between the 3 in. paired-rows 1 in. below the seed in 1987 and between the 6 in. paired-rows 1 in. below the seed in 1988. Broadcast fertilizer was surface applied at seeding. Fertilizer rate and placement treatments were arranged in a randomized complete block design with four and six replications in 1987 and 1988, respectively. Treatments included check (no fertilizer applied); 30 lb N/ac, 9 lb P/ac, 15 lb K/ac, and 10 lb S/ac (30 N); 45 lb N/ac, 9 lb P/ac, 15 lb K/ac, and 10 lb S/ac (45 N). All nutrients were either banded or broadcast. The N, P, K, and S sources were urea, treble superphosphate, potassium chloride, and elemental sulfur; respectively. The 30 lb N/ac rate is what most dryland small grain producers apply and the 45 lb N/ac rate is 1.5 times the recommended rate. Soil water content to 6 ft. was determined using a neutron moisture meter on two and three replications in 1987 and 1988, respectively. Plant samples were taken at Feekes plant development stages 5-6 (end of tillering) and 11.4 (harvest) by sampling two 4.0- and 3.3-ft^2 areas in 1987 and 1988, respectively, from each plot to determine dry matter production (Large, 1954). Grain yield was measured using a small plot combine to harvest 400 and 166 ft^2 in 1987 and 1988, respectively.

Plant and grain N concentrations were determined by macro Kjeldahl procedures (Bradstreet, 1965); P concentrations were determined using autoanalyzer procedures on samples digested with a nitric-perchloric acid mixture (Technicon Industrial Systems, 1973).

RESULTS AND DISCUSSION

Spring wheat growing season precipitation (May to August) was 91% (6.0 inches) and 27% (1.8 inches) for 1987 and 1988, respectively, of the 39 year-average of 6.6 inches. Therefore, data represent a normal and a dry year. Water use, grain water-use efficiency (WUE), and dry matter WUE at plant development stage 11.4 were not influenced by fertilizer rate or placement in either year (Table 1). July 1987 was very dry and reduced yield potential. Also, soil NO_3 -N (56 lb/ac in the 0- to 2-ft. depth) may have been adequate for the amount of water used and grain yield. In 1988, limited precipitation, above normal temperatures, and minimal soil water drastically reduced grain yield and other plant parameters.

In 1987, plant N content at plant development stage 5-6 was significantly increased by fertilizer and fertilizer placement (Fig. 1). Banded fertilizer increased N content 21 lbs/ac more than the check, whereas broadcast fertilizer did not significantly increase N content above the check. The higher plant N content on banded fertilizer treatment plots can be attributed to greater plant dry matter production rather than increased plant N concentration when compared to the check. Better fertilizer N utilization during early plant development stages can reduce the potential for environmental contamination due to N. Plant P content was also significantly increased by banded fertilizer. The P content was three times greater for banded fertilizer as compared to the check and two times greater than P content for the same broadcast fertilizer rate.

In 1988, limited water reduced N and P content to 25 and 15%, respectively, of the comparable treatment in 1987 (Fig. 1). Under dry conditions, banded fertilizer significantly increased N content when compared to broadcast fertilizer application for plant development stage 5-6. Limited precipitation probably reduced movement of broadcast N into the soil where it could be utilized by spring wheat.

Table 1. Water use and water-use efficiency (WUE) as influenced by fertilizer rate and placement.

	Treatment †						
	Check	Banded		Broadcast		$LSD_{0.05}$	CV
		(30N)	(45N)	(30N)	(45N)		(%)
	1987						
Water use ‡ (in.)	12.4	12.9	12.8	12.8	12.8	2.3	6.4
Grain WUE (lb/ac/in.)	230	239	218	237	222	57	8.9
Dry matter WUE (lb/ac/in.)	456	478	473	461	443	107	8.3
	1988						
Water use ‡ (in.)	5.9	5.9	5.7	5.7	6.0	0.8	7.5
Grain WUE (lb/ac/in.)	90	90	95	88	93	29	16.8
Dry matter WUE (lb/ac/in.)	246	233	258	240	239	66	14.3

† 30 N = 30 - 9 - 15 - 10 lbs/ac of N, P, K, and S respectively; 45 N = 45 - 9 - 15 - 10 lbs/ac of N, P, K, and S respectively.
‡ Water use is precipitation plus soil water at seeding minus soil water at harvest (soil water to 6 ft.).

Plant P content was also significantly greater with banded fertilizer when compared to broadcast fertilizer even though P content in 1988 was reduced when compared to 1987. Greater N content for banded plots in 1988 was due to a combination of greater dry matter production and greater N concentration, while the greater P content for banded plots was due to significantly greater P concentration. Plant development stage 5-6 is at a critical time period (early June) when precipitation could exceed evapotranspiration which would lead to N fertilizer leaching. Banded fertilizer appears to reduce the risk of N fertilizer leaching by increasing dry matter production as well as concentration.

Fertilizer rate and placement did not significantly increase grain or straw production in either year although dry matter production (grain plus straw) for 1987 was significantly different (Fig.2). Possible reasons for no differences in grain or straw production may have been adequate amounts of soil N for the amount of water available and low yield potential. Dry conditions in 1988 reduced grain production to 20% and straw production to 30% of the quantities in 1987.

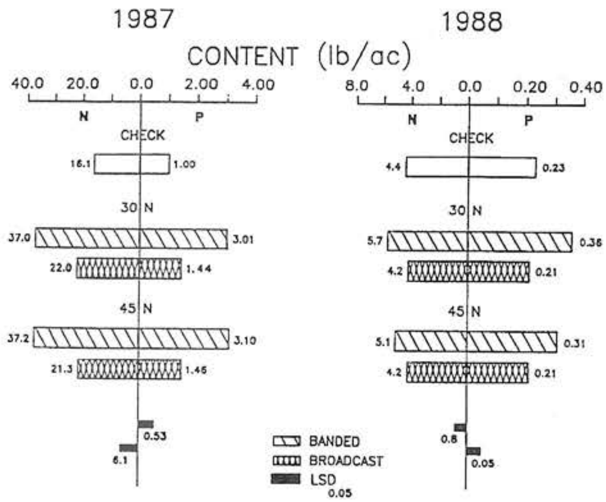

Figure 1. Spring wheat plant N and P content for 1987 and 1988 at plant development stage 5-6 as influenced by fertilizer rate and placement.

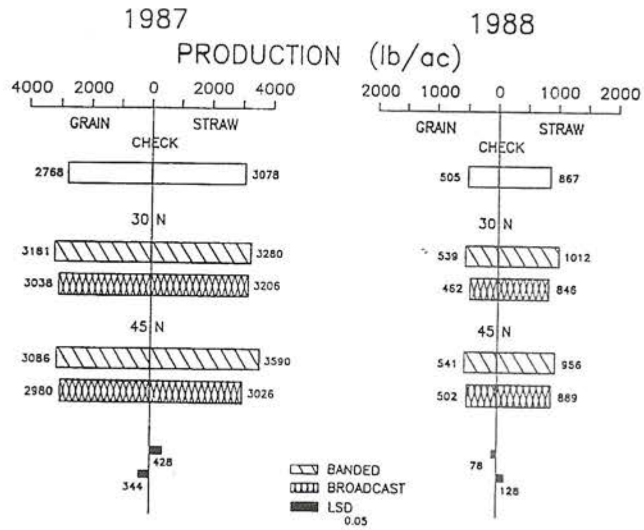

Figure 2. Spring wheat grain and straw production for 1987 and 1988 at plant development stage 11.4 as influenced by fertilizer rate and placement.

Fertilizer significantly increased spring wheat grain plus straw (harvest) N content from 78 lb/ac for the check to at least 93 lb/ac for the fertilized treatments in 1987 (Fig. 3). Differences reflect increased dry matter production for fertilized plots at harvest along with increased grain N concentration. In 1987, dry conditions during grain fill reduced grain and straw production and resulted in no treatment differences in N content. Dry climatic conditions in 1988 resulted in no fertilizer rate or placement differences for grain plus straw.

Grain N concentration in 1987 was significantly increased above the 2.28% for the check treatment with broadcast 30 N and 45 N and banded 45 N treatments (Fig. 4). Banded 30 N treatment was not different from the check because the greater grain and straw production diluted grain N concentrations (data not shown). Grain N content for all banded and broadcast fertilizer treatments was significantly greater than the 63 lb/ac for the check. This illustrates the greater grain and straw production for the banded 30 N as well as the other fertilizer placement treatments when compared to the check.

The study was repeated in 1989 because of extreme weather conditions encountered the previous two years which resulted in difficulty determining fertilizer recommendations and predicting yield potential for dryland areas. Based on 1987 and 1988, it appears that banded fertilizer, when compared to broadcast, can increase N and P use efficiencies at plant development stage 5-6 and reduce the potential for N fertilizer leaching.

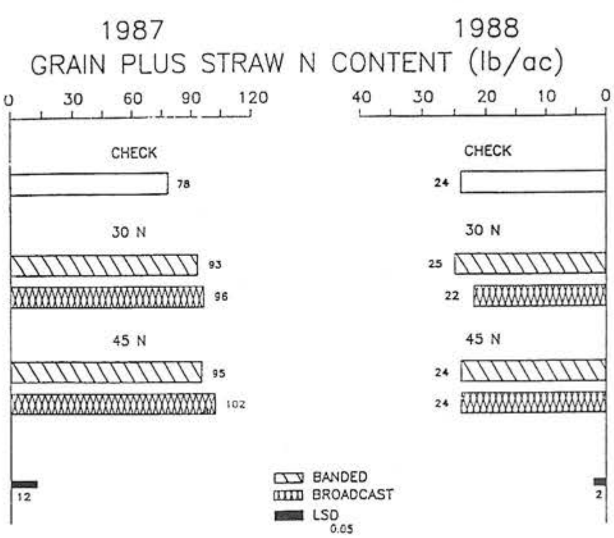

Figure 3. Spring wheat grain plus straw N content for 1987 and 1988 as influenced by fertilizer rate and placement.

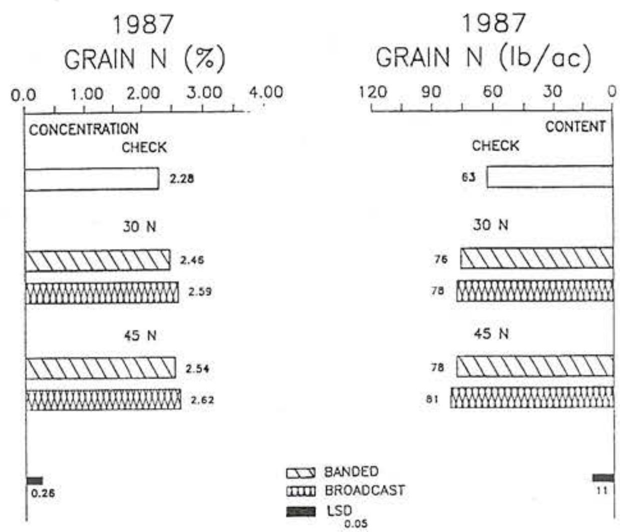

Figure 4. Spring wheat grain N concentration and content for 1987 as influenced by fertilizer rate and placement.

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ADDITIONAL SOIL FERTILITY RESEARCH PROGRAMS

Response of irrigated spring wheat to sulfur. PI: J. Eckhoff.

Intensive crop management of spring wheat. PI: J. Eckhoff.

Application of N on dryland spring wheat during tillering. PI: J. Eckhoff.

Soil fertility-disease relations in Montana crops. PI: R. Engel.

Available moisture-soil fertility relations in Montana crops. PI: R. Engel.

Kinetics of calcium phosphate precipitation in the presence of water-soluble soil organic matter. PI: W.P. Inskeep.

No-till small grain fertilizer and variety evaluations. PI: G. Jackson, G. Kushnak, and R. Berg.

Maximum small grain yields for dryland no-till seeding methods. PI: G. Jackson.

Specialty crop nitrogen requirements. PI: G. Jackson.

Monitoring soil productivity in Montana. PI: J.S. Jacobsen.

Nitrogen rate, placement, timing and source evaluations for small grains in Montana. PI: J.S. Jacobsen, and J.W. Bauder.

Snow management and fertilizer use efficiency in alfalfa/grass pastures. PI: J.S. Jacobsen.

Differential fertilization and navigation of fertilizer applicator with the global positioning system (GPS). PI: G.A. Nielsen.

Water use control for flexible dryland green manure cropping systems. PI: J. Sims.

Rotations for cereal/legume cropping systems in Montana. PI: J. Sims.

Nutrient uptake, fertilizer placement, fertilizer and water use efficiency effects on spring wheat. PI: D. Tanaka, J. Jacobsen, and J. Bauder.

Phosphorous uptake by selected legumes LISA PROJECT. PI: M. Westcott.

Phytoavailability soil test development. PI: E. Skogley.

Fertilizer placement in conservation tillage safflower production. PI: D. Tanaka, J. Jacobsen, J. Bergman, and N. Riveland.

SOIL SAMPLING UNDER NO-TILL BANDED PHOSPHOROUS FERTILITY

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ABSTRACT

Uncertainty exits as to the best sampling procedures on no-till soils containing residual P fertilizer bands. This study was conducted to determine the distribution of residual P fertilizer bands and to define soil sampling procedures that minimize variability while approximating the "true P soil test" value. Three central Great Plains soils under no-till banded P fertilization were sampled laterally away from the band 1-2 years after fertilization, and plant available P determined with a $NaHCO_3$ and acid-fluoride extraction. Bands were accurately described by the exponential decay model (mostly r^2 values of 0.98 or better). The derived exponential equations were used in computer simulation of soil sampling procedures. When the location of P bands are known, sampling as described by the following equation will result in a P soil test level approximately equal to the "true P soil test" value

$$S = 8\ (BS\ /\ 30\ cm)$$

where: S = the number of core samples to be taken between-the-bands for every core sample taken in-the-band, and BS = band spacing in cm. When the location of P bands are unknown, paired-sampling consisting of the first sample completely random and the second sample 50% of the band spacing distance from the first sample, perpendicular to the band direction, will reduce variability over completely random sampling. The greatest deviation from the "true P soil test" of the field occurs when inadequate sampling includes rather than excludes the band, and will under-estimate P fertilizer needs.

OBJECTIVES

Soil sampling procedures are well defined for conventionally tilled soils, but are known to be inadequate for no-till systems where band application of phosphorus (P) is common. Soil sampling may generate variable soil test results, depending on whether the band is either included or excluded. To avoid the variability problem created by banding, some have suggested building up soil P by over-fertilizing prior to initiating no-till management (Halvorson and Black, 1985). With convergent cost and profit margins, investments of this nature usually are not economical. Information regarding proper soil sampling procedures under no-till production where P fertilizer has been banded is lacking. Therefore, the objectives of this study were to: (1) determine the distribution of residual P fertilizer bands via a P soil test, and (2) develop soil sampling procedures that minimize variability and represent the "true P soil test".

MATERIALS AND METHODS

Three no-till experiments were initiated in eastern Colorado and western Kansas during 1986 and 1987. Soils were a Keith clay loam (fine, silty mixed, mesic, Aridic Argiustolls), a Woodsen silt loam (fine, montmorillonitic, thermic, Abruptic Argiaquolls), and a Harney silt loam (fine, montmorillonitic, mesic, Typic Argiustolls). Initial selected physical and chemical characteristics are presented in Table 1.

Table 1. Selected physical and chemical characteristics, and cropping history of study soils.

Soil Series	TEXTURE Sand	Silt	Clay	pH (1:1)	$CaCO_3$	Initial $NaHCO_3$-P	Initial Crop	Band Spacing
	--- %		----		g kg^{-1}	mg kg^{-1}		- cm -
Keith loam	42	34	24	7.0	3	4.7	sorghum	76
Woodsen silt loam	20	54	26	5.3	0	4.9	sorghum	61
Harney silt loam	22	54	24	7.2	40	7.2	wheat	30

Solution P fertilizer was banded 3 cm below the seed at planting. Soil samples to a 15-cm depth were taken during the fallow period 12, 15, and 23 months following planting and fertilizer application for the Keith, Woodsen, and Harney soils, respectively. Undisturbed crop residues were used as markers to identify the band location. Plant available P was determined using 0.5 mol L^{-1} $NaHCO_3$ extraction. Non-linear regression using a modified exponential decay model (Eq. [1]) was used to obtain equations to describe residual P bands.

$$Y = A\exp(-Bx) + C \qquad [1]$$

where: Y = the soil test value, x = lateral distance from the band, A and B are curve fitting parameters, and C = soil test level when un-affected by the P band. The "true mean P soil test value" was defined by the value obtained when dividing the integrated exponential equations by the band spacing distance.

Potential soil sampling procedures were defined and evaluated based on the criterion of whether the location of the residual P band was known or unknown. When unknown, sampling can be controlled to include, or exclude, the P band. A soil test value was obtained by mathematical averaging of soil test levels from in-the-band and between-the-bands, and comparing to the "true mean" as obtained by the integrated exponential decay equations.

Where the location of P-bands is unknown, random sampling, or some modification thereof, is the only choice. Simulation sampling using the exponential decay equation was performed to determine the standard deviation of means and range of soil test P as sub-sample size increased. Soil sampling procedures evaluated were: (1) completely random sampling (CR), and (2) paired-sampling consisting of the first core completely random and the second core taken 50% of the band spacing distance from the first core perpendicular to the band direction (CR+50%).

RESULTS AND DISCUSSION

The exponential decay function accurately described the soil test P moving laterally away from the residual P bands for all three soils (Figure 1).

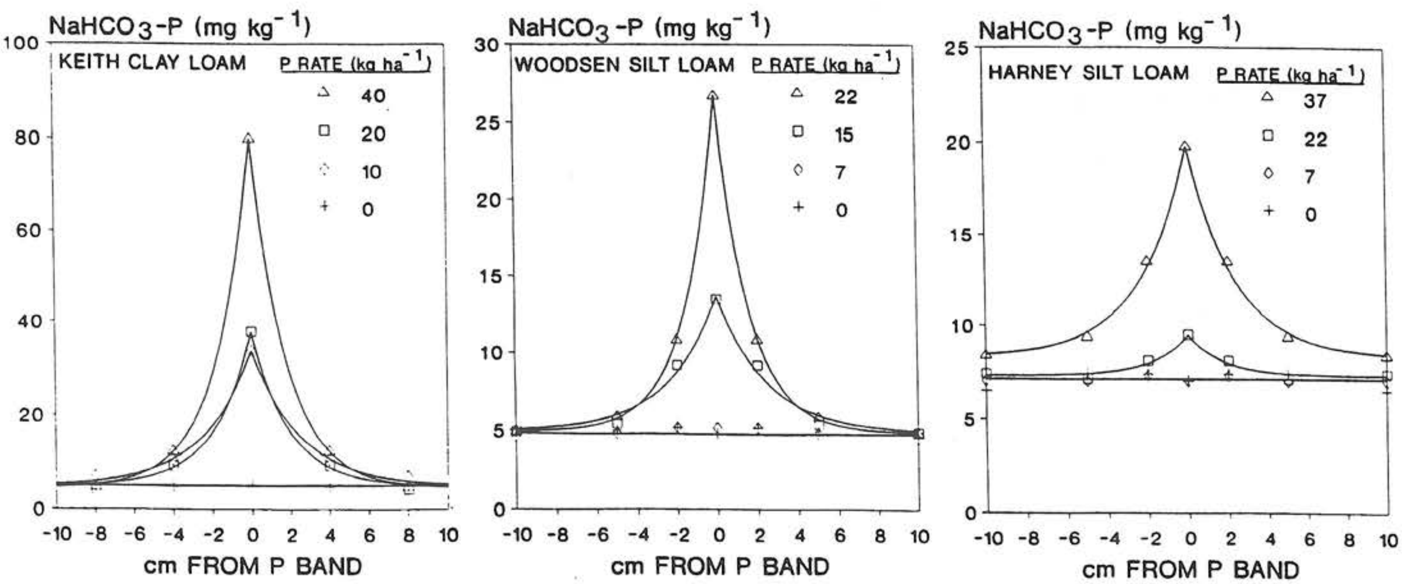

Figure 1. Exponential equations (solid lines) and measured soil test P (points) of residual P fertilizer bands in three Great Plains soils.

The r^2 values for the exponential decay equations were 0.98 or better. Fertilizer P bands in all three soils maintained their integrity over the time periods involved. The level of soil test P in the P bands increased with P rate. The actual amount of P fertilizer in a band in the Keith soil was 2.5 times more with a 76-cm band-spacing than the Harney soil with a 30-cm band-spacing.

Essentially, no residual P was detectable in the band on the Woodsen and Harney soils fertilized with 7 kg P ha^{-1}. These two soils have silt + clay contents that are 20% higher than the Keith soil. Fixation of fertilizer P increases with increasing content of silt and clay size particles (Olsen and Watanabe, 1963; Baldovinos and Thomas, 1967). Fixation also increases with calcium carbonate content (Lewis and Racz, 1969; Holford and Mattingly, 1975), such as is found in the Harney soil.

Sampling Procedure When P Band Location is Known

The effect of the band on soil test P level was calculated using various ratios of in-the-band to between-the-band sampling (Table 2). A comparison was made with the "true mean" obtained from integration of the exponential equations.

Table 2 shows that with a ratio of 1:20 in-the-band cores to between-the-band cores for 76-cm band spacing, a ratio of 1:16 for 61-cm band spacing, and a ratio of 1:8 for 30-cm band spacing, the resultant P soil test level for both extractants approximately equals the "true P soil test mean". This relationship held over all P rates and all three soils, and can be generalized in the following equation:

$$S = 8 \; (BS \; / \; 30 \text{ cm}) \qquad [2]$$

where: S = the number of core samples to be taken between-the-bands for every core sample taken in-the-band to obtain the true mean, and

Table 2. Calculated soil test P levels with various ratios of in-the-band soil to between-the-band soil.

Extraction Method	Ratio of In-the-Band to Between-the-Band Sampling	Band Spacing (cm): 76, Keith			61, Woodsen		30, Harney	
		P Rate ($kg\ ha^{-1}$)						
		10	20	40	15	22	22	37
		mg P kg $soil^{-1}$						
$NaHCO_3$-P	1:1	19	21	42	9	16	8	14
	1:3	12	13	23	7	10	8	11
	1:5	10	10	17	6	8	8	10
	1:8	8	8	13	6	7	8	10
	1:12	7	7	10	6	6	7	9
	1:16	7	7	9	5	6	7	9
	1:20	6	6	8	5	6	7	9
	1:24	6	6	7	5	6	7	9
"True P soil test" Mean		7	6	8	5	6	8	10

BS = band spacing in cm. Equation 3 can be used as a guideline for soil sampling procedures for no-tilled fields where P fertilizer has been band applied and the location is known.

Sampling Procedure When P Band Location is Unknown

When the location of the P bands are unknown, completely random sampling, or some modification thereof, is the only choice. A computer simulation of two soil sampling procedures (CR and CR+50%) was performed using selected exponential decay equations to represent soil test P. Standard deviations of means (SD), used to assess variability, and mean ranges were obtained from 100 means for the two sampling procedures and are compared in Table 3. The standard deviations relate to variability associated with the P band exponential models, and cannot account for variability within bands and/or natural field variability. Standard deviation and width of range increased with P rate, band spacing, and fewer sub-samples. The greatest error will arise when too few, rather than too many, sub-samples are collected. Soil test level variability in the Harney soil, with narrower band spacing and a greater P-fixing capacity, was much less than in the other soils. Using the CR+50% sampling procedure slightly reduced sampling variability compared to the CR procedure.

Phosphorus fertilizer banding in high P fixing soils and with narrow band spacing (30 cm) does not require increased sampling intensity (Table 3). Typical soil sampling recommendations, calling for 10-30 sub-samples per composite (Whitney et al., 1985), are adequate. Soils low in P-fixing capacity and/or with wide band spacing require greater sampling intensity (30-60 sub-samples) to obtain P soil test values that approach the "true value". This is especially necessary when sampling follows high rates of banded P fertilization.

Table 3. Computer simulation standard deviations for two soil sampling procedures at selected banded P fertilizer rates, based on 100 means.

Soil Sampling Procedure	Number of Sub-samples in Composite	Band Spacing (cm): 76, Keith				61, Woodsen		30, Harney	
		P Rate ($kg\ ha^{-1}$): 40		20		22		37	
		mg P kg^{-1} soil: SD	range	SD	range	SD	range	SD	range
Completely Random	6	4.1	4-30	2.0	5-14	1.3	5-12	1.2	8-14
	10	3.8	4-25	1.5	5-12	1.0	5-10	0.9	8-13
	20	2.2	4-15	1.1	5-10	0.7	5-9	0.6	9-12
	40	1.6	5-12	0.8	5-9	0.5	5-8	0.4	9-11
	80	1.2	6-11	0.6	5-8	0.4	5-7	0.3	9-11
CR+50%§	6	4.1	4-23	1.9	5-13	1.1	5-11	0.7	8-11
	10	2.9	4-16	1.4	5-11	0.9	5-9	0.6	8-11
	20	2.2	4-15	0.9	5-9	0.7	5-8	0.4	8-10
	40	1.5	5-13	0.7	5-8	0.4	5-7	0.3	9-10
	80	1.2	6-11	0.5	5-8	0.3	5-7	0.2	9-10
"True P soil test" mean		8		6		6		10	

Paired-sampling: first sample, completely random; second sample, 50% of the band spacing distance from the first sample, perpendicular to the band direction.

CONCLUSIONS

Soil test variability in soils containing residual P bands will be less in soils that have a high P fixing capacity than with non-P fixing soils. Other factors contributing to increased variability are high P fertilizer rates and wide-band (row) spacing. When residual P bands can be located, the best soil sampling procedure is to collect samples using the ratio from in-the-band to between-the-band as described in Eq. 2.

If the location of the bands can not be identified, variability created by the bands will be minimized using the CR+50% sampling procedure. In light of these sampling-procedure findings, several other considerations should be emphasized. Prior to initiation of no-till management, P soil testing should be accomplished to insure the soil's P supplying capacity is understood. Soil test measurements do not change rapidly and thus can be used for fertilizer recommendations for 2-4 years (Whitney et al., 1985). The application of liberal rates of banded P fertilizer increases subsequent P soil test variability and therefore should be avoided.

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MAXIMUM ECONOMIC YIELD IN SASKATCHEWAN

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ABSTRACT

An extensive on farm research demonstration program was established in Eastern Saskatchewan to develop a maximum economic yield package for farmers. Net returns from seed placed fertilizer were compared to banding. Ammonium nitrate-phosphate and urea-phosphate blends were seed placed with an air seeder and compared to urea and anhydrous ammonia banded. Results show a significant higher net return from the use of seed placed fertilizer for cereal production. The second component in the MEY Program was to evaluate intercropping peas and canola in order to minimize equipment investment for field Pea Production in Eastern Saskatchewan. The pulse gain from using peas in rotation was also documented. These results will have a dramatic input towards the establishment of a MEY package for Eastern Saskatchewan with a strong emphasis on soil conservation.

OBJECTIVE

Grain farmers continue to struggle in the cost-price squeeze with relatively low commodity prices as well as high input and equipment costs. Recommendations on how to obtain maximum economic yields (MEY) are demanded by producers. Fertilizer use efficiency and new cropping options without major new investments in equipment are the initial components for a MEY package. The objective of this study was to initiate an MEY Program by establishing on farm research demonstrations on fertilizer use efficiency comparing seed placed fertilizer with banding and to evaluate the potential for intercropping peas and canola (peaola) with respect to yield, economic gain over peas alone, harvesting efficiency and disease control.

INTRODUCTION

Fertilizer is one of the major input costs for crop productin in Western Canada. Research on fertilizer use has been extensive in Canada with somewhat variable results. Recently the consenses among researchers is that banding is one of the most efficent methods for fertilizer application, Harapiak (1985). Prior to the recent research on banding, there has been considerable variation in results and recommendations, with respect to the most efficent source, application time and placement. In recent research and farm reports, Barclay (1987), the majority of comparisons have been banding vs broadcasting and not banding vs seed placement of fertilizer.

Research by Soper (1959 - 1965) in Manitoba showed ammonium nitrate as superior to urea as a nitrogen source for seed placement. Relative efficiencies of urea and ammonium nitrate for cereals were also research in Saskatchewan by Ukrainetz. (1983) who reported urea was less efficient than ammonium nitrate when seed placed with barley at high rates. In general, the early research supported the recommendation that if the seed bed is moist, up to 40 lbs. per acre of nitrogen may be applied with the seed, provided that no more than 20 lbs. of this is urea nitrogen and the total amount of fertilizer does not exceed 175 lbs. In terms of availability to the plant, this is the most efficient way of applying nitrogen to cereals, Racz (1987).

Peaola is a new cropping system in which canola and peas are intercropped. The interest in legume crops such as field peas and lentils continue to grow especially since legumes add considerably to soil nitrogen and are suitable for rotation with cereals. General consensus is that up to 40 lbs. per acre of nitrogen is available from using a pulse crop in rotation.

The production of peas usually requires additional investment in equipment including swather attachments such as vine lifters and pickup reels. Also pea swaths tend to roll in the wind resulting in harvest losses. Straight cut header attachments can be used however a costly desiccation treatment is usually required. Diseases such as mildew and ascochyta can further deteriorate the quality of the crop. Earth tagging of the seed is also a problem when peas are harvested with soil picked up by the header.

This study was conducted to develop a production package for peaola to identify potential for improved economic returns over peas, including a study of seeding rates and depths, weed control, fertility and harvesting/handling techniques since no research had been done on the subject.

MATERIALS AND METHODS

Fertilizer Trials

Replicated (randomized complete block design 3 treatments, 3 replicates) trials were established on Yorkton clay loam soil with pH 8.0 - 8.2. Fertilizer treatments for wheat and barley were:

1) seed placed ammonium nitrate-phosphate (26-13-0) @ 153 lbs/acre.
2) seed placed urea-phosphate (34-17-0) @ 117 lbs/acre.
3) banded urea (46-0-0) or anhydrous ammonia (82-0-0) with seed placed phosphate (11-51-0)

Net returns were calculated by subtracting fertilizer and/or banding cost ($4.00/acre) from gross returns. Farm scale equipment was used in this study. An air seeder was used to seed directly into standing stubble using seed placed fertilizer. Seed placed rates were 40 lbs. of nitrogen and 20 lbs. of phosphate. Banding rates were higher up to soil test recommendations.

INTERCROP TRIALS

Various varietal combinations of field peas and canola were evaluated for yield, net return, ease of harvesting disease, seeding rates, weed control and pulse grain.

Yield data was obtained by using a portable scale that weighed grain directly from the combine.

RESULTS AND DISCUSSION

FERTILITY STUDY

The average net return per acre for seed placed fertilizer was approximately $10 per acre higher compared to banding as shown in Tables 1 - 3.

Table 1. Net return for banding vs. seed placement for wheat, 1985 - 1989

Site	Crop	Seed Placed AN-P	Seed Placed U-P	Banding Urea or NH3
1	Wheat	$ 49.57	$ 50.35	$ 42.10
2		65.24	67.38	43.10
3		20.77	25.80	16.04
4		47.45	48.51	40.75
5		1.57 **	4.14 **	6.98 **
6		145.43	144.05	134.69
7		136.91	136.03	129.21
8		89.39	83.31	50.47
9		18.36 ***	10.75 **	-3.04 **
	Mean	$ 63.85 a*	$63.37 a*	$51.14 b*

* Net return was significantly greater for seed placed fertilizer treatments. Duncan's multiple range test 5 % level, sites were used as replicates. Numbers with the same superscript were not significantly different.
** drought

Table 2. Net return for banding vs seed placement for barley. 1985 - 1989

Site	Crop	Seed Placed AN-P	Seed Placed U-P	Banding Urea or NH3
1	Barley	87.87	-	78.74
2		82.42	-	61.30
3		75.85	-	69.74
4		93.42	-	62.82
5		99.69	107.46	115.53
6		121.54	115.51	109.80
7		89.86	-	41.89
	Mean	$ 92.95 a *		$ 77.12 b *

* Net return was significantly higher for seed placed fertilizer treatments. Duncan's multiple range test 5 % level, sites were used as replicates.

Table 3. Net return for banding vs seed placement for flax

Site	Crop	Seed Placed AN-P	U-P	Banding Urea or NH3
1	Flax	99.60	105.22	81.60
2		61.35	-	43.04
	Mean	$ 80.48		$ 62.32

In all cases the banding rates were higher than seed placed rates however, only limited data has been obtained for flax. In the analysis the banding cost ($4.00/acre) plus extra fertilizer test was deducted from net return. The relatively dry conditions during the previous three (1987 - 1989) growing seasons may have minimized the fertilizer responses. This data supports the recommendation that 40 lbs. of nitrogen and 20 lbs. of phosphate seed placed for cereals is the most cost efficient fertilizer placement method. This is efficient not only from the cost view point but also soil moisture and soil conservation since the crop is planted with minimum tillage directly into standing stubble.

There was no difference in efficiency for seed placed urea-phosphate vs ammonium nitrate-phosphate for wheat. This is useful data for farmer's since urea is much cheaper and more readily available.

INTERCROPPING

A potential profit of $ 20 per acre can be achieved by intercropping peas and canola as shown in Table 4.

Table 4 Gross returns per acre for peaola vs. peas. (1984 - 1989).

Year	Peas	Peaola	# of Sites
1984	152.50	215.25	2
1985	150.00	192.25	2
1986	164.00	143.46	2
1987	180.00	200.00	2
1988	130.60	146.97	5
1989	116.82	116.73	5
Mean	$ 148.99	$ 169.11	

Additional benefits for intercropping include:

1) pulse gain from peas in rotation.

2) no additional equipment required for pea production such as pick up guards, reels, etc.

3) superior quality of peas produced since no desiccation is required and seed is free of earth tagging and disease.

CONCLUSION

This study shows that two components of a maximum economic yield package for producers are the use of seed placed fertilizer in a minimum tillage system and intercropping peas and canola for extending rotations.

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Westermun

Iowa .75/TON

OHio BMP's

Arizona BmP's

Kansas 1.40/TON

Oklahoma .35/TON ($225,000/YR)

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NITRATE-N ACCUMULATION UNDER CONTINUOUS WINTER WHEAT

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ABSTRACT

Proper nitrogen management in winter wheat production is extremely important to achieve optimum yields and to minimize risks of NO_3-N movement to groundwaters, lakes, and streams. Nitrate accumulation in soils from long-term soil fertility experiments under continuous winter wheat was measured. Significant NO_3-N accumulation did not occur in lower depths of soil profiles unless the N rate grossly exceeded current N recommendations. In wheat production systems with average rainfall of 28 and 32 inches per year respectively, the N rate for optimum yield coincided closely with the most environmental acceptable N rate.

OBJECTIVE

To determine the effect of long-term annual applications of N on grain yield and NO_3-N accumulation in soils cropped to winter wheat.

MATERIALS AND METHODS

Multiple rate N, P, and K long-term fertility experiments were established on Kirkland silt loam and Grant silt loam soils respectively, at the Stillwater and Lahoma Research Stations. The main purpose of the experiments was to determine the effects of N, P, and K fertilization on grain yield of continuous winter wheat and to calibrate soil test indices for fertilizer recommendations. Annual fertilizer applications were applied broadcast to the same plots each year and disk incorporated prior to seeding during the 17 and 19 years respectively, at Lahoma and Stillwater. Ammonium nitrate was used as the N source at both locations. Grain yields were measured each year. Selected fertilizer plots that had multiple N rates with constant adequate applications of P and K were selected for deep sampling. Soil cores were taken from plots that had received annual applications of 40, 80, and 120; and 30, 60, 120, and 240 lbs of N per acre respectively, at Stillwater and Lahoma. Four replications at each experimental location were sampled. Soil cores were taken to a depth of 7 feet and divided into the following increments: 0-6, 7-12, 13-18, 19-24, 25-36, 37-48, 49-60, 61-72, and 73-84 inches and analyzed for NO_3-N.

RESULTS

Stillwater

Total N loading due to 19 annual N applications of 40, 80, and 120 lbs of N per acre as ammonium nitrate resulted in additions of 760, 1520, and 2280 lbs of N per acre in the experimental plots that were sampled. Average grain yield during this 19 yr period was increased from 22 to 29 bushels per acre with the most significant increase occurring with the 40 lb N rate. A small yield increase was observed by increasing the N rate from 40 to 80 lbs per acre but additional N beyond that rate had no effect on grain yield.

After 19 years of continuous winter wheat production using 40, 80, and 120 lbs of N annually, NO_3-N accumulation in 7 ft cores with the first two N rates showed little increase above that observed without N fertilization. However, when the N rate was increased to 120 lbs per acre significant accumulation of NO_3-N occurred. The observed increase in NO_3-N concentration was confined to the upper 3 feet of the soil profile.

Regression analysis of relative grain yield and relative NO_3-N accumulation in soil vs N fertilization rates indicated that the N rate required for optimum grain yield coincided closely with the most environmental acceptable N rate.

Lahoma

Annual applications of 30, 60, 120, and 240 lbs of N per acre for 17 years resulted in total N loading rates of 510, 1020, 2040, and 4080 lbs of N per acre. Grain yield was increased from 29 to 39 bushels per acre with N fertilization. Yield increases were observed with both 30 and 60 lbs of N per acre annual applications during the 17 year period of the study.

Nitrate-N accumulation due to N fertilization was minimal in 7 ft cores with annual applications of 30, 60, and 120 lbs of N per acre. However, when N was applied at 240 lbs of N per acre for 17 years which is approximately 3 to 4 times the recommended N rate for grain yield in this area, significant accumulation of NO_3-N occurred in the 4 to 7 foot depth of the profile.

Quadratic regressions of relative grain yield and relative NO_3-N accumulation in soil vs N fertilization rates showed that the most acceptable environmental N rate was similar to the N rate for optimum yield.

DISCUSSION

Grain yields for winter wheat in Oklahoma fluctuate annually due to a wide range of rainfall patterns, temperature stress, diseases and insect problems. Yields at these two locations typically range from 50 to 60 bushels per acre in more favorable years. During the 17 and 19 years in which the experiments have been conducted there were some less than favorable years with yields of 10 to 12 bushels per acre. Nitrogen applications were made annually regardless of past yield history and residual soil NO_3-N that could have been accounted for by soil tests. In normal management practices, N recommendations to produce desired yield goals would be adjusted to include residual soil NO_3-N in the surface 0 to 6" and in some cases the top 24" of the soil profile if unusual climatic factors were encountered that reduced yield significantly. Utilizing residual soil NO_3-N and adjusting N rates accordingly further reduces the risk of NO_3-N movement to groundwater, lakes, and streams.

SUMMARY

Significant accumulation of NO_3-N in soil profiles did not occur with typical N applications for winter wheat production in the Southern Great Plains with average rainfall of 28 to 32 inches per year. Excessive N applications beyond the amount of N required to produce optimum yield caused NO_3-N to accumulate in both the surface and lower depths of the soil profiles.

Although very little NO_3-N moved vertically to lower depths of soil profiles under typical N management systems, the potential for contamination of groundwaters, lakes, and streams still exist due to soil erosional processes.

Protect your right to use adequate fertilizers for crop production by (a) practicing good soil stewardship and (b) using soil tests to determine fertilizer requirements that supply adequate but not excessive amounts of nutrients that meet the needs of the crop for optimum yield yet, minimizes the risk of pollution of groundwaters, lakes and streams.

Prudent fertilizer use today will pay dividends tomorrow.

Stillwater

#N	19 yr Acc	To 84"
0	198	
40	255	
80	284	
120	406	

30 Bu wheat

Alarming — At 120# the accumulation is in the upper profile (Rooting zone

80×19 = 1520 #/A
120×19 = 2280 #/A

Max N Rate w/o leaching ≅ 60-80#
*(2#N/Bu for a 60 Bu crop.)

Lahoma	N	#N to 84"
	0	253
	30	261
(30 Bu wheat)	60	271
	120	368
	240	1504

deep N leaching!
(Not much diff up to 120#)

60 × 17 yr = 1020#
240 × 17 yr = 4080#
*(88# N/A for ~40 Bu/A yield)

Oklahoma model

*No Biological Accomodation
Worst case scenario
No Runoff factor.

Kirkland soil
Stillwater   Nitrate pulse (15yr data)

1. After 5 yrs the N Pulse w/station Rain
   NO_3 could move past 5'
2. 19 yr period time could move to
   ~8"

Lucahoma
1. including a 15" Rain moved N from
   ~30" to 80"

N Distribution "western"

50% taken up by crop
25% to NH_4^+ in organic fraction
25% to NO_3 ⇒ leaching, denitrification etc

RECOVERY OF RESIDUAL FERTILIZER 15-N BY FIVE YEARS OF WINTER WHEAT

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ABSTRACT

In a split plot design 36 corn plots at Akron Colorado were divided into 3 sprinkler irrigation blocks (0.8, 1.0, and 1.5 ET). The 12 plots within an irrigation block were fertilized yearly for 3 years with depleted $(^{15}NH_4)_2SO_4$ at rates of 0, 112, 224, and 336 lb ^{15}N/ac. The three corn crops recovered 223, 388, and 458 lb tagged N/ac respectively and depleted ^{15}N in percolated water was 0.18, 4.2, and 7 lb N/ac respectively. Subtracting these values from the depleted ^{15}N applied resulted in a possible carry-over of fertilizer ^{15}N after the corn crops of 112, 278, and 541 lb N/ac respectively for the various fertilizer N rates. After corn the plots were then returned to dryland conditions and continuously cropped with winter wheat for 4 years, fallowed 1 year and then cropped 1 more year to determine the effect of prior water and fertilizer treatments on wheat yields and recovery of residual fertilizer N by long-term winter wheat cropping. A total of 19.6, 75.8, and 182.9 lb N/ac of depleted ^{15}N was recovered from the respective fertilizer treatments for the five cropping years resulting in percent recoveries of 18, 27 and 34 for the respective fertilizer treatments. The residual depleted ^{15}N results in additional soil N recovery by the crops or a 'added N interaction, ANI'. If we assume N from the ANI is the same as tagged N and added this to the recovered depleted ^{15}N and calculate recovery we obtain recoveries of 55, 52 and 51% for the respective fertilizer treatments. Recovery can also be calculated by a difference method (total N recovered in fertilized plots minus total N in check plots). Using this method recoveries of 57, 53, and 52% were calculated for the respective fertilizer treatments.

OBJECTIVES

Numerous studies have shown utilization of fertilizer N commonly is about 50 percent for corn but varies with crop species and the rate and regime of fertilizer application. In the arid soils of Western United States evidence has accumulated that substantial amounts of residual fertilizer N following a heavily fertilized crop like corn may be distributed through the rooting zone and that this carryover N can have nutritional effects on subsequent crops. Management methods (crop species, population density, the amount and regime of applying fertilizer N and irrigation water) can have a significant bearing on the magnitude of fertilizer N carried-over and its distribution in the soil profile. Physical properties of the soil govern water penetration and the downward flux of water and nitrate through the soil profile and thus have a substantial effect on the storage of residual N.

The objectives of this study were to determine how prior water regimes and varying amounts of residual depleted ^{15}N affect long-term winter wheat yields and the recovery by wheat of carry-over ^{15}N.

METHODS

A dryland site at the U.S. central Great Plains Field Station, Akron, CO. was selected. The site had been in a wheat fallow rotation and had never been fertilized. The soil was a Weld silt loam, a member of the fine, montmorillonitic, mesic Aridic Paleustolls. An area 175 by 90 ft was divided into 3 irrigation blocks (1.5, 1.0, and 0.8 ET) separated by 10 ft alleys. The 12 plots within the blocks were each 20 by 15 ft. The plots were fertilized yearly for 3 cropping seasons with depleted $(^{15}NH_4)_2SO_4$ at rates of 0, 112, 224, and 336 lb N/ac (3 replications). Under each plot at a depth of 4 ft (undisturbed profile) a Duke-Haise (1973) vacuum extractor was installed to quantify deep percolation and the nitrate in percolation water. The yearly above ground corn production was measured and all corn residue removed from the plots. After 3 years of corn cropping we ceased fertilizing, irrigating and monitoring the percolate for these plots. The soil profiles contained by a difference method carry-over of 112, 278 and 541 lb ^{15}N/ac for the respective fertilizer treatments. The site was returned to dryland conditions and continuously cropped with winter wheat for 4 years, fallowed 1 yr, and then cropped with winter wheat 1 more yr. Yearly, after obtaining yields, the grain was harvested and all straw and chaff was removed from the plots. Total N in plant samples was determined by Kjeldahl digestion, Bremner (1965a) and NO_3-N in percolation water was determined by steam distillation methods outlined by Bremner (1965b). The abundance of ^{15}N was determined on an AEI MS-20 isotope ratio mass spectrometer using the NH_4 to N_2 conversion technique of Porter and O'Deen (1977). The data has been statistically analyzed with SPSS-X release 2.0.

RESULTS AND DISCUSSION

Prior irrigation treatments had no significant effect ($P = 0.539$) on total wheat yields. Yields (means of 5 crops) for each irrigation block were used to construct figure 1. Prior irrigation regimes had not altered the soil profiles or their N content enough to affect overall yields. This is true on this heavy textured soil where the downward N and water flux are relatively slow. It may not be true of sandy soils where fluxes are relatively rapid.

There was a significant year by residual N interaction ($P = <0.001$) indicating that the effect of residual fertilizer N on total yield was not consistent over years. There was a significant trend for increasing amounts of residual fertilizer N to increase total wheat yields, figure 2. This figure was constructed by taking the means for 5 crops for each residual fertilizer treatment over all irrigation blocks. The figure clearly illustrates that each increasing increment of carry-over depleted ^{15}N caused an increase in yield with the 541 lb N/ac of residual ^{15}N doubling the total (grain+chaff+straw) yield compared to the zero rate.

The proportion of the plant N derived from fertilizer (%Ndff) varied depending upon how much carry-over depleted ^{15}N was in the soil at the start of cropping, figure 3. This figure was constructed by calculating %Ndff mean for the 5 winter wheat crops over all irrigation blocks. It demonstrates that the larger the residual depleted ^{15}N pool the greater was the proportion of N in the plant derived from that N pool. When the pool only contained 112 lb N/ac the proportion of ^{15}N in the plant was only 10 % whereas, when the pool contained 541 lb N/ac the proportion of ^{15}N was over 40 %. The %Ndff declined as the residual ^{15}N pool declined with cropping resulting in a significant year by fertilizer interaction (P = <0.001). This is shown in figure 4 for the 278 lb N/ac residual depleted ^{15}N treatment where the %Ndff was 50% the first cropping year and decrease to about 13% in the fifth cropping year. For the 541 lb residual ^{15}N/ac the %Ndff was over 60% in year 1978 and decreased to about 30% in 1983 whereas, at the 112 lb N/ac residual depleted ^{15}N %Ndff was 18% in 1978 and declined to 7% in 1983. This agrees with the observations of Power (1983) who found a long-term influence of residual N on wheatgrass yields and that recovery of fertilizer N by the grass increased by 20% after fertilization ceased. In these studies greater amounts of residual N remained in the soil than in the study of Power and the greater quantities of residual N resulted in even greater recoveries by wheat than he reported for wheatgrass.

The plant recovery of residual fertilizer N can be determined by two different methods, direct recovery of depleted ^{15}N and by the difference method, i. e. subtraction of the N yields from the check plots from the N yields of the fertilized plots. Data for direct depleted ^{15}N recovery are given in table 1. They show a recovery ranging from 17% at the 112 lb residual N/ac to 34% at the 541 lb residual N/ac.

Table 1. Recovery of residual depleted ^{15}N by 5 crops of dryland winter wheat.

	Prior fertilizer treatments		
	L	M	H
	-------lb ^{15}N/ac-------		
Residual ^{15}N at start of exp.	112	278	541
^{15}N recovered by 5 wheat crops	19.6	75.8	182.9
Residual ^{15}N recovered (%)	17.5	27.3	33.8

Whereas, utilizing the difference method, table 2, the amounts of residual N change and the recovery ranged from 57 % at the 45.5 lb residual N/ac to 52 % at the 504 lb residual N/ac. These recovery values differ drastically from those that were observed in table 1.

Table 2. Residual N and recovery of residual N calculated by the difference method (Fert. Plots minus Check Plots).

	Prior fertilizer treatments		
	L	M	H
	---------lb N/ac-----------		
Residual N at start of exp.	45.5	233	504
Total N recovered by 5 wheat crops	25.9	123	261.4
Residual N recovered (%)	57	53	52

However, the addition of depleted ^{15}N resulted in an additional soil N uptake over the checks for both the corn crops and wheat crops. This increased uptake of soil N caused by fertilizer addition has been termed 'priming or added N interactions (ANI)', Jenkinson, et al (1985). If we assume that this soil N caused by the ANI is the same as tagged N and recalculate both the residual fertilizer N remaining after corn and the residual tagged N recovered by the wheat crops then recoveries, table 3, were 55, 53 and 52 % or essentially the same for the two methods.

Table 3. Recovery of residual depleted ^{15}N by 5 wheat crops calculated assuming the increased soil N uptake over check plots cause by applied fertilizer ^{15}N (ANI) is equivalent to depleted ^{15}N.

Added nitrogen interaction (Priming)

	Fertilizer Treatments		
	L	M	H
	--------lb N/ac--------		
Residual soil ^{15}N after Corn	112	278	541
ANI, soil N uptake by corn	64.6	45.9	32.5
Residual N after corn (residual ^{15}N-soil N uptake)	46.9	231.9	509.3
Recovery of ^{15}N by 5 wheat crops	19.6	75.8	182.9
ANI, soil N uptake by 5 wheat crops	6.3	47	79.2
Total N recovery by 5 wheat crops (^{15}N recovery + soil N recovery)	26.0	122.8	262.1
Recovery by 5 wheat crops (%)	55.3	52.9	51.5

Tagged vs Residual

Priming - increase N up w/additions

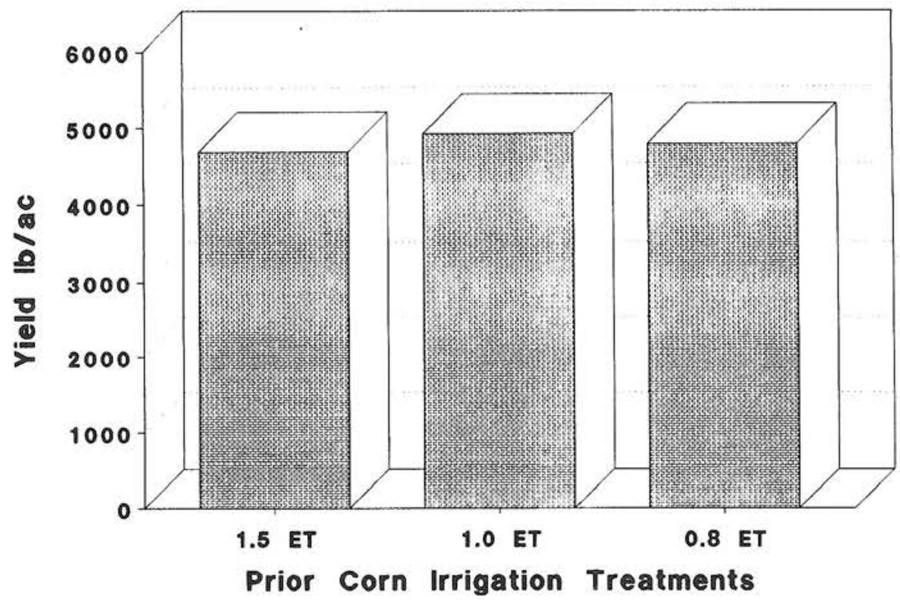


Figure 1. Dryland winter wheat yields as affected by prior corn irrigation regimes (mean of 5 crops).

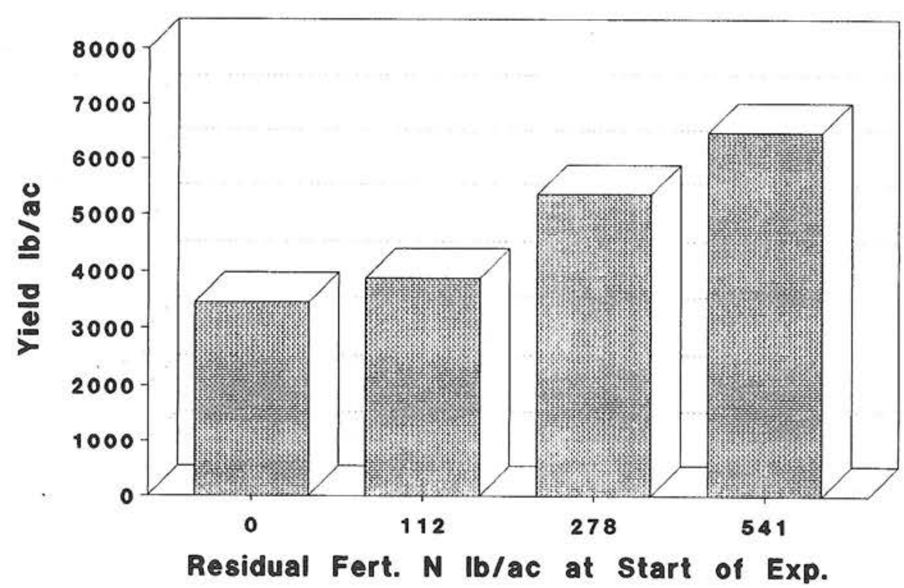


Figure 2. Dryland winter wheat yields as affected by residual fertilizer N from prior corn crops (mean of 5 crops).

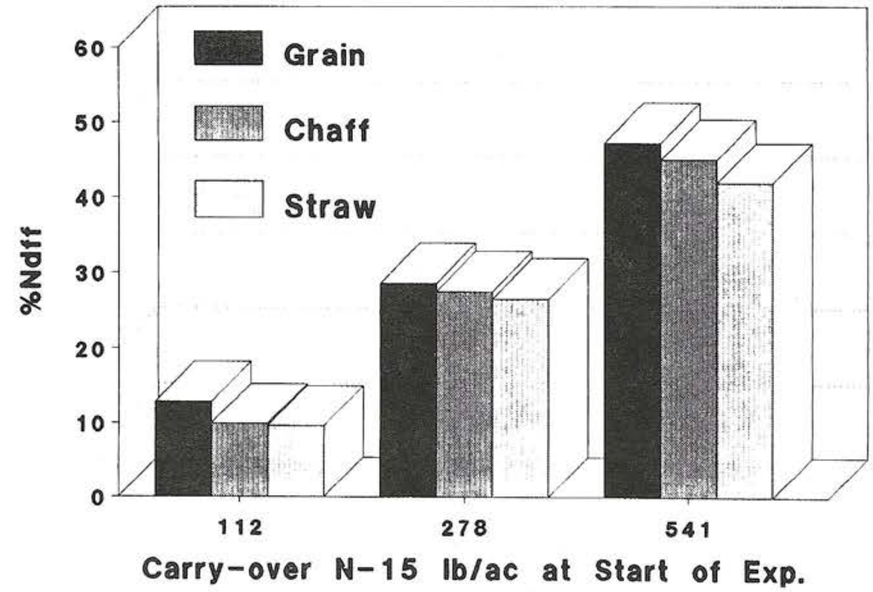
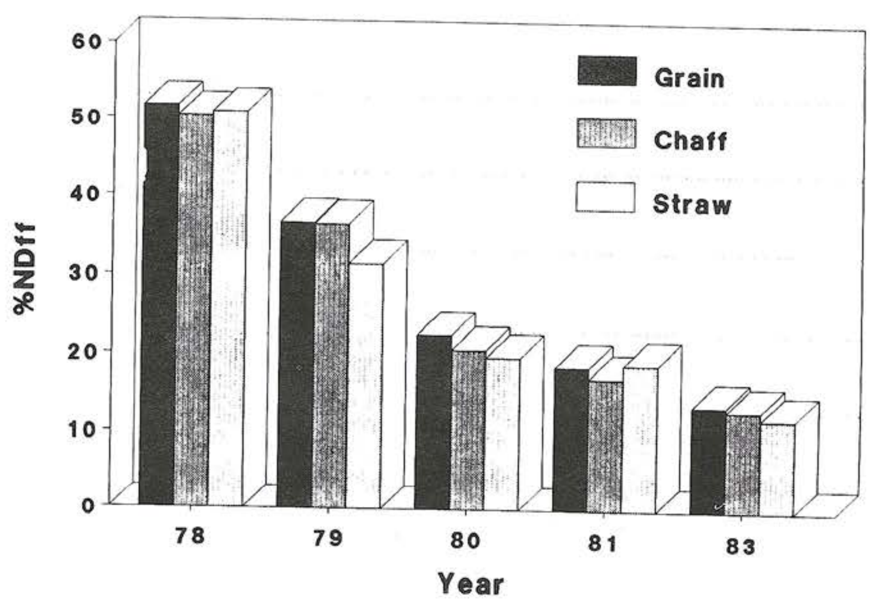


Figure 3. Percent N derived from fertilizer N (%Ndff) for winter wheat yields as affect by size of residual fertilizer N pool (mean for 5 crops).



N from fertilizer

Figure 4. Yearly percent N derived from fertilizer N (%Ndff) for winter wheat yields for the 278 lb N/ac residual N treatment (mean of 5 crops).

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Note

1. Lighter Isotope went to grain, heavier isotope went to straw & chaff.

2. Recovery is a long term event.
   Doubled uptake

3. Amt. of Residual N uptake diminishes as the pool decreases.

"In the arid west, potential Evap exceeds ppt, so a residual N pool can stay a long time. It only moves out when ppt exceeds evapotranspiration".

"Tagged N usually underestimates the amt of N Recovered"

"Added N interaction on recovery is real & must be accomodated"

~~Buldg~~ Bulges in N at ~60" are common.

FERTILIZER P DISTRIBUTION AND WHEAT YIELD

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ABSTRACT

Since application spacing of knifed-in P bands (dual placement of liquid ammonium polyphosphate and ammonia) affects distribution of P in the band, four experiments were established in southeastern Nebraska from 1988 thru 1989 to determine the effect of diluting the liquid fertilizer P with water on winter wheat yield and P uptake. Soils were Sharpsburg and Crete sicl in 1988 and Sharpsburg sicl and Pawnee sic in 1989. Diluting with water provided treatments that ranged from continuous bands to bands that had droplets placed up to 7.6 cm apart. Results indicated that applied P increased grain yields on three of the four soils studied. Diluting the liquid P fertilizer with water had minor effects on yield parameters at harvest in 1988. However, dilution substantially increased dry weight, P concentration, and P uptake at the end of the tillering stage (Feekes stage 5). Root length was also increased marginally with dilution in the fertilizer band application area. In 1989, dilution increased grain yield on the Pawnee soil, but significantly decreased yield on the Sharpsburg soil. Although grain yields were relative good, wheat was under severe drought stress at times in both years, wheat may have reduced the effectiveness of dilution.

INTRODUCTION

Band application of soluble P fertilizers usually results in increased fertilizer P efficiency compared to broadcasting especially when soil P availability is low (Fiedler et al., 1989). It is believed that band application is superior to broadcast application because it reduces soil fertilizer contact resulting in less "fixation" and provides greater opportunity for root contact (Sleight et al., 1984). Since the probability of root-fertilizer P contact appears to be an important factor affecting fertilizer P uptake, the distribution of fertilizer P in the band area becomes potentially important (Tang, 1989). It is known that commonly used "squeeze pumps" distribute liquids as droplets of variable spacing depending on the rate and spacing of the application (Eghball and Sander, 1987). It has also been shown that dry fertilizer P particles spaced 2.8 cm from one another in a 30-inch band spacing produced winter wheat yields that were less than when particles were spaced to provide a continuous band (Sander and Eghball, 1988). It appears that the distribution of P in the band either in a dual placed band or P placed in the seed row may affect P fertilizer efficiency in that the root must contact many liquid droplets or dry particle sites for P uptake in a discontinuous band while roots may proliferate in the band area of continuous bands (Eghball and Sander, 1989).

OBJECTIVE

The objective of this research was to evaluate the effect of different liquid P fertilizer droplet spacings in the P band on wheat yield and P uptake.

MATERIALS AND METHODS

Two experiments were established in the fall of 1987 on Sharpsburg and Crete sicl and two experiments were established in 1988 on Sharpsburg sicl and a Pawnee cl. All soils tested low in available P (less than 10 mg ha^{-1} B & K No. 1). Treatments in 1988 included four rates (7.5, 15.0, 22.5, 30.0 kg ha^{-1}) as ammonium polyphosphate (10-15-0, N-P-K), with three dilutions (0:0, 1:1, 2:1, water:10-15-0). In 1989 experiments included five P rates (5.0, 7.5, 10.0, 12.5, 15.0 kg ha^{-1}) with the same three dilutions of water and liquid fertilizer. Distribution of liquid P in the band is shown in Table 1. Fertilizer P was dual placed in 30 cm spacings in 1988 and placed with the seed in 30-cm rows in 1989. Fertilizer P was applied with a John Blue squeeze pump. Nitrogen was applied as ammonia in 1987 and topdressed in 1989 to provide a total of 90 kg N ha^{-1}. Brule wheat was seeded with a John Deere hoe drill in the fall of 1987 and 1988 at a rate of 90 kg ha^{-1}.

Table 1. Spacing between droplets of liquid 10-15-0 as influenced by P rate and dilution with water.

P Rate	Spacing between droplets 0:0[1]	1:1	2:1
kg P ha^{-1}	cm		
5.0	7.7[2]	3.3	1.8
7.5	4.8	1.8	0.9
10.0	3.3	1.1	0.4
12.5	2.4	0.6	0.1
15.0	1.8	0.4	Conti
22.5	.9	Conti	Conti
30.0	Conti	Conti	Conti

[1] Dilution ratio (water:10-15-0)
[2] Based on Eghball and Sander, 1987

At maturity, grain and straw was harvested from 2 rows, 3 meters long from each plot. Wheat bundles were air dried, weighed and threshed. Head counts were made by counting heads from 60-cm of row and seed counts/weight made from 10 randomly selected heads from each treatment. Root length measurements were made from soil samples taken with a 2.3-cm diameter open face soil sampling tube in 1988. Six cores were taken over a 14.4-cm distance directly over the fertilizer band (marked with flags at application time) at depths of 5-10, 10-15, and 15-20-cm at late heading. Roots were washed free of soil and length per unit volume of soil determined by the intercept method.

RESULTS AND DISCUSSION

1988 Wheat

Wheat yields were surprisingly good in 1988 considering the precipitation received. Both experiments in southeastern Nebraska received 40 to 50% below normal precipitation during the growing season. By early heading, soil was near the permanent wilting point to a depth of 60-cm at all three locations. In fact, surface soil was nearly air dry by flowering time. However, at late heading or at pollination both locations received about 10-cm of precipitation. This precipitation, coming at a very optimum time, resulted in yields of 3.5, and 3.9 Mg ha^{-1} on the Crete and Sharpsburg soils respectively (Table 2). Applied P significantly increased grain yields and head numbers on both soils and increased straw yields on the crete soil.

Table 2. Effect of P rate and dilution on grain yield and yield components on two soils in southeast NE. 1988.

Variable	Yield kg ha^{-1}	Heads/ha x 10^6	Seeds/ head	wt/100 seed gram	Straw yield Mg ha^{-1}
		Crete (eroded) sicl			
P Rate(kg P/ha)					
0	2082	1.94	31	3.1	3.61
7.5	3258	3.70	31	2.9	5.16
15.0	3375	3.21	32	3.3	5.01
22.5	3508	3.72	32	2.9	5.29
30.0	3638	4.22	34	2.9	5.51
Dilution[1]					
1	3441	3.71	31	3.1	5.19
2	3443	3.76	33	3.0	5.35
3	3449	3.66	32	3.1	5.18
		Sharpsburg (eroded) sicl			
P Rate (kg P/ha)					
0	3516	2.65	30	3.9	4.52
7.5	3678	2.80	32	4.0	5.10
15.0	3817	3.00	33	4.0	4.78
22.5	3871	3.08	32	4.0	4.75
30.0	3935	2.96	32	4.0	5.14
Dilution					
1	3874	2.90	33	4.1	5.04
2	3794	3.05	32	3.9	4.63
3	3808	2.93	31	4.1	5.11

[1] Dilution 1=0:0; 2=1:1; 3=2:1 (water:10-15-0 solution)

The effect of diluting the P fertilizer with water was visually apparent early in the growing season at both locations up to approximately the jointing stage of development. This increased growth resulted in dilution significantly increasing oven-dry weight, plant P concentration and P uptake at both locations (Table 3). Significant rate x dilution interactions indicated dilution increased plant dry weight up to the 22.5 kg P ha^{-1} applied P rate. Above the 22.5 kg P rate, all dilutions were continuous bands. Early plant concentrations tended to parallel early plant weight in response to dilution.

Table 3. Effects of P rate and dilution on early plant dry matter yield, P concentration and P uptake on Crete and Sharpsburg soils.[1]

Variable	Crete sicl O.D. Wt.	Crete sicl Conc.	Crete sicl P Uptake	Sharpsburg sicl O.D. Wt.	Sharpsburg sicl Conc.	Sharpsburg sicl P Uptake
	g	g kg^{-1}	mg	g	g kg^{-1}	mg
P rate, kg P/ha						
0	18.5	2.17	44	44.0	2.17	126
7.5	35.9	2.44	103	52.6	2.54	139
15.0	58.8	2.84	182	72.6	3.08	216
22.5	61.0	3.34	182	89.8	3.32	267
30.0	73.5	3.63	240	97.6	3.53	302
Dilution[1]						
1	53.2	2.63	145	71.6	2.88	226
2	58.2	2.96	177	77.6	3.04	230
3	60.5	3.61	208	80.7	3.42	236
			Analysis of Variance			
Rate (R)	0.01	0.01	0.01	0.05	0.01	0.01
Linear	0.01	0.01	0.01	0.01	0.01	0.01
Quad	0.01	ns	ns	ns	ns	ns
Dilution (D)	0.01	0.01	0.02	0.01	0.01	ns
1 vs. 2	0.01	0.01	0.15	0.09	ns	ns
1 vs. 3	0.01	0.01	0.01	0.01	0.01	ns
2 vs. 3	0.09	0.01	ns	0.10	0.01	ns
R*D	0.01	0.01	ns	0.01	0.07	0.01
R(Linear)*(1vs2)	0.01	0.01	ns	0.01	0.01	0.04
R(quad)*(1vs2)	0.01	ns	ns	ns	ns	ns
R(Linear)*(1vs3)	0.01	0.02	0.01	0.01	0.01	0.01
R(quad)*(1vs3)	0.05	ns	ns	ns	ns	ns
R(Linear)*(2vs3)	0.05	0.03	ns	0.01	0.01	0.01
R(quad)*(2vs3)	0.05	ns	ns	ns	ns	ns

[1] Dilution 1=0:0; 2=1:1; 3=2:1. Water: 10-34-0 fertilizer
[2] P uptake: mg/60 cm row

Root length in the fertilizer band area was significantly increased by applied P and there was a strong trend for dilution to increase root length in the 10-15-cm depth where the fertilizer band was placed (Table 4 and 5). There was essentially no effect of treatments at the 5-10-cm or 15-20-cm depths.

Table 4. Root length density on the Sharpsburg soil as affected by P rate and dilution.

Variable	5-10	Soil Depth 10-15	15-20
		cm^{-2}	
P rate, kg P/ha			
0	0.065	0.153	0.112
7.5	0.066	0.184	0.119
15.0	0.038	0.203	0.119
22.5	0.041	0.238	0.116
30.0	0.025	0.229	0.131
Dilution'			
1	0.047	0.198	0.117
2	0.047	0.223	0.128
3	0.034	0.221	0.119
		Analysis of Variance	
P Rate (R)	0.11	0.01	ns
Linear	0.03	0.01	ns
Quad	ns	ns	ns
Dilution (D)	ns	0.17	ns
1 vs. 2	ns	0.12	ns
1 vs. 3	ns	ns	ns
2 vs. 3	ns	ns	ns
R * D	ns	ns	ns

' 1=0:0; 2=1:1; 3=2:1: water:10-34-0 dilution.

1989 Wheat

Two additional locations were studied in 1989. Drought conditions existed again in the spring of 1989 with timely precipitation (near flowering) resulting in fair wheat yield (Table 6), especially on the Sharpsburg soil. While applied P had little effect on yield on the Sharpsburg soil, applied P significantly increased grain and total plant weight in the Pawnee soil. Dilution of liquid P fertilizer with water significantly increased grain yield and total plant weight on the Pawnee soil, while grain yield was significantly depressed with dilution on the Sharpsburg soil. Analysis for early plant weight and P content has not been completed, but no visual differences were present at any time. It is not known why dilution depressed yields on the Sharpsburg soil when other results appear to be positive. Another experiment was established on this soil for 1990 similar to the experiment in 1989.

Table 5. Root length density on the Crete soil as affected by P rate and dilution.

Variable	Soil Depth - cm 5-10	10-15	15-20
	------------- cm^{-2} -------------		
P rate, kg P/ha			
0	0.028	0.124	0.07
7.5	0.033	0.122	0.06
15.0	0.025	0.159	0.09
22.5	0.024	0.217	0.09
30.0	0.030	0.232	0.08
Dilution'			
1	0.028	0.167	0.08
2	0.028	0.185	0.09
3	0.029	0.199	0.08
	Analysis of Variance		
P Rate	0.09	0.01	ns
Linear	ns	0.01	ns
Quad	0.01	ns	ns
Dilution	ns	0.17	ns
1 vs. 2	ns	ns	ns
1 vs. 3	ns	0.06	ns
2 vs. 3	ns	ns	ns
Rate*dilution	ns	ns	ns

' 1=0:0; 2=1:1; 3=2:1; water:10-15-0 fertilizer

Table 6. Effect of rate of applied P and dilution on wheat grain yield and total plant weight. 1989.

Variable	Sharpsburg sicl Grain Yield	Sharpsburg sicl Total Plant Weight	Pawnee sic Grain Yield	Pawnee sic Total Plant Weight
		kg ha'		
P rate, kg ha'				
0	2619	6559	1186	3175
5.0	2704	6563	1402	3220
7.5	3031	7382	1694	3821
10.0	2846	7490	1656	3650
12.5	2800	6830	1847	4000
15.0	2830	7257	1978	4279
Dilution				
1	3111	7513	1541	3353
2	2853	6981	1882	4203
3	2561	6819	1723	3827
		Analysis of Variance		
P Rate (R)	NS	NS	.05	.07
Dilution (D)	.01	.17	.08	.02
R x D	NS	.10	NS	NS

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1. Diluting liquid P increases Efficiency
(Especially for Early Growth)

2. Continuous Bands effective
(if concentration is high Enough)

3. All Bands are not necessarily the same.

YIELD VARIABILITY AND THE YIELD GOAL DECISION[1]

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Wheat production in the Great Plains is typified by wide year-to-year variations in yield, largely due to climatic factors. These yield variations make it difficult for farmers to evaluate need for variable inputs for crops. Of particular concern is nitrogen (N) fertilizer, which is an input of great economic importance and is subject to yearly management decisions by the farmer. The purpose of this study was derive a method by which the degree of year-to-year yield variability can be included in setting nitrogen fertilization yield goals for spring wheat.

Two methods exist for setting fertilization yield goals for spring wheat. The first method requires the delay of fertilization until near seeding time. At this time the amount of stored soil water is estimated and a yield is projected based on a yield model based on expected growing season evapotranspiration. The second method is the traditional "yield goal" approach, where a farmer usually soil tests in the fall, and fertilizes in the fall using a projected yield based on his own experience.

The first method has the advantage of being able to adjust fertilizer rates if stored soil water levels at seeding are widely different than normal. However, there are three problems with this method:

1. The farmer must delay fertilization until shortly before seeding, which many spring wheat growers are reluctant to do.

2. The evapotranspiration-yield relationships used to drive these prediction models are based on small research plots on very good soils. Thus, the models typically over-predict actual whole-field yields.

3. Only one parameter of the growing season evapotranspiration (stored water at seeding) is known when the model must be employed. The growing season precipitation, run-off, water remaining at harvest, unusual heat stress events, poor distribution of rainfall, etc., is <u>not</u> known when the model must be employed. Thus, the use of ET-driven models is to establish fertilization yield goals is typically not any more accurate than a yield goal established by the experience of the grower.

The second method of establishing yield goals is the only one that can be employed when the farmer soil tests and fertilizes in the fall, as none of the factors in an ET-driven model can be known at the time the yield goal decision must be made.

[1]This paper is a brief summary of the paper: Prunty, Lyle, and R. J. Goos. Potential yield variability and economic nitrogen fertilization of spring wheat. West. J. Agric. Econ. (In review).

One factor that has not been studied with respect to the setting of fertilization yield goals is how year-to-year yield variability is incorporated into the making the yield goal. This may not be an important factor to an irrigated corn grower, where yields may vary less than 20% from year to year, but this should be a very important factor for dryland spring wheat growers in the Great Plains.

Examples of such yield variability are shown in Table 1. The data are from well-manicured variety trials at three sites in the Great Plains region of North Dakota. Wheat yields on recrop (continuous crop) or after summerfallow are shown. As would be expected by anyone who has worked in the Great Plains, the yields show typical wide variability. The variability is usually greater for continuously-cropped wheat, as also would be expected.

If you were a fertilizer dealer in an irrigated region, and you had a client whose corn yields varied from 125-150 bu/A over the past 10 years, it would not be difficult to set a yield goal. A yield goal of 140 bu/A could probably be economically and environmentally justified. But if you were a fertilizer dealer at Minot, ND, and your client had recrop wheat yields of 8-54 bu/A (Table 1), what yield goal would you suggest then?

We attempted to answer this question by mathmatically combining the NDSU fertilizer recommendation equation (a linear response and plateau function), with variable plateau yields. When you do this, you obtain a curvilinear function that can be used to estimate the most profitable long-term yield goal.

The mathmatics of this manipulation are documented in the paper cited. Our results agree pretty well with common sense. If a hypothetical field produces 35 bu/A wheat every year, without variability, then the most profitable yield goal is 35 bu/A. If another hypothetical field also has an average yield of 35 bu/A, but because of year-to-year variability the yield is sometimes higher or lower than the average, the most profitable long-term yield goal is somewhat higher than 35 bu/A. A field with an average yield of 35 bu/A but with wide swings in annual productivity above and below this level would have a most profitable yield goal considerably higher than 35 bu/A.

The summary of our findings is found in the right-hand column in Table 1. In all cases the most profitable yield goal is substantially higher than the average yield. A close approximation of our results is that the the yield goal should be one standard deviation above the average yield. In other words, a farmer's yield should reach his fertilization yield goal about 1 year in 6. If a farmer reaches his yield goal more often than that, he should consider increasing his goal. However, the common "MEY" practice of setting sky-high yield goals above previously-obtained yields can not be justified economically or environmentally.

We feel that this study is just a beginning point in the analysis of yield variability and the yield goal decision. Notable points excluded from our analysis are:

1. The value of residual nitrate in years of N overfertilization.
2. Protein premiums in years of N overfertilization.
3. The yield and test weight decline that is sometimes observed from N overfertilization. Certain diseases are also stimulated from N fertilization.
4. The ability of wheat to partially adjust for modest nitrogen limitations by filling grains with more starch and less protein. For example, fertilization for 35 bu/A wheat could lead to a 40 bu/A crop in a good year, but with lower grain protein.
5. Our analysis, as does every analysis of fertilization economics, assumes that the farmer has sufficient money (or credit) to fertilize up to the most profitable point. This assumption is often not realized in the real world.

Table 1. Variability of yields of spring wheat grown in two crop rotations, western ND, 1980-1988.

Site	Rotation	Average yield	Range	C. V.	MPYG+
		---------bu/A-------		%	bu/A
Dickinson					
	Recrop	18	0-39	74	32
	Fallow	38	8-55	40	54
Minot					
	Recrop	32	8-54	58	52
	Fallow	42	18-61	32	55
Williston					
	Recrop	20	1-41	69	35
	Fallow	26	6-60	58	42

Wheat variety was 'Len' at Minot and Williston, the variety was the current recommended variety at Dickinson. All common cultural practices (seeding rate, fertilizer, herbicide, seed treatment, etc.) were managed so as not to limit yields. Data courtesy of the Dickinson, Minot, and Williston Branch Stations.
+MPYG=most profitable yield goal, based upon our calculations and current wheat and N prices.

DRYLAND SYSTEMS: DOES INCREASING CROPPING INTENSITY INCREASE NUSE EFFICIENCY?

by

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The traditional cropping system used in the western Great Plains Region is wheat-fallow (WF) under stubble mulch cultivation. This system has been practiced for over 50 years. However, the conversion to no-till cropping systems would allow farmers to increase their cropping intensity (more years of crop and less years of fallow) because of increased storage of natural precipitation that occurs under the no-till system. Viable cropping systems are wheat-corn-fallow (WCF) or even wheat-corn-millet-fallow (WCMF). Little information is available on the N use efficiencies of these more intensively managed cropping systems. Since the net result of these more intensive cropping systems is that more N fertilizer will be applied over the same time period, information is needed to determine the long-term implications on potential groundwater pollution, even in this arid environment.

Long-term experiments were initiated in 1986 in eastern Colorado to determine the interactions of cropping systems, N fertilizer rates and N placements on N cycling in this dryland agroecosystem. This report summarizes our latest results on the effect of cropping system, N rate and N placement on fertilizer use efficiency.

MATERIALS AND METHODS

Studies were initiated in 1986 to determine the production potential of various cropping systems with the goal of maximizing water use efficiency. The dryland cropping systems used were: the traditional WF, and the more intensive cropping systems of WCF and WCMF. The experiments were located at three sites in a 16-inch rainfall zone in eastern Colorado, going from north to south. Associated with this north to south direction is an increase in evapotranspiration due to higher temperatures in the south in southern Colorado. Therefore, sorghum was substituted for corn in the rotation at the southern locations. Further details regarding experimental procedures have been outlined by Peterson et al., 1988 and Kitchen et al., 1988.

RESULTS AND DISCUSSION

The effect of cropping intensity on NO_3-N distribution after 4 years of production is shown in Figure 1. These data represent the cumulative effect of the various rotation systems that were initiated in 1985. It is very evident that as the intensity of cropping increases (more years of cropping and less years of fallow), the residual nitrate remaining in the profile decreases. For example, in the WF rotation, which only had two wheat crops during the 4-year period, showed considerably larger residual NO_3-N in 1989 as compared to the WCMF rotation which had three years of crop during the 4-year period. The amount of fertilizer applied to the various rotations was also considerably different (Table 1). The amount of fertilizer applied to the more intense WCMF rotation was 157 kg N/ha from 1985 to 1989 as contrasted to only 90 lbs N/A for the WF. Even with the larger amount of N applied, there was considerably less NO_3-N left in the soil at the end of this 4-year period. The profile distribution is somewhat different with the various cropping systems (Figure 1). There is essentially a linear decrease in residual NO_3-N in the profile from the 0-180 cm (6 ft) depth with the WCMF fallow while the WF fallow showed equal concentrations in the 120-150 and 150-180 cm depth, indicating the wheat crop is not utilizing the residual NO_3-N at these levels. This observation is substantiated by the profile distribution of water after wheat harvest in 1989 (Figure 2). The WCMF rotation had used considerably more water at the lower profile depths than did the WF rotation. This demonstrates that as farmers convert to no-till systems, they should consider increasing their cropping intensity in order to decrease the potential of NO_3-N leaching into the groundwater.

There is also a large difference in the 12-year projected total grain production and water use efficiency between the various cropping systems (Table 2). The 1988-89 grain production at these sites has been used to project total grain production for a twelve-year period with the three rotations. The WF rotation resulted in a total projected grain production of 13.9 mg/ha (12,400 lb/A) while the WCF resulted in 28.6 mg/ha (25,500 lb/A), and WCMF in 29.7 mg/ha (26,500 lb/A). It is very evident that increasing the cropping intensity also increases the total potential grain production under these dryland no-till production systems. Concomitant with the increase in grain production is increase in water use efficiency ranging from 2.9 kg grain/mm annual precipitation with the WF system to 6.2 with the WCMF cropping system (Table 2). This large increase in water use efficiency accompanied by a substantial increase in grain production demonstrates the economic benefits of increasing the cropping intensity under no-till management. These same advantages cannot be achieved under stubble mulch tillage because of the lower water storage use efficiency. The only sustainable cropping system under stubble mulch management is WF in the western Great Plains Region.

In a second study where N fertilizer use efficiency (NUE) is being studied using the WF and WCF fallow cropping systems, a 6% increase in NUE was observed with the WCF system as compared to the WF (Table 3). The NUE for the WCF fallow averaged 44% over the N rates evaluated, while the NUE for the WF averaged 38%. Fertilizer placement also had an effect on NUE (Table

4). The application of urea ammonium nitrate (UAN) preplant broadcast resulted in a 27% NUE when averaged across 11 crops over a 3-year period at two locations. The NUE for UAN either banded below the seed with some side dressing, banded below the seed with 70% dribbled over the seed, or urea granules broadcast resulted in NUE ranging from 32 to 35%. The urea material used in the study was TVA's lignosulfonate impregnated urea granules.

CONCLUSIONS

The results from studies conducted from 1986 to 1989 at three locations in eastern Colorado under no-till dryland cropping systems revealed that increasing the cropping intensity from the traditional WF rotation to more intensive systems, such as WCMF, increased the N use efficiency as well as decreased the amount of fertilizer N carryover in the soil profile. This decrease in N residual NO_3-N carryover resulted despite the fact that more fertilizer N is applied to the more intensive cropping systems as compared to the traditional WF rotations. When farmers convert to no-till production systems, they should increase their cropping intensity to decrease the potential negative environmental impact of movement of residual soil NO_3 into soil groundwater. Increasing the cropping intensity will also result in more total grain production, and associated with it, larger economic return.

Table 1. Amount of N fertilizer applied to wheat-fallow (WF), wheat-corn-fallow (WCF) and wheat-corn-millet-fallow (WCMF) systems between 1985 and 1989.

Cropping system	N fertilizer
	(kg/ha)
WF	67
WCF	150
WCMF	125

tillage | % water Storage
Plow
Fallow-Plow | 25%
WCF | 32%
WCMF | 44%
efficiency

Accompanying Poster Paper

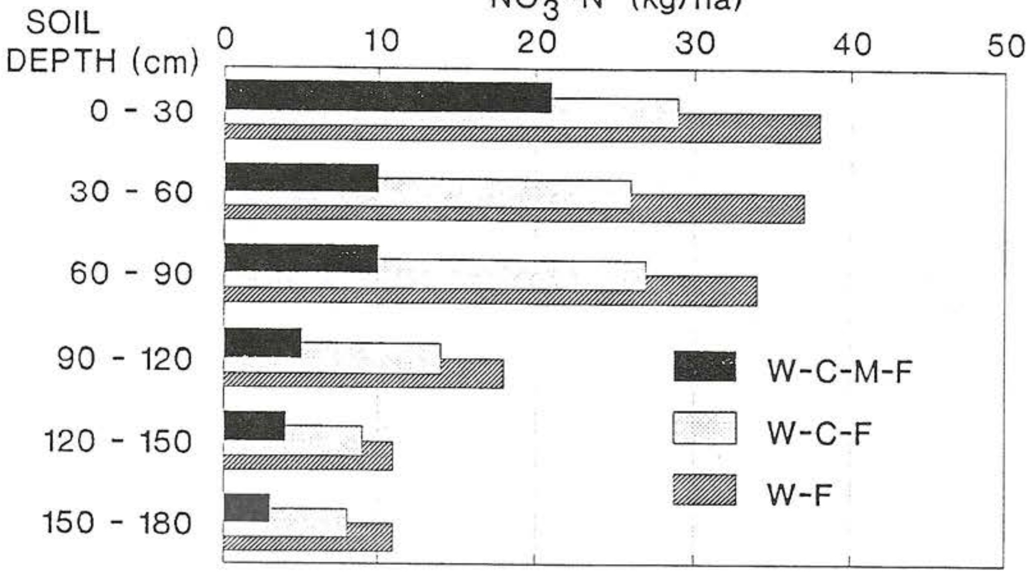

Figure 1. Residual soil NO_3-N levels at wheat planting under three cropping systems after 4 years of production

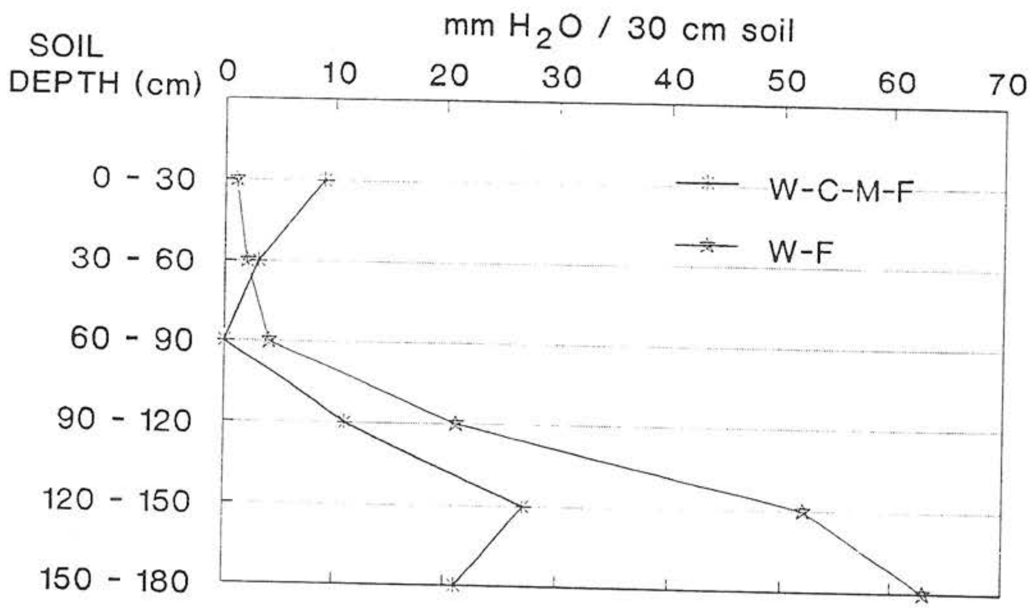

Figure 2. Plant available water at harvest in 1989 under two cropping systems after 4 years of no-till management.

Table 2. Projected total grain production and water use efficiency after 12 years of production from wheat-fallow (WF) wheat-corn-fallow (WCF) and wheat-corn-millet-fallow (WCMF) cropping systems.

Cropping system	Projected: 12 years				
	Grain production				Water use efficiency
	wheat	corn	millet	total	Kg grain/mm annual precipitation
	--- Yield (Mg/ha)[1/] ---				
WF	13.9	--	--	13.9	2.9
WCF	10.8	17.8	--	28.6	6.0
WCMF	8.3	13.9	7.5	29.7	6.2

1/ Mg/ha x 893 = lbs/A

Table 3. Nitrogen fertilizer use efficiency (NUE) for 3 years from a wheat-fallow (WF) and a wheat-corn-fallow (WCF) cropping system. ✓

Rotation system	N rate (kg/ha)			
	28(34)[1/]	56(67)	84(101)	Average
	NUE (%)			
WF	41	38	35	38
WCF	50	41	41	44

1/ N rates used for corn are in parentheses

Table 4. Nitrogen fertilizer use efficiency (NUE) of dryland wheat, corn and sorghum as influenced by fertilizer source and placement. (Average of 11 crops over 3 years at 2 locations).

Fertilizer placement method	NUE
	%
UAN pre-plant broadcast	27
UAN 30% banded below the seed & 70% side dressed	32
UAN 30% banded below the seed & 70% dribbled over the seed	35
Urea broadcast	34

Increasing cropping intensity decreases N left in the profile. Also decreases water left in the profile. figs 1+2.

Wf — 67 Kg N/HA
WCF — 150 " "
WCMF — 125 " "
] no fallow N Buildup

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OVERVIEW OF S RESEARCH AND APPLICATION IN THE GREAT PLAINS

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ABSTRACT

Sulphur deficiencies have been identified in the Great Plains with increasing frequency over the past 10-20 years. Likely reasons for this include increased use of S-free fertilizers, increased crop yields and thus S removal and decreased atmospheric sulphur dioxide levels. Many reports of S responses on several crops have been documented in the Great Plains. To date, a majority of the responses have occurred on coarse textured, low organic matter soils. The $SO_4^{=}$-S soil test is a useful tool in trying to assess S needs, but knowledge of other factors including soil organic matter content, soil texture, type of crop and yield potential and S content of irrigation water is critical to best evaluate fertilizer S needs. A continued active field S research effort in the Great Plains is necessary because of the factors mentioned above. Quality aspects of crop responses to S should be a part of this research.

INTRODUCTION

The importance of sulphur (S) and the important roles S plays in plant nutrition has been recognized for more than 200 years. Sulphur is essential for plant growth and is required in similar amounts to phosphorus. Sulphur is required for synthesis of certain proteins and enzymes and other functions in plants.

Sulphur deficiencies have now been reported in at least 72 countries, including the United States and Canada (Morris, 1987). In North America alone, S deficiencies have been documented in 42 states-- up from only 13 states in 1962. Every province in Canada, from Ontario west, has now reported crop responses to S fertilization.

The rapidly increasing occurrence of S deficiencies can be explained by the following:

1. Use of high-analysis fertilizers that contain little or no S.
2. Higher yielding crops and cropping sequences that remove more S from the soil.
3. Reduced industrial emissions of S and decreased use of high-sulphur fuels.
4. Decreased use of S in pesticides.
5. Declining levels of soil S and crop production on soils with low inherent S status.
6. Increased use of crop residues either for feed or fuel which has increased S removal from soil.

All of these facts certainly have had an impact on the increased reports of S deficiencies, but the most important one is the increased production and consumption of S-free, high analysis fertilizers. In the past, the predominant P fertilizer consumed was single superphosphate (12% S). Currently, nearly all P fertilizers (TSP, MAP, DAP, APP) produced and consumed contain little or no S. Another important factor is the change in N fertilizer consumption. Although the use of ammonium sulphate (24% S) has remained steady over the past 10-12 years worldwide, its percentage as a share of total N consumption has declined because total N application has more than doubled during the same time period.

While visual symptoms of S deficiency are not always dramatic, crop responses to S fertilization can be of great economic importance to the grower. Yield responses vary from as little as 5-10% where S deficiency is marginal to over 1000% in cases of severe deficiency. Increased crop and forage yields are the most obvious beneficial result of S fertilization, but effects on crop or forage quality can be equally important--or in certain cases even more important.

The need for fertilizer S is hard to determine and depends on many factors including soil S levels; S contribution from rainfall, irrigation water, crop residues and organic matter; type and yield of crop grown; and potential S loss through leaching. Soil properties are helpful in predicting the need for fertilizer S. Sulphur deficient soils are usually low in organic matter, course textured and well drained, however, deficiencies are not limited to such soils.

OBJECTIVES

The objectives of this paper are to: 1) review results from field evaluations of S fertilization in the Great Plains, 2) discuss how S needs are being assessed and 3) discuss future S research needs.

RESULTS AND DISCUSSION

Field S Studies

Most, if not all, of the states and provinces in the Great Plains have conducted field studies involving S fertilization on many different crops. A representative number of these trials will be reviewed beginning with the southern Plains states and progressing northward.

Numerous responses to S fertilization have been reported in the southern Plains states. In Texas, cotton was one crop responding to S with yield increases ranging from 14 to 20% (Sunderman, et.al., 1969). Responses have also been documented on forage grasses, corn, grain sorghum and sugar beets. Although only a few cases of crop response to S fertilization have been reported in New Mexico and Oklahoma, both states have considerable acreage of coarse textured soils. In Oklahoma, over 30% of the total land area is coarse textured soils, while in New Mexico, approximately 20% of available cropland is coarse textured.

Moving north, a great deal of S research has been conducted over the past several years in Colorado, Kansas and Nebraska. Some of this research is summarized in Table 1.

Table 1. Summary of S research in Colorado, Kansas and Nebraska

State	Crop	No. of Tests	Crop yield, bu/a or Hay yield, lb/a Without S	With S	% Increase	Reference
Colorado	Wheat	7	49.0	50.5	3.1	Follett, et.al., 1988
	Wheat	7	42.0	42.0	0.0	Follett, et.al., 1989
	Corn	4	161.0	150.0	---	Henson, et.al., 1984
	Hay	1	7200	7800	8.3	Follett, et.al., 1989
Kansas	Wheat	12	41.0	44.0	7.3	Lamond, et.al., 1985-89
	Wheat	9	51.0	53.0	3.8	Lamond, et.al., 1985-89
	Bromegrass	5	4520	4870	7.7	Lamond, et.al., 1985-89
Nebraska	Corn	4	159.0	168.0	5.7	Rehm, 1984
	Corn	2	104.0	107.0	2.9	Rehm, 1980
	Native Meadow	2	5720	6140	7.3	Hergert, et.al., 1983

In Kansas and Nebraska, much of the work where significant yield increases occurred was done on coarse textured soils. In Colorado, where most research locations were fine textured, and on Nebraska and Kansas fine textured sites, responses have been much smaller and inconsistent. For example, in Colorado, only 3 of 24 sites showed a significant S response with dryland wheat as a test crop (Follett, et.al., 1989). Since S responses have been consistent on coarse textured soils, however, the potential need for S is substantial. Nebraska and Kansas have fairly large acreages of coarse textured soils under cultivation.

Progressing northward in the Great Plains, S responses become more isolated. Only a few instances of S deficiency have been recorded in South Dakota and these occurred on coarse textured soils. Recent work at 7 sites indicated S fertilization had no effect on wheat grain yields or protein levels (Gerwing and Gelderman, 1987). None of the seven sites had coarse textured soils. Sulphur deficiencies in North Dakota are even more rare. One reason S responses are difficult to find is because many soils have layers of gypsum within a few feet of the surface. Crested wheatgrass has responded to S, however, with forage yield increases of nearly 2000 lb/a (Dahnke, 1989). Isolated instances of S response have been recorded in Wyoming, though a considerable acreage of coarse textured soils exist.

Responses to S in Montana have been found mainly in the western one-third of the state, and this region doesn't have large acreages of cultivated land. Recent work, however, indicated a significant yield increase of orchardgrass to S fertilization (Gavlak, 1982). Maximum yields were obtained with 30 lb S/a. Montana does not have large acreages of coarse textured soils, but there are scattered areas in central and eastern Montana.

Responses to S fertilization in Canada have been observed for many years, being first reported in Alberta in 1927. Since then, responses have been reported in all provinces as far east as Ontario, though most responses have been in the prairie provinces and British Columbia. A summary of S responses in Canada (Beaton, et.al., 1971) is shown in Table 2.

Table 2. Sulphur responses in Canada.

			Crop Yield, lb/a		
Province	Crop	No. of Tests	Without S	With S	% Increase
British Columbia	Alfalfa	15	4019	5009	42
	Rapeseed	1	90	1097	1119
Alberta	Alfalfa	5	1055	1944	84
	Oats	4	1832	2775	51
	Wheat	1	1116	1425	28
Saskatchewan	Alfalfa	9	1043	2220	113
	Oats	4	1480	1790	21
	Wheat	5	1656	2098	27
	Rapeseed	2	955	1184	24
Manitoba	Rapeseed	3	1454	1832	26
	Alfalfa-Grass Hay	4	3055	3992	31

Assessing Sulphur Needs

In reviewing the literature and visiting with colleagues about this paper, one very common thread emerged. There is near universal agreement that trying to determine S needs is a very complicated task. For each specific case, S needs are affected by: type and yield of crop (crop need for S), S status of the soil, soil texture, soil organic matter, and S contribution of irrigation and/or rain water.

Individual crop yields and total production per acre per year (intensive cropping sequences) continue to increase. As yields and overall production go up, S needs increase. In addition, crop and forage quality concerns are of increasing importance and S can be a factor in quality. These factors all contribute to an increased need for S and, as a group, total the amount of S needed for a given situation.

The other side of the equation is the potential for the soil system to provide needed S. Soil organic matter can supply S so organic matter content is important. Since sulphate-sulphur ($SO_4^{=}$-S) is leachable, soil texture is also important. Sandy, low organic matter soils are prime candidates for S deficiency because of low S supplying power and the potential for leaching.

Soil $SO_4^{=}$-S levels are also important. Most university and private soil testing laboratories in the Great Plains provide an $SO_4^{=}$-S soil test. Though this test is useful, many soil fertility specialists agree that this test alone is not a good consistent predictor of S response. However, soil $SO_4^{=}$-S levels coupled with soil organic matter content, soil texture and potential S contribution from irrigation and/or rain water provide a good basis for predicting S fertilizer needs for most crops. There is general agreement that determining soil $SO_4^{=}$-S concentrations to a depth of at least two feet is necessary since $SO_4^{=}$-S is mobile. When soil $SO_4^{=}$-S levels are high, there is little chance of an S response, and when levels are very low there is a good probability for response. The marginal $SO_4^{=}$-S levels require the additional factors be considered to most accurately predict S needs.

In irrigated areas, it is critical to know the S levels of the water. In many cases, depending on how much irrigation water is applied, significant amounts of S will be furnished to the crops.

Plant tissue S concentrations and N:S ratios can also be used to evaluate S needs. Use of these tools in evaluating S status of a crop can be limited by variable field conditions. The N:S ratio, particularly, has limitations because: 1) the ratio has been shown to be quite variable with adequate S nutrition, and 2) examination of current data indicates a poor correlation between the ratio and yield. In addition, little data exists for many crops and growing conditions as to what is an acceptable ratio.

If fertilizer sulfur is needed, several good sources are available. Ammonium sulphate and ammonium thiosulfate are good S sources which also provide some nitrogen. Gypsum, several sources of mixed materials containing S and several forms of elemental S are also available and have proven to be effective S sources.

Future S Research Needs

A continued active field research program to assess S needs of crops in the Great Plains is warranted. With the continued use of essentially sulphur-free high analysis fertilizer materials, higher crops yields and increased cropping intensity, and decreased atmospheric sulphur dioxide levels; sulphur research should remain a priority.

Many of the documented S responses have occurred on sandy low organic matter soils. With the increased importance of the factors listed above, more work should be initiated on finer textured soils (silt loams and silty clay loams).

To date, most crop responses to S have been reported as increased yield or dry matter production. In the future, more emphasis should be placed on quality aspects of S nutrition. Since sulphur is an essential component of the amino acids methionine, cystine and cysteine; its importance in the nutritional quality of food and feed for humans and animals should not be overlooked.

Finally, work should be continued with the correlation of $SO_4^{=}$-S soil tests and crop response. Identification of and further refinement of other associated factors should also be continued. In short, the evolution through research of an effective and efficient means of accurately predicting S needs for all crops is important. Special emphasis should be placed on so-called alternative crops where they may be important. Canola, for example, appears to have a high S requirement and interest in this crop in the Central Great Plains is rapidly increasing with little S research information available. Further investigation and refinement of "critical" crop tissue S levels and N:S ratios is warranted.

ACKNOWLEDGEMENT

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17. Synchrony and contribution of legume nitrogen for grain production under different tillage systems. J. L. Havlin, C. W. Rice, and J. P. Shroyer.

Numerous other soil fertility projects are ongoing at the Kansas Agricultural Experiment Station Branch locations and at Agronomy Fields.

SUNFLOWER YIELDS AS AFFECTED BY CONSERVATION TILLAGE SYSTEMS AND N-FERTILIZATION

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ABSTRACT

Conservation tillage (minimum-till or no-till) crop production systems for sunflower are needed for the northern Great Plains to provide adequate soil erosion protection. An undercutter- (32-inch sweeps) or no-tillage system for sunflower production in a spring wheat-winter wheat-sunflower rotation has been developed to provide 40 to 80% crop residue cover following sunflower planting. In 1988 and 1989, when growing season precipitation was less than 7.6 inches, minimum-till and no-till produced 220 and 460 lb/ac more sunflower, respectively, than conventional-till with 30 or 60 lbs N/ac applied. In 1985, 1986, and 1987 minimum-till and no-till produced sunflower yields equal to conventional-till of 2110, 2120, and 2200 lb/ac with 90 lb N/ac when growing season precipitation was greater than 10.7 inches. Annual applications of 90 lb N/ac increased sunflower seed yields 200 to 300 lb/ac compared to the 30 lb N/ac rate in 1985, 1986, 1987, and 1988 independent of tillage system. In 1989 sunflower seed yields were significantly lower for the 90 lb N/ac treatment than with 30 or 60 lb N/ac for the conventional- and minimum-till treatments but not for the no-till treatment. Sunflower yields were improved with minimum- and no-tillage systems compared to conventional till with proper N-fertilization and simultaneously provided sufficient crop residue cover to protect the soil resource.

PROBLEM AND OBJECTIVE

Conservation tillage (minimum-till or no-till) crop production systems for sunflower are needed for the northern Great Plains. In the United States, the 1985 Food Security Act prompted renewed interest in conservation tillage systems that would significantly reduce soil loss by erosion compared to conventional (bare soil) tillage systems. Sunflower acreages have declined about 50% in recent years in the northern Great Plains for reasons such as low market value, pest problems, and changes in crop acreage allotments. Another contributing factor to the decline is that conventional (clean-till) sunflower production practices in a crop rotation do not provide adequate soil protection to meet the requirements of the new legislative mandate. The sunflower oilseed industry may be in jeopardy if conservation tillage systems cannot be developed that afford adequate soil erosion protection.

The objective of our study was to show the feasibility of using minimum-till and no-till production systems for sunflower production in a 3-year rotation of spring wheat-winter wheat-sunflower.

MATERIALS AND METHODS

A conservation tillage-cropping systems field research project has been conducted since 1984 on a 63-acre site on a Williams loam soil at the USDA-ARS and Area IV SCD Research Farm about 2 miles southwest of the Northern Great Plains Research Laboratory at Mandan, ND. The experimental variables in three replications are all combinations of (1) two cropping sequences; spring wheat-fallow and spring wheat-winter wheat-sunflowers (main blocks 540 by 250 feet), (2) three conservation tillage treatments; conventional-, minimum- and no-tillage, (main plots 150 by 240 feet), (3) three fertilizer N rates; 0, 20 and 40 pounds N/ac for crop-fallow and 30, 60, and 90 pounds N/ac for continuous cropping, (subplots 150 by 80 feet) and two varieties of each crop grown, (sub-subplots 75 by 80 feet). We now have five years of crop yield data for each crop in the rotations. Only the sunflower yield results will be reported at this conference.

Our conservation tillage systems are defined in terms of target crop residue levels at planting. With winter wheat preceding sunflowers, the target residue levels at planting are as follows: conventional-till, 30% or less crop residue on the soil surface; minimum-till, 30 to 60% residue cover; and no-till, 60% or greater residue cover. Our combines are equipped with both straw and chaff spreaders to distribute straw and chaff materials uniformly over the the width of the header.

In our rotation, fall weed control on the winter wheat stubble (or spring wheat in years when winterkill occurred in 1985 and 1989 in minimum-till and conventional-till plots) is accomplished with Roundup[1] (with or without 2,4D ester). The stubble is left standing overwinter in all tillage treatments to trap snow and enhance soil water storage from snowmelt.

Tillage and N treatments were initiated in 1984. All crops were in the proper sequence beginning with the 1985 crop season. Soil samples have been collected by 1-foot increments to a depth of 6-feet just prior to planting and after harvest for soil water and nitrate-nitrogen determinations (data not analyzed). N-fertilizer was broadcast applied at the designated rates of 30, 60 or 90 lb N/ac in April each year prior to initial tillage or planting operations using ammonium nitrate as the source.

In the spring, the tillage treatments preceding sunflower seeding operations for each tillage system are as follows: (1) The conventional tillage treatment consists of using the Haybuster undercutter (32-inch sweeps) with a granular applicator mounted on the front to apply Treflan TR-10 granules (1.0 lbs ai/ac initially, but reduced to 0.9 lbs ai/ac in 1989 because of residual carryover due to the 1988 summer drought) and to accomplish the first incorporation in mid-April each year. This is followed by a tandem disk operation about May 15

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[1]Mention of any product trademark in this paper does not imply endorsement of the product by the USDA, Agricultural Research Service.

just before planting the sunflowers. (2) The minimum-tillage treatment consists of using the Haybuster undercutter with granular application for applying Treflan TR-10 granules in mid-April each year for the first operation. The second incorporation for minimum-tillage consists of using the Haybuster undercutter about May 15 and avoiding the same tillage pattern of the first undercutting. It is critically important that the depth of undercutting (tillage) be kept as shallow as possible (about a 2-inch depth) and that the period between the time of application-first tillage and the second tillage incorporation be about three weeks apart to enhance TR-10 granule activity on weed control. (3) The no-tillage treatment consisted of a fall-spray application (late-October) of Surflan at a rate of 1.25 lbs ai/ac and a spring burndown spray application using Roundup herbicides just before seeding.

In all years, sunflowers were planted May 15-23 using the 800 IHC Cylo-Seeder, no-till, 4-row unit planter (36-inch row spacing) for all three tillage systems. This planting unit is a precision planting unit capable of cutting through large quantities of surface residues (3000 lbs/ac) and establishing uniform plant populations across tillage treatments. Sunflower populations have varied from 19,000 to 21,000 plants/acre depending on the year, from a potential plant population (planting rate) of 23,000 seeds/acre. In no year has there been a significant difference in population among tillage treatments. We applied Furadan insecticide at 0.5 lbs ai/ac in the sunflower row to assist insect control in 1984, 1986, 1987 and 1988 but not in 1989. Some stem weevil damage occurred in 1989, particularly with the earliest maturing variety, but none occurred in the other four years. The two varieties of sunflower planted each year represent early- and medium-maturity classes (AgriPro No. 2057 or No. 4000).

RESULTS AND DISCUSSION

Growing season precipitation (May through Sept.) for the years 1985, 1986, 1987, 1988, and 1989 was 10.4, 14.4, 15.0, 7.6 and 6.3 inches, respectively, compared to the long-term average (1941-1989) of 11.5 inches.

Seed yields of sunflower were significantly influenced by tillage system and by rate of N applied each year but there was no marked difference in seed yields between the early- and medium-class maturity varieties. Therefore, only seed yields for the early-maturity class variety (AgriPro 2057) are shown in Table 1 for the 5-year period.

Application of 90 lb N/ac increased sunflower seed yields (averaged across all tillage systems), about 200 lb/ac each year compared to the 30 lbs N/ac treatment, except for 1986 and 1989. In 1986, seed yields for the 30 and 60 N rates were 100 to 300 lbs/ac lower for the no-till treatment than conventional-till. This suggests that some tie-up of N occurred in the third year in the no-till system. However, with 90 lbs N/ac, seed yields were the same across all tillage treatments in 1986. In 1989, total available N from N applied in 1988 when the spring wheat crop failed plus 90 lb N/ac applied again in 1989 was too high causing a marked decrease in sunflower yields in conventional- and minimum-till systems but not with no-till.

Table 1. Seed Yields of the Early-Maturity Class Sunflower Variety as Influenced by Tillage System and Rate of N Applied.

Year	N applied	Sunflower Seed Yields			
		Conv. Till	Min. Till	No-Till	Avg (N-rates)
	lb N/ac	---------- lbs/ac ----------			
1985	30	1950	2050	2060	2020
	60	2110	2250	2130	2160
	90	2230	2260	2370	2290
	Avg (tillage)	2100	2190	2190	2160
1986	30	1760	1670	1480	1640
	60	1840	2020	1720	1860
	90	2080	2100	2120	2100
	Avg (tillage)	1890	1930	1770	1860
1987	30	1760	1920	1740	1810
	60	1960	1980	2130	1960
	90	2020	2000	2100	2040
	Avg (tillage)	1910	1970	1850	1960
1988	30	710	820	790	770
	60	840	940	900	890
	90	830	1040	1050	970
	Avg (tillage)	790	930	910	880
1989	30	390	780	660	610
	60	360	840	600	600
	90	210	450	750	470
	Avg (tillage)	320	680	670	560

Tillage treatments significantly influenced seed yields in the two drought years 1988 and 1989, wherein the no-till and minimum-till treatments produced about 200-300 lbs/ac more seed than conventional-till, with 60 or 90 lb N/ac applied annually. In the years 1985, 1986, and 1987 when available water supplies were good, seed yields for the 90 lb/ac N-rate averaged 2110, 2120, and 2200 for the conventional-, minimum- and no-tillage systems, respectively. Therefore, minimum- and no-tillage systems, produced sunflower yields equal to, or greater than conventional tillage systems over a 5-year period. As importantly, the minimum- and no-till systems provided 40 to 80% crop residue cover (mainly winter wheat stubble) to provide soil protection and control soil erosion.

RECENT DEVELOPMENTS

We were hoping that Surflan would be labeled for sunflowers in addition to soybeans for fall use in no-till systems. The manufacturer has notified dealers that Surflan will not be re-registered for use on soybeans, so there will be little chance of ever having Surflan registered for use in no-till sunflower production system as defined in this study. Therefore we are investigating the use of Sonalan G-10 granules as a potential alternative to Surflan for the no-till system.

The herbicide industry will be manufacturing Sonalan granules (10% active ingredient) in 1990 and we are working with them in the development of a label for both Treflan, TR-10, and Sonalan, G-10 granules specifically for conservation tillage-sunflower production systems. In 1989, we conducted an experiment comparing the effectiveness of Treflan TR-10 granules with Sonalan G-10 granules in a minimum-till systems at several rates ranging from 0.6 to 1.2 lbs ai/ac. Both herbicides adequately controlled weeds at a rate of 0.8 lbs ai/ac or higher. We have initiated additional studies involving time of application (fall or spring) and method of incorporation (no fall incorporation, one undercut in fall, one undercut in fall plus one undercut in spring versus spring application with undercut-undercut system) for both Treflan and Sonalan granules applied at comparable rates.

ADDITIONAL SOIL FERTILITY RESEARCH
USDA-ARS, NORTHERN GREAT PLAINS RESEARCH LABORATORY

Title: Optimizing no-till winter wheat production systems.

Objective: Determine leaf-spot disease levels of winter wheat seeded no-till into standing spring wheat or spring barley stubble as affected by N-fertilization (0, 30, 50, 70, 90, or 120 lb N/ac) and cultivar. Investigators: Joe Krupinsky and A. L. Black

Title: Root development comparisons between spring and winter wheat in no-till cropping systems.

Objective: Determine root density and length using rhizotron-video imagery by plant development stages, water use patterns and grain yields as affected by available-N levels of 50,100, and 150 lb N/ac. (Available-N is the sum of residual soil nitrate-nitrogen plus N-fertilizer added.) Investigators: Steve Merrill, Armand Bauer and A. L. Black

Title: Conservation tillage-cropping systems for efficient water use.

Objective: Determine effect of crop rotation (spring wheat-fallow and spring wheat-winter wheat-sunflower) and tillage systems (conventional-, minimum- and no-till) on crop water- and nitrogen-use efficiencies at three N-fertilizer levels. Investigators: A. L. Black and Armand Bauer

Title: N-fertilizer management of spring wheat based on plant development stage.

Objective: Determine optimum amount and time of N-fertilization using granular and/or foliar N sources based on plant development stage to enhance grain yields, quality (protein) and N-use efficiency. Investigators: Armand Bauer and A. L. Black

WINTER WHEAT RESPONSE TO SIMULATED GROWING SEASON PRECIPITATION AND N APPLICATION

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ABSTRACT

Available water, growing season precipitation (GSP) plus stored soil water, is the principal factor which determines winter wheat yield potential and response to fertilizer N in the Northern Great Plains. Field studies were conducted in south central Montana to determine the interactive effect of GSP and fertilizer N on grain yield of two winter wheat cultivars. The two cultivars tested, 'Redwin' and 'Centurk', were characterized by high and low grain protein, respectively. Results indicated that yield potential, response to water, and response to fertilizer N were much greater in 1987 than 1988. A significant yield reduction occurred at high fertilizer N rates in 1988, but not in 1987. It was believed the large differential in grain-fill air temperatures, 8.5 ^{O}F cooler in 1987 than 1988, was the principle seasonal factor that caused the response to water and N to differ. Cultivar selection affected yield potential and the response to each incremental unit of fertilizer N. Under most GSP and N conditions Centurk yielded more than Redwin. Centurk, the lower protein cultivar, required less N and water to achieve each incremental increase in grain yield than Redwin. Grain protein concentrations were higher in 1988 than 1987. The extreme heat in 1988, which shortened the duration of grain-filling, apparently affected carbohydrate translocation to the kernel more than protein.

INTRODUCTION

Winter wheat (Triticum aestivum L.) in the Northern Great Plains of the United States is grown on approximately 5.0 million acres of land (Black, 1983). In this predominantly semi-arid region available water, stored soil water and growing season precipitation (GSP), greatly affects winter wheat yield potential (Jackson and Sims, 1977) and response to fertilizer (Jackson et al., 1983). Over several growing seasons wheat producers typically face a wide range of water conditions because of variable rainfall patterns, tillage operations, residue management, and crop rotations. Nitrogen fertilizer often represents the largest cost input by wheat producers. Thus, an understanding of the interactive effects of available water and N on grain yield is important for economical wheat production. The effect of several levels of N and simulated GSP on grain yield and protein of two winter wheat cultivars, are summarized in this report. The two winter wheat cultivars tested, 'Redwin' and 'Centurk', are characterized by high and low grain protein, respectively.

MATERIALS AND METHODS

Field experiments were conducted on a Yegen sandy loam in south central Montana during 1986-87 and 1987-88, or the 1987 and 1988 seasons, respectively. A line-source sprinkler irrigation system (Hanks et al., 1976) was used to establish five water levels of increasing drought (WL5, WL4, WL3, WL2, and WL1) delineated by distances 0-13′, 13-26′, 26-39′, 39-52′, and 52-65′ (dryland) away from the sprinkler line. Water application was done at a rates that insured a minimum of water stress within WL5. Irrigation was applied when soil water readings indicated a deficit of approximately 1.5-2.0" of plant available water in the soil profile (0-24" depth). The application rate was sufficient to return the soil profile to field capacity within WL5.

Stripped at right angles to the line-source were 14 treatments consisting of seven fertilizer N rates (0, 40, 80, 120, 160, 200, and 240 lbs N/a) and two cultivars of winter wheat (Redwin and Centurk) in complete factorial arrangement. The cultivar and N rate factors were arranged within each water level as a split-plot design, with cultivar and N rates being the main-plots and sub-plots, respectively. Treatments were replicated four and five times in 1987 and 1988, respectively.

Seeding dates were 16 October, 1986 and 27 September, 1987. Both cultivars were seeded at 90 lbs/a in 12" rows oriented, perpendicular to the sprinkler line using plots 6-rows or 6′ wide. Nitrogen was banded at seeding approximately 5" deep using liquid urea-ammonium nitrate (32-0-0) in 1987 and aqua ammonia (20-0-0) in 1988. Mean water application rates across each water level plus precipitation received between April 1 (the approximate beginning of spring regrowth) and the hard dough were considered GSP. Stored soil water use was not considered in the GSP totals, but was estimated to be estimates, 6.3" in 1987 and 6.5" in 1988.

RESULTS AND DISCUSSION

Differences in air temperature between two seasons had a profound effect on wheat development rate (Table 1). Wheat experienced extreme heat during grain-filling (anthesis to maturity) in 1988. Air temperature during grain-filling were 8.5 ^{o}F higher in 1988 than 1987. This had a profound effect on the duration of the grain-fill period. In 1987 the grain-fill period lasted 46 days, while in 1988 it was only 32 days. This 14-day difference was consistent with reports by Wiegrand and Cuellar (1981) of a 3.1-day reduction in grain-filling per 1.8 ^{o} F rise in mean daily air temperature.

The yield response to N fertilization across the five WLs and maximum yields at WL5 (minimum water stress) were greater in 1987 than 1988 (Table 2). The larger response to fertilizer N in 1987 was in part a result of the lower indigenous soil NO_3-N levels. Chemical analyses of the 0-12", 12-24", and 24-48" depths revealed a NO_3-N level of 3.1, 0.9, and 1.3 ppm or 27 lbs N/a in 1987; and 5.6, 3.4, and 3.9 ppm or 67 lbs N/a in 1988. The extreme heat during grain-filling in 1988 may have also reduced the yield response to N. Low grain kernel weights and increased floret sterility are two results of heat stress in wheat. This was the principle reason for the lower maximum yields and response to water in 1988 than 1987.

Significant ($P< 0.05$) yield depressions from high levels of available N occurred in 1988, but not 1987. In 1988 the depression from high N fertility was apparent in both cultivars across all WLs. In relative terms the size of this yield depression became greater as GSP decreased. Excessive water use early in the season did not appear to be the cause of this yield depression. Soil water content and depletion rates (data not presented) were affected by N fertilizer only within WL5. Foliar and root diseases, did not appear to be a factor in this study, and lodging occurred only in one cultivar, Centurk, at WL4 and WL5. The results suggest high levels of fertilizer N had a negative effect on plant metabolism. This N-induced yield depression may be related to the heat stress that occurred in 1988.

Comparison of the two cultivars indicated that over most GSP and N application levels Centurk out yielded Redwin. Only under WL1 and the 0 N rate in 1987 did the yield of Redwin compare favorably with Centurk. In general, the yield differential between the two cultivars became larger as GSP and N increased up to the point where Centurk began to lodge. This effect was most evident in 1987. Apparently Centurk, with its low grain protein, required less fertilizer N and water to achieve each incremental increase in grain yield than Redwin, the high grain protein cultivar.

Grain protein concentrations in 1988 were generally higher than in 1987. The extreme heat in 1988, which shortened the duration of grain-filling, apparently affected carbohydrate translocation to the kernel more than protein. As anticipated grain protein concentrations of Redwin exceeded Centurk. The differences were generally greater in 1987 than 1988. Fertilizer N increased grain protein in most instances. The only exception to this was during 1987. In 1987 application of the first 40 lbs N/a resulted in a reduction in grain protein concentration over the 0 N control at WL3-WL5.

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Table 1. Summary of mean air-temperature data over several stages of winter wheat development during 1987 and 1988.

Growth stage (GS+)	Date (end of GS)		Mean Temperature over GS					
	1987	1988	1987			1988		
			Max.	Min.	Avg.	Max.	Min.	Avg.
			°F					
April 1-L.tiller	1 May	27 April	71.6	32.0	51.8	62.8	30.2	46.5
L.tiller-Boot	16 May	16 May	81.5	42.6	62.1	69.1	38.5	53.8
Boot-Flower	5 June	2 June	70.9	44.2	57.6	78.1	47.3	62.7
Flower-Maturity	21 July	4 July	79.5	50.5	65.0	91.9	55.0	73.5

+ Interpretation of growth stages by the Feekes scales (Large, 1954) are as follows: Late tiller = 5; boot= 9-10; flower = 10.5.1-10.5.3; maturity = 11.3.

Table 2. Effect of fertilizer N (FN) on grain yield of two winter wheat cultivars (C) at several levels of growing season precipitation (GSP). 1987 and 1988.

FN	Water level & GSP									
	1987					1988				
	WL1 4.3"	WL2 5.7"	WL3 8.5"	WL4 11.5"	WL5 14.3"	WL1 3.9"	WL2 5.7"	WL3 9.4"	WL4 12.6"	WL5 15.9"
lbs/a	Centurk, bu/a									
0	19.5+	19.7	23.3	24.3	26.1	35.1	38.8	52.7	61.5	58.6
40	33.3	39.2	47.0	58.6	60.9	35.8	42.4	58.5	70.1	72.3
80	35.6	43.2	65.4	79.2	86.1	33.2	39.4	60.0	71.3	71.5
120	37.7	44.8	66.2	85.0	90.3	29.3	37.4	57.9	69.5	67.9
160	38.1	47.4	67.8	85.1	94.3	27.5	37.4	58.3	68.2	66.2
200	37.6	47.7	68.0	87.8	94.5	26.2	33.5	52.8	64.2	66.8
240	38.0	46.5	68.4	81.1	93.0	25.6	33.3	52.5	61.7	62.6
LSD (.05)	4.2	4.2	5.1	7.2	4.7	3.0	4.2	6.2	6.7	8.9
lbs/a	Redwin, bu/a									
0	20.2	21.8	21.9	22.5	23.2	32.2	35.3	46.0	48.1	49.9
40	34.2	39.1	47.5	50.1	51.7	31.3	39.9	51.3	58.4	58.9
80	35.4	41.8	56.6	63.8	71.5	28.6	35.9	51.1	60.7	63.3
120	35.6	44.2	63.8	73.2	79.1	25.4	32.9	46.9	59.6	62.1
160	34.9	42.5	56.8	76.6	83.1	24.3	31.7	43.5	56.0	57.2
200	36.6	44.5	62.8	79.6	86.2	21.6	28.4	41.0	53.4	56.2
240	37.6	44.4	59.9	73.7	90.7	16.8	30.2	39.7	53.0	53.6
LSD	4.5	3.3	4.5	6.4	6.3	3.7	3.7	4.7	5.6	5.0
Source	Probability > F									
C	.34	.04	***	***	***	.02	.06	.01	.01	.01
FN	***	***	***	***	***	***	***	***	***	***
C x FN	.80	.21	.04	.14	.02	.91	.89	.29	.94	.77

+ Grain yield results corrected to a moisture level of 12%.

*** Significant at or below the .001 level.

slope 7.5 #N / " water

Table 3. Effect of fertilizer N (FN) on grain protein of two winter wheat cultivars (C) at several levels of growing season precipitation (GSP). 1987 and 1988.

FN	Water level & GSP									
	1987					1988				
	WL1 4.3"	WL2 5.7"	WL3 8.5"	WL4 11.5"	WL5 14.3"	WL1 3.9"	WL2 5.7"	WL3 9.4"	WL4 12.6"	WL5 15.9"
lbs/a	Centurk, %									
0	8.7+	8.6	8.9	8.8	8.6	12.3	10.9	9.6	8.5	8.5
40	10.5	9.6	8.6	7.8	8.1	14.3	13.2	10.8	9.7	9.5
80	13.2	12.4	9.8	8.5	8.6	16.0	14.9	12.7	11.2	11.1
120	14.1	13.3	11.3	9.3	8.9	17.2	16.0	14.0	13.4	13.1
160	14.6	14.5	13.4	12.0	11.4	17.6	16.8	15.5	13.9	14.6
200	14.7	14.3	14.0	13.2	13.3	17.9	17.6	16.1	15.3	15.1
240	14.7	14.3	14.4	13.7	13.1	17.9	17.4	16.4	15.5	15.6
LSD (.05)	1.9	0.4	0.6	0.5	0.5	0.6	0.9	0.7	0.5	0.6
lbs/a	Redwin, %									
0	10.2	10.1	10.7	10.7	10.3	12.9	12.4	11.6	10.7	11.0
40	12.1	11.6	10.1	9.6	9.5	15.2	14.6	13.5	12.1	12.2
80	15.0	13.7	11.7	10.5	10.5	16.4	16.2	14.7	13.3	13.3
120	15.5	14.8	13.2	12.0	11.8	17.4	17.1	15.9	14.8	14.4
160	16.7	16.4	15.8	13.7	13.9	17.9	17.5	17.1	16.1	15.7
200	16.5	16.4	15.7	14.9	14.3	18.0	17.8	17.1	16.6	16.3
240	16.9	16.8	16.1	15.3	14.9	17.9	18.0	17.2	17.0	16.6
LSD (.05)	1.5	1.5	1.8	1.4	1.5	0.7	0.7	0.8	0.5	0.6
Source	Probability > F									
C	.01	.01	.01	.01	***	.03	.01	***	***	***
FN	***	***	***	***	***	***	***	***	***	***
C x FN	.61	.15	.85	.37	.04	.24	.01	.01	.20	***

+ Grain protein results corrected to a moisture level of 12%

NITRATE SOIL TEST CORRELATION AND ECONOMICS - CORN AND SORGHUM

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ABSTRACT

Optimizing profits from fertilizer-N requires establishing a relationship between nutrient supplying power of the soil and crop yield response to applied fertilizer coupled with appropriate economic analysis. The purpose of this presentation is to describe one such system that we have found to be useful.

Field studies were conducted on irrigated clay loam soils and relationships developed between residual soil nitrate-N, applied fertilizer N and grain yield of sorghum and corn. These relationships were subjected to both static and dynamic economic analyses. Fertilizer N amounts necessary to optimize profits from investment in fertilizer were found to be relatively independent of changes in crop prices, fertilizer costs and interest rates. Due to carry over effects in the clay loam soils of these studies, initial application rates of fertilizer N to maximize profit were 12 to 14 lbs N/acre more for long-term than for a single year production. Due to the interaction effects of residual soil nitrate-N, fertilizer N and grain yield, an annual soil test was found to be very important. Reductions in fertilizer N necessary for optimum long-term profit resulted in much greater lost revenue than savings in fertilizer cost. Net returns in subsequent years was adversely affected by sub-optimal N application in the current year due to the carry-over effect. Results indicate, that in order to maximize long-term profits, a producer could afford to borrow money at a very high rate of interest to apply the optimum rate of fertilizer N.

OBJECTIVE

Development of "Best Management Practices" for N use in crop production for protecting both the environment and producers profits will require knowing the N fertilizer needed to achieve the most profitable yield. Insufficient applications of fertilizers are costly in lost yields and over application results in unwarranted production costs and increases the opportunity for fertilizers to end up in non-targeted areas. Correct application amounts can be determined through the development of relationships between the nutrient supplying power of the soil, applied N fertilizer and crop yield that can be subjected to economic analysis. The objective of this presentation is to describe one such system developed over a period of years, that we have found to be useful.

MATERIALS AND METHODS

Irrigated field trails were conducted at several locations on Olton clay loam (fine, mixed thermic Aridic Paleustolls) and Pullman clay loam (fine, mixed thermic Torrertic Paleustolls) which are major soils on which irrigated grain sorghum (Sorghum bicolor L. Moench) and corn (Zea mays L.) are grown on the Southern High Plains. Nitrogen fertilizer rates varied from 0 to 160 lbs/a for sorghum and 0 to 200 lbs/A for corn and were broadcast on flat land prior to bedding. Plots were 6 to 8 beds wide, with the center of the beds 40 inches apart, and were 50 feet long arranged in a randomized complete block design with four replications.

Composite soil samples were taken from each plot prior to fertilizer applications in depth increments of 0-6, 6-12, 12-24 and 24-36 inches, air dried, ground and analyzed for nitrate-N (NO_3^--N) by standard methods. Hybrids planted and all cultural practices were those currently recommended for optimum production for the area. Grain yields were obtained either by hand harvesting with subsequent threshing or by use of a plot combine. Analysis of variance and regression analyses were performed by standard methods. The marginal rate of substitution (MRS) was calculated using the algebraic expression:

$$MRS = -[\partial y/\partial N_r / \partial y/\partial N_f] \qquad [A]$$

where N_r = residual NO_3^--N and N_f = applied fertilizer N.

For economic analyses, increased value of grain due to N application was discounted in order to account for potential income from alternative investments of money invested in fertilizer. A discount rate of 12% was used from fertilizer purchase to grain selling with the price of N set at $0.30/lb.

Calculations of long-term optimal levels of applied N were made by direct maximization of the discounted value of N applications over a 10 year planning horizon using the following model.

$$\text{maximize } L(Nt, Rt, Ht) =$$

$$\sum_{t=1}^{T} B_t[P_y\, Y(N_t, R_t) - PnN_t] +$$

$$\sum_{t=2}^{T} H_t[S(N_{t-1}, R_{t-1}) - R_t] + H_1(R_o - R_1) \qquad [B]$$

$$N_t, R_b \geq 0, \text{ all } t,$$

where

T = the length of the planning horizon (e.g. 10 yr)
B_t = the discount factor for t

P_y = the price of the crop
P_n = the price of applied N
R_t = amount of residual NO_3^--N in the top 6 in. of soil profile in year t. R_0 is given by the initial test.
$Y(N_t, R_t)$ is the yield of corn which depends on the amount of applied and residual N
$S(N_{t-1}, R_{t-1})$ is the amount of residual NO_3^--N in year t which depends on previous quantities of applied and residual nitrogen.
H_t = the Lagrangian multiplier for year t. A measure of the amount by which having an additional unit of residual NO_3^--N would increase long term profits.

Residual NO_3^--N for succeeding years was determined by use of the carry-over equation obtained through regression analysis of soil sample NO_3^--N data. Dynamic optimization calculations were made using the Box Complex (1965) routine. This is an interactive non-linear constrained optimization routine. For use in this analysis, the constraint was that the amount of residual NO_3^--N in any given year was a function of the amounts of residual NO_3^--N and applied fertilizer N from the previous year.

RESULTS AND DISCUSSION

Several models were investigated for relating grain yield to residual soil NO_3^--N and applied N fertilizer. Some of these models along with coefficients of determination (R) and standard errors of estimate (SE) are given in Table 1 where y = grain yield, N_f = applied fertilizer N, N_r = residual soil NO_3^--N and $N = N_f + N_r$.

Table 1. Regression equation models, with typical coefficients of determination (R^2) and standard errors of estimate (SE), used to relate grain yield of corn and sorghum to residual soil NO_3^--N and applied fertilizer N.

Soil Sample Depth (in)	Eq. No.	Regression equation model	R^2		SE	
			G.S.	Corn	G.S.	Corn
	1	$y = C + aN_f - bN_f^2$	0.59	0.61	1074	27.6
0-6	2	$y = C + aN - bN^2$	0.71	0.88	908	15.5
0-12	3	$y = C + aN - bN^2$	0.76	0.93	820	11.4
0-24	4	$y = C + aN - bN^2$	0.82	0.93	712	11.4
0-36	5	$y = C + aN - bN^2$	0.82	0.90	705	13.8
0-6	6	$y = C+aN_f-bN_f^2+CN_r-dN_r^2-eN_fN_r$	0.81	0.96	793	9.0
0-12	7	$y = C+aN_f-bN_f^2+CN_r-dN_r^2-eN_fN_r$	0.81	0.96	780	9.7
0-24	8	$y = C+aN_f-bN_f^2+CN_r-dN_r^2-eN_fN_r$	0.83	0.97	745	8.7
0-36	9	$y = C+aN_f-bN_f^2+CN_r-dN_r^2-eN_fN_r$	0.84	0.97	733	8.0

The poorest relationship for either crop was obtained when only applied N fertilizer was considered with yield (Eq. 1). The relationship was greatly improved as measured by R^2 and SE, when residual NO_3^--N was included (Eq. 2, 3, 4 and 5). These equations have the sum of fertilizer N and NO_3^--N as a single independent variable. A further improvement in the relationship was found when applied fertilizer N and residual NO_3^--N were included as separate independent variables (Eq. 6, 7, 8 and 9).

The behavior of applied fertilizer N and residual NO_3^--N as separate independent variables indicated a difference in utilization by the crop. This was confirmed by calculation of marginal rates of substitution. As an illustration these are given in Table 2 for two yield levels of corn and four levels of residual NO_3^--N in the 0-6 inch sampling increment. These data indicate that the MRS of residual NO_3^--N for fertilizer N is variable, increasing with increasing levels of residual NO_3^--N. The data also indicate that there is a level of residual NO_3^--N that represents a minimum below which it would have little effect on grain yield. For the data in Table 2, that value would appear to be slightly below 15 lb/A for 100 bu/A and between 15 and 25 lb/A for 125 bu/A.

It was found that the amount of residual NO_3^--N in the current year was influenced by the amount of N applied the previous year. The model used

Table 2. Fertilizer N, residual NO_3^--N and marginal rates of substitution of residual soil NO_3^--N for applied fertilizer N for two yield levels of corn. Response function model - Eq. 6, Table 1.

Yield (bu/A)					
100			125		
Fertilizer N	Residual NO_3^--N	MRS	Fertilizer N	Residual NO_3^--N	MRS
- - - lbs/A - - -			- - - lbs/A - - -		
36.8	15	-0.20	61.4	15	0.12
32.0	25	-0.77	60.0	25	-0.44
20.7	35	-1.54	51.8	35	-1.27
1.0	45	-2.48	33.6	45	-2.40

is as follows: $N_r = C + aN_{f-1} + N_{r-1}$, where: N_r = current level of residual NO_3^--N, N_{f-1} = fertilizer N applied the previous year and N_{r-1} = level of residual NO_3^--N at beginning of previous year. Since the amount of fertilizer N applied in one year influences the amount of residual NO_3^--N and consequently, crop response to applied N in subsequent years, the appropriate economic analysis would be dynamic rather than static. However, for the producer who has a one year planning horizon (e.g. tenant with 1-yr lease) an analysis of the static system is useful and additionally provides a comparison with dynamic analysis. The marginal productivity (MPPn) of applied fertilizer N is calculated from the first derivative of the response function, in this case, Eq. 6 from Table 1.

$$MPP_n(bu) = a - 2bN_f - eN_r \quad [C]$$

where: MPP_n = marginal product and is the amount of additional corn, in bushels, obtained from one additional unit of applied N or residual NO_3^--N. N_f and N_r are as previously defined. Utilizing the relationship in [B] and [C] and data from a four year study with irrigated corn, Table 3 was developed. The calculations shown in Table 3 indicate that 12 to 14 lb more N/acre would be needed to maximize long-term returns than for single year returns. This is due to the carry-over effects previously discussed and indicates that the initial N application following a soil test is important. Unless a carry-over function superior to the one we have been able to develop to this point becomes available, soil tests should be conducted annually.

The question arises as to why go to all the trouble to obtain the relationships between soil N supplying power, fertilizer N and plant yield and subject that data to the latest economic analysis. The consequences of over application of N are obvious in increased production costs. However, consequences of under application are less obvious and are, therefore, illustrated in Table 4. If for some reason (lack of knowledge, lack of production capital, etc.) less than the optimum amount of fertilizer N is applied, reductions in profit can be several times greater than any savings in fertilizer cost that occur. Furthermore, due to the carry-over effect, the profit reductions become greater with each successive year that less than optimum amounts of N are applied. These calculations show that a producer could afford to borrow money at very high interest rates in order to apply N fertilizer at its optimal level.

Table 3. Profit maximizing N fertilizer levels for single-year planning and the first year of 10-yr planning for three N fertilizer and corn prices and two levels of residual NO_3^--N.

	N price ($/lb)					
	0.25		0.30		0.35	
	Planning Period					
Corn	1-yr	10-yr	1-yr	10-yr	1-yr	10-yr
$/bu	- - - - - - - - - - - - - - lb N/acre - - - - - - - - - - - -					
	Soil test = 10 lb NO_3^--N/acre					
2.25	166	180	162	175	158	171
2.75	170	183	166	180	163	177
3.25	173	186	170	182	167	180
	Soil test = 30 lb NO_3^--N/acre					
2.25	149	162	145	158	141	153
2.75	153	165	150	162	146	158
3.25	156	168	153	165	150	162

Adapted from Stoecker, A.L. and A.B. Onken. 1989. J. Prod. Agric. 2:309-317.

Table 4. Discounted differences in fertilizer expense and profits from a limited N fertilizer use program on irrigated corn.[1/]

Years limitation in effect	Initial soil test NO_3^--N: 10 lb/acre		30 lb/acre		50 lb/acre	
	Max N. lb/acre[2/]					
	100	150	100	150	100	150
	$/acre					
	Reduction in fertilizer cost					
1	24	9	19	4	14	0
2	48	15	37	9	31	3
3	60	20	54	14	48	8
	Reduction in profits					
1	59	9	36	2	19	0
2	102	13	75	5	54	2
3	138	16	112	8	90	5

1/ Adapted from Stoecker, A.L. and A.B. Onken. 1989. J. Prod. Agric. 2:309-317.

2/ Applied N restricted to this amount.

ADDITIONAL TEXAS SOIL FERTILITY PROJECTS

A.B. Onken, Lubbock - Fertilizer and interrelated responses of soils and crops grown on the Texas High Plains. Primary research activities include soil test correlation; investigation of factors influencing reaction rate, solubility and release rate of native and applied P and identification and quantification of factors influencing the relationship between soil fertility and water use efficiency.

A.B. Onken, Lubbock - Nutrient use efficiency in sorghum. Objectives are to identify sorghum genotypes with superior nutrient use efficiency and determine responsible mechanisms.

B.W. Hipp, Dallas - Primary research activities include evaluation of residue management practices on N requirement of wheat, fertility requirements of landscape and nursery plants, alternative management systems for turfgrass, fertilizer requirements of turfgrass and ornamentals seeded on disturbed urban soils, and effect of management level on fertilizers and pesticides in runoff from urban landscapes.

R.H. Loepport,
College Station - Soil and plant factors influencing Fe deficiency stress in calcareous soils. Studies are underway to evaluate the plant, soil, environmental, and nutritional factors which influence the occurrence of Fe deficiency stress and the effectiveness of plant response to Fe deficiency stress. The goal is to obtain an improved understanding of the complex plant and soil factors influencing Fe mobilization and uptake.

W.B. Anderson,
College Station - Soil fertility management and plant nutrition to improve forage productivity. Objective is to delineate both the environmental and soil factors which influence fertilizer N loss from surface applications, with emphasis on urea hydrolysis and ammonia volatilization.

F.T. Turner,
Beaumont - A current major research effort is the evaluation of a hand held chlorophyll meter to help determine the need for topdress nitrogen for rice.

R.P. Wiedenfeld,
Weslaco - Plant nutrition management and crop production systems for subtropical South Texas. Research is being conducted to improve understanding of N dynamics in the soil-plant system and to develop cultural practices to efficiently meet crop requirements; to develop efficient crop production systems which integrate the latest information from various disciplines; and to improve understanding of the effects of water availability on crop growth.

USE OF THE SOIL NITRATE TEST TO PREDICT FERTILIZER N NEEDS OF CORN

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ABSTRACT

Nitrogen rate field experiments conducted over three years were used to relate relative yield of corn to the soil nitrate test using several depth increments. Water soluble nitrate-nitrogen was measured at planting at 0-6 inches (N6), 0-12 inches (N12), 0-24 inches (N24), 0-36 inches (N36), or 0-48 inches (N48). Simple correlation coefficients between relative yield of check treatments and the above indices over 26 sites were 0.07, 0.09, 0.28, 0.33, and 0.36, respectively. These relationships are relatively poor presumably due to some drought affected sites. Relationships with nitrogen uptake is somewhat better.

A good relationship existed between maximum yield of responsive sites and the fertilizer N plus the nitrate-N needed to achieve maximum yield at that site. This type of relationship allows direct estimation of the fertilizer N required for a desired yield.

OBJECTIVES

The nitrate-nitrogen soil test has proven useful for recommending nitrogen for small grain crops of the Great Plains. Limited data has been collected for corn; although, an estimated 50% of the total fertilizer nitrogen used in South Dakota is applied to corn. The objective of this study is to determine the relationship of the nitrate-nitrogen test to yield response of corn to nitrogen fertilizer.

MATERIALS AND METHODS

A total of 26 N-response trials were conducted between 1987 and 1989. Twenty of these sites were located on farmer fields with the remainder located on research farms of South Dakota State University. All were located in the eastern half of South Dakota at different sites each year. None of the sites were manured, although 7 of the study sites had soybeans as the previous crop. Most of the remainder of study sites had small grain as the previous crop. All sites had nutrient levels other than N that were deemed optimum or nutrients were added in sufficient quantities to eliminate that nutrient as a limiting factor. In all cases, management of the plots were performed by the farmer or station manager.

Rates of nitrogen varied from site to site but most were 0, 30, 60, 90, and 120 lbs N/acre. The N form used was NH_4NO_3, surface applied by hand within a few days of planting. The experimental design used was either a randomized complete block with four replicates or a latin square design with five replications. At maturity (black layer) grain yield was determined by hand harvesting two center rows twenty feet in length. Stover yields were also taken from this area; the plants were weighed, chopped and subsamples taken for moisture and N content. Soil nitrate-N was determined with a nitrate sensitive electrode (Gelderman and Fixen, 1988).

Linear or nonlinear models (SAS Institute, Inc., 1982) were used to describe each responsive site's grain-yield response function. Most could be adequately described using a segmented model in which an ini- tial linear portion rises to a linear yield plateau. The relative yield of the check plot is considered as the grain yield of the check plot divided by the plateau (maximum yield) for the site. Responsive sites were determined by analysis of variance or orthogonal contrasts. (SAS Institute, Inc., 1982).

RESULTS AND DISCUSSION

The range and means of the organic matter and nitrate-N levels found at the study sites are shown in Table 1. These levels are very similar to "typical" soils that are found in eastern South Dakota. Grain yields reflect the above average moisture conditions experienced in 1987, the drought conditions of 1988 and the below-average moisture conditions of 1989 (Table 2). Yields of individual sites ranged from 44 to 172 bu/A. Yields of responsive sites ranged from 48 to 145 bu/A for check plots.

Table 1. Range and mean of nitrogen soil tests for 26 N-corn sites, 1987-1989.

Soil Test[1]	Units	Range	Mean	Median
N6	lb/A	5-53	20	16
N12	"	10-72	34	34
N24	"	27-165	61	62
N36	"	36-185	81	74
N48	"	43-201	96	79
O.M.	%	1.9-3.8	3.0	3.0

[1]Where: N6, N12, N24, N36, and N48 is the content of NO_3-N in the 0-6", 0-12", 0-24", 0-36", and 0-48" profile depths, respectively. O.M. = Walkley Black organic matter concentration of the 0-6" profile depth.

Correlation of relative check yields with soil nitrate-N concentrations at various depths are listed in Table 3. The relationships are con-sidered poor. The reason for the poor relationship can be shown in Figure 1. This Cate-Nelson graph shows 73% of the points in the posi-tive quadrants (either lower left or upper right). The remainder of the plots are in the upper left hand quandrant and were severely drought stressed. These plots would have been expected to respond except that water was probably more limiting than available nitrogen.

Table 2. Yield parameters, nitrate-N concentrations and N rate at maximum yield for study sites.

Site	--Grain Yield--- Check	Maximum[1]	Relative[2] yield	N Rate[3] at maximum yield	---NO3-N--- N24	N36[4]
	------bu/A-----		%	------------lb/A----------		
1987						
Cod	145	157	92	96	95	152
Rob1	100	127	78	90	67	94
Rob2	90	131	69	93	32	44
Day	42	40	105	0	66	110
Spk	78	99	79	87	42	56
Jer2	129	130	99	0	81	123
Jer1	83	100	82	33	37	53
Dav1	92	104	90	59	73	89
Dav2	91	95	96	0	111	127
Lin	96	102	94	0	165	185
Moo	121	172	70	86	63	77
Brk	128	141	91	30	39	46
1988						
Rob2	69	67	103	0	40	48
Spk	68	70	97	0	32	39
Hig	72	70	103	0	55	64
Jer2	70	75	93	0	27	36
Jer1	45	48	94	0	39	53
Dav2	48	61	79	27	35	45
Dav1	44	44	100	0	71	88
Moo	147	139	106	0	76	96
Brk	61	82	74	33	62	71
1989						
Cod	101	101	100	0	71	141
Rob	90	136	66	81	31	48
Spk	46	51	90	0	49	64
Moo	128	149	86	50	68	80
Brk	109	125	87	45	70	76

[1]Maximum yield of site at plateau for responsive sites.

[2]Relative yield = check yield/plateau yield x 100.

[3]The nitrogen rate at which the plateau yield begins.

[4]The NO_3-N content at planting of the 0-24" and 0-36" profile levels, respectively.

Table 3. Relationship between nitrogen soil tests with relative yield and nitrogen uptake.

Soil Test Index [1]	Relative check yield	Stover[2] nitrogen uptake
	---------------r value---------------	
N6	.07	0.44*[3]
N12	.09	0.46*
N24	.28	0.44*
N36	.33*	0.60*
N48	.36*	0.64*
O.M.	.21	0.31

[1]Where: N6, N12, N24, N36, and N48 is the content of NO_3-N in the 0-6", 0-12", 0-24", 0-36", and 0-48" profile depths, respectively.
O.M. = Walkley Black organic matter concentration of the 0-6" profile depth.
[2]1987 and 1988 data only (21 sites).
[3]* indicates significance at the 0.10 level.

Relationships between nitrogen uptake by the stover and the soil nitrate-N content by profile depth indicates that the relationship generally improves with deeper depths (Table 8). A rather large improvement in the relationship is seen from 24 to 36 inch profile depth.

Further examination of Figure 1 indicates that all but one plot in the lower left quadrant were responsive to additional nitrogen. In addition, only one plot in the upper right quadrant was responsive to added N. This would indicate that soil nitrate is a good predictor of the probability of a response to nitrogen. Similar graphs prepared for each soil depth yielded the data of Table 4.

Table 4. A summary of Cate-Nelson analysis of relative corn yield with soil nitrate-N.

Soil nitrate test [1]	Critical nitrate-N value	Relative check yield	Points in positive quadrants[2]
	lb/A	---------------%---------------	
N6	28	91	62
N12	46	92	58
N24	75	92	69
N36	95	92	77
N48	110	92	73

[1]Where: N12, N24, N36, and N48 is the content of NO_3-N in the 0-12", 0-24", 0-36", and 0-48" profiles, respectively.
[2]The positive quadrants are the lower left and upper right quadrants in a Cate-Nelson graph.

In all cases, the relative yield is approximately 92%. The percent of points in the positive quadrants is approximately the same for the 2, 3, and 4 foot profiles. This would indicate that a 2 or 3 foot depth would be sufficient to adequately represent NO_3-N. A critical NO_3-N level of 46 pounds per acre is indicated for the 12 inch profile (Table 4). This is consistent with recent data from Iowa (Blackmer et al, 1989) and Pennsylvania (Fox et al, 1989).

Using the critical level of 75 lbs. NO_3-N/a, for the two-foot profile (Fig. 1), 12 of 21 sites (57%) significantly responded to fertilizer N. However, if the severe drought stressed sites are eliminated, we have 10 of 11 plots or 91% that had a significant grain yield response to added N.

A fair relationship is found between plateau fields of the responsive sites with fertilizer N + NO_3-N (Figure 2 and 3) (one outlier site is not included). The X axis is the amount of fertilizer N needed to produce the plateau or maximum yield at the particular site plus the spring soil nitrate-N levels found in that profile depth. If sites that had soybean as a previous crop are eliminated, the r^2 values increase to 0.74 and 0.72 for Figs. 2 and 3, respectively. Three of the 4 soybean plots were above the repression line (Figure 2), indicating high yields with relatively low fertilzier N + NO_3-N. This would be expected if significant organic N from soybean residue was mineralized.

The data in Figures 2 and 3 indicate that absolute corn yield is related to fertilizer N required plus soil NO_3-N content of the profile. The regression line of Figure 2 (soybean sites eliminated) is: yield = 37.6+.62 (soil NO_3-N + fertilizer N). If we assume that we can substitute yield goal for yield and assume that the efficiency of the NO_3-N and fertilizer N are the same, we can solve for fertilizer nitrogen. We have: Fertilizer N = 1.62 yield - soil NO_3-N - 61. .62

The difference between this equation and the present SDSU corn-N recommendation (1.45 yield - soil NO_3-N - 21) is about 15-25 lbs/A over a yield goal range of 160-80 bu/A. It is premature to derive recommendations from this study. More data from responsive sites are needed; however, we can draw some preliminary conclusions from the data.

1. Spring soil NO_3-N concentrations are useful in predicting corn response to fertilizer nitrogen.

2. Depth of sampling for soil NO_3-N appears to be from 2 to 3 feet for best relationships.

3. Corn sites with soybeans as the previous crop appear to be less responsive and need to be addressed in separate correlation studies.

4. It appears that the profile soil nitrate-N content and yield goal can be used in making fertilizer N recommendations.

use .66 for soil N
corn

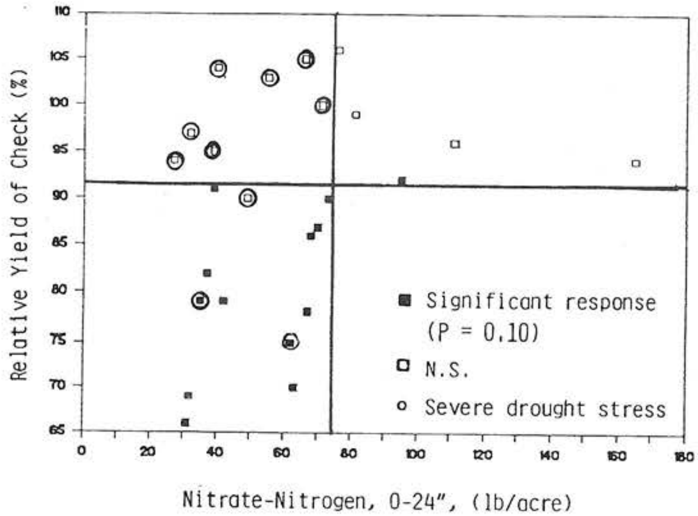

Figure 1. Relationship of soil nitrate-N, (0-24") to relative yield.

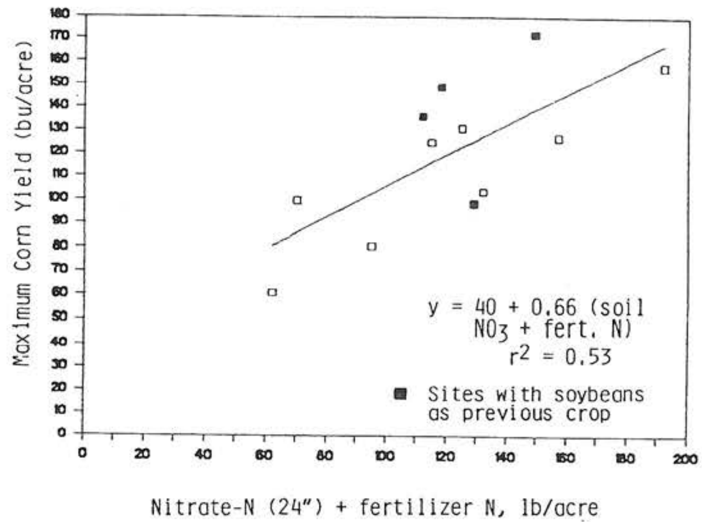

Figure 2. Relationship of soil (24") plus fertilizer nitrogen to maximum corn yield.

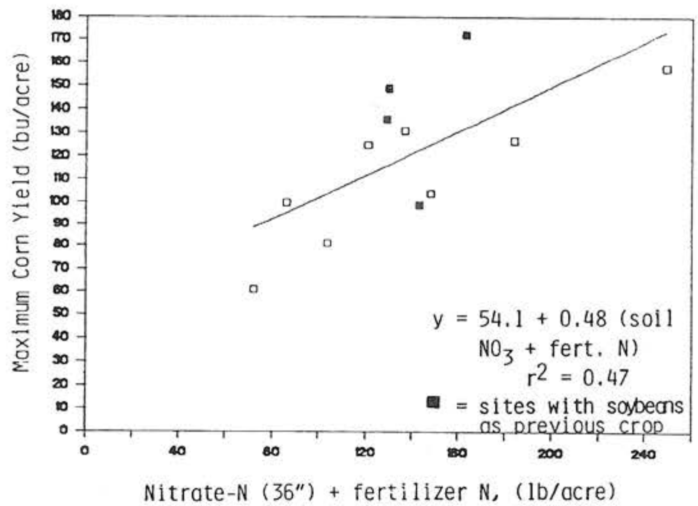

Figure 3. Relationship of soil (36") plus fertilizer nitrogen to maximum corn yield.

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Gelderman, R. H. and P. E. Fixen. 1988. Recommended nitrate-N tests. In W. C. Dahnke (ed.) Recommended Chemical Soil Test Procedures for the North Central Region. North Central Region Publication No. 221 (Revised). North Dakota Agricultural Experiment Station Bulletin No. 499 (Revised).

.66 soil N

fert N = 1 soil N = .66

1989 South Dakota Soil Fertility Research
Plant Science Department, South Dakota State University

I. Nitrogen
   a. Correlation and Interpretation of Several Soil Nitrogen Indices for Corn - Ron Gelderman.
   b. Economically and Environmentally Sound N Management in Tillage/Rotation Systems - Diane Rickerl, Jim Smolick, Dwayne Beck and Dale Sorensen.
   c. Effects of Tillage and Nitrogen Rates on Corn Yields and Nitrogen Leaching - Barney Gordon and Diane Rickerl.
   d. Effect of N timing, split applications, and N form on protein content and yield of three spring wheat varieties - Ruth Beck and Fred Cholick.
   e. Influence of nitrogen application on grass forage and seed production - Jim Gerwing, Ed Twidwell and Ron Gelderman.

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   a. Residual Effects of Fertilizer Phosphorus on an Egan Silty Clay Loam - Paul Fixen, Brad Farber and Dale Sorenson.
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   g. Development of Integrated P Management Recommendations Based on a Mechanistic Approach to Soil Test Interpretations: (Phase 1) Determination of Soil P Supply Parameters and Model Fitting - Paul Fixen, Tom Schumacher and Greg Carlson.
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IV. Other Studies
a. Subsoil and Parent Material P, K, and S Levels in MLRA 102B (southeastern) SD Soils - Doug Malo, Paul Fixen and Andy Drymalski.
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f. The effects of soil physical properties on the branching and distribution of corn roots and phosphorus uptake - Mohammad Hajabassi, Tom Schumacher and Paul Fixen.

EFFECT OF SOIL NITRATE DEPTH ON SOFT WHITE WHEAT PRODUCTION

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ABSTRACT

Soft white wheat was grown on a clay loam soil for 2 yr with a wide of soil nitrate (SN) (63-250 lb ac^{-1}) and fertilizer nitrogen (FN) (0-357 lb ac^{-1}) treatments. The field experiment was designed to determine the slopes of the yield response curves to FN ($\delta y/\delta FN$) and to SN ($\delta y/\delta SN$), to deterine how the ratio of ($\delta y/\delta SN$)/($\delta y/\delta FN$), or marginal rate of substitution, is affected by FN, SN, and depth of SN, and to determine if refinements to the current FN recommendations for irrigated soft white wheat are required. The slope of the yield response curve to SN ($\delta y/\delta SN$) was less when SN was situated in the 12- to 48-in soil layer than in the 0- to 12-in at low amounts of SN. Since $\delta y/\delta SN$ increased as SN increased, when SN was situated in the 12- to 48-in soil layer, there was only a small effect of depth of SN on FN recommendations. The MRS or ratio of the slope of the yield response curve to SN and the slope of the yield response curve to FN ($\delta y/\delta SN$)/($\delta y/\delta FN$) were greatly affected by the amount of FN, SN, and depth of SN. The variable MRS did not support the assumptions on which one-to-one substitution models for FN recommendations are based. The FN at maximum profit occurred at a greater combined amount of SN and FN for the higher SN levels in both years. Fertilizer N recommendation models would be improved if the combined amount of SN and FN did not have a fixed ceiling at every SN level. Once verified by additional field research, inclusion of the above findings into the current FN recommendations could improve the accuracy of FN predictions for irrigated soft white wheat.

OBJECTIVES

Soft white wheat is grown extensively on irrigated land in southern Alberta. Recent field experiments have been carried out to develop fertilizer N recommendations for soft white wheat production in southern Alberta (Bole and Dubetz 1986; Mackenzie et al. 1987). Current recommended fertilizer N rates for irrigated soft white wheat in Alberta are based on the differences between a maximum rate of 161 lb ac^{-1} of fertilizer N and the amount of soil nitrate sampled to a depth of 24 in (Laverty et al. 1987). These recommendations are based on the assumption that SN to a 24 in depth was equal to FN. Researchers in the United States have reported that the marginal rate of substitution of SN for FN was much less than one (MRS equals the grain yield increase per unit of SN divided by the grain yield increase per unit of FN) (Haby et al. 1983; Onken et al. 1985). Further research work was suggested to establish the relative efficiency of SN as a function of soil depth so that FN recommendations could be improved. The objectives of this study were: 1) to determine how the MRS of SN is affected by amount of SN and FN and soil depth, and 2) to determine if refinements to the current FN recommendations for irrigated soft white wheat are required.

MATERIALS AND METHODS

Field experiments were conducted from 1984 through 1986 on a Chin clay loam (Typic Haploboroll). The soil had a pH of 8.0 and a soil organic matter content of 3.24 % as determined by standard methods (McKeague 1976). The site had been cropped to spring wheat since 1981.

In 1984, fertilizer N was broadcast at 0, 45, 89, 179, 268, and 357 lb ac^{-1} of N as NH_4NO_3 along with fertilizer P at 45 lb ac^{-1} of P as superphosphate. A randomized, complete block design was used with six replications and 33 x 33 ft treatment plots. In 1985, six rates of N as NH_4NO_3 were broadcast at 0, 18, 36, 71, 107, and 143 lb ac^{-1} in a random design within each 1984 fertilizer treatment using 5.5 x 33 ft treatment plots. In 1986, six rates of N as NH_4NO_3 at 0, 18, 36, 71, 107, and 143 lb ac^{-1} were broadcast after they were randomly assigned to the treatment plots used in 1984.

Soft white wheat was seeded annually at 112 lb ac^{-1}. The crop was irrigated when the available soil moisture in the rooting zone was depleted to 50% of the total available soil water. Soil moisture was measured using tensiometers installed at soil depths of 6 and 12 in. Neutron probe readings for soil moisture were taken weekly at soil depths of 6, 12, 24, 36, 48, and 60 in. In the 1984 crop year, irrigation was curtailed at heading to limit crop growth, so that a large proportion of FN would remain in the soil after harvest. Generally, three to five irrigations of 3 in of water were required during each growing season. Irrigation water was added through 8-in diam. hand-laid pipewith sprinkler heads on 36-in risers.

Yield estimates were obtained by hand-sampling from two 39-in^2 areas in 1984. In 1985-86, plot yield samples were taken with a small combine from an area 4 by 26 ft. After separation of grain and straw, sub-samples were air-dried, ground (<1 mm sieve), and analyzed for total N (Bremner 1965).

Soil samples were taken from field plots to a soil depth of 48 in in 6-in increments using a 2-in coring tube in the spring and fall. Soil density was calculated from the weight of oven-dried soil in the 18-in^3 volume of each increment. The soil moisture was determined gravimetrically. Soil samples were air-dried, ground (2-mm sieve), extracted with 2N KCL, and analyzed for inorganic N using a steam distillation procedure (Bremner 1965).

Data from each year were statistically analyzed using analyses of variance. Tukey's test (Steel and Torrie 1980) was used to evaluate differences between treatment means. For the 1985 and 1986 data, quadratic response surface regressions were performed to relate grain yield (y) to FN and SN

(0-48-in depth). Regressions were calculated using metric units, kg ha^{-1}.

1985-1) $y=1525 + 27.07\ FN - 0.0631\ FN^2 + 37.84\ SN - 0.0741\ SN^2 - 0.0680\ FN.SN$
1986-2) $y=2696 + 24.53\ FN - 0.0689\ FN^2 + 3.837\ SN + 0.0136\ SN^2 - 0.0593\ FN.SN$

The change in grain yield in response to FN ($\delta y/\delta FN$) and SN ($\delta y/\delta SN$) was calculated by taking the appropriate partial derivatives of the fitted quadratic response surface equations for 1985 and 1986. The partial derivatives, $\delta y/\delta SN$ adn $\delta y/\delta FN$, are linear functions of FN and SN:

1985 - 3) $\delta y/\delta FN = 27.0710 - 0.1262\ FN - 0.0680\ SN$
- 4) $\delta y/\delta SN = 37.8362 - 0.1482\ SN - 0.0593\ SN$
1986 - 5) $\delta y/\delta FN = 24.5315 - 0.1378\ FN - 0.0593\ SN$
- 6) $\delta y/\delta SN = 3.8374 + 0.0272\ SN - 0.0593\ FN$

Soil N (0-48 in) prior to seeding ranged from 73 to 246 lb ac^{-1} in 1985 and from 73 to 196 lb ac^{-1} in 1986. Most of the change in SN (93%) was concentrated in the 0-12-in soil layer in 1985. In 1986, most of the change in SN (88%) occurred below 12 in.

The $\delta y/\delta FN$ equations for 1985 and 1986 were used to calculate the FN at maximum profit. The maximum profit will occur when the differential yield with respect to FN equals the unit cost:price ratio of fertilizer N and soft white wheat (Bole and Dubetz 1986). A price of \$.56 kg^{-1} (\$.25 lb^{-1}) was set for FN and \$.11 kg^{-1} (\$.05 lb^{-1}) was set for soft white wheat. For example, in 1985 at SN = 80 kg ha^{-1} (71 lb ac^{-1}) FN at maximum profit was calculated as follows:

$$27.07 - 0.1262\ FN\ \text{maximum kg ha}^{-1} - 0.068\ (80\ \text{kg ha}^{-1}) = \frac{\$.56\ \text{kg}^{-1}}{.11\ \text{kg}^{-1}}$$

FN maximum = 131 kg ha^{-1} (117 lb ac^{-1})

A more detailed description of methods and presentation of results was given in a previous paper (Carefoot et al. 1989).

RESULTS AND DISCUSSION

The large amount of SN in 1985 and 1986 was achieved by applying up to 357 lb ac^{-1} of FN in 1984 and by curtailing the irrigation at heading. Independence of FN and SN values was essential for the objectives of the experiment. This was achieved by superimposing a complete range of FN (0-43 lb ac^{-1}) over treatments containing a wider range (73-250 lb ac^{-1}) of SN. In 1985 and 1986, the grain yield response curves were described by quadratic response surfaces (equations 1 and 2) with R^2 values of 70 and 57% for 1985 and 1986, respectively. In 1985, 93% of the change in SN was in the 0-12 in soil layer and in 1986, 88% of the change in SN was in the 12-48-in soil layer. Thus, it was assumed that the MRS values for 1985 and 1986 would approximate the MRS for the 0-12-in and 12-48-in soil layers, respectively. The MRS (grain yield increase per unit of SN divided by the grain yield increase per unit of FN) was calculated over a range of SN and FN levels (Table 1).

amount of SN and FN increased from 108 lb ac^{-1} at 22 lb ac^{-1} of SN up to 181 lb ac^{-1} at 134 lb ac^{-1} of SN.

Table 2. Current fertilizer N recommendations for irrigated soft white wheat based on soil NO_3-N (SN) in the 0-24-in soil layer and fertilizer N (FN) at maximum profit in 1985 and 1986 based on quadratic response surface regressions relating grain yield to FN and SN in the 0-48-in soil layer

SN (0-24 in)	Recommended FN	SN (0-48 in)	FN at maximum profit 1985	FN at maximum profit 1986
		lb ac^{-1}		
45	116	71	117	96
80	80	107	98	79
116	45	143	79	64
152	9	179	59	49
170	0	196	50	41
188	0	214	40	34
205	0	232	30	26
223	0	250	21	19

The improved yield response to a combination of FN and SN compared with one N source alone indicates that the placement, source, and/or timing of FN was not ideal. This type of yield response may not have been observed if the FN had been banded. It is possible that high rates of broadcast FN were not adequately exposed to plant roots for uniform uptake of N through the critical parts of the season for soft white wheat as the FN could be restricted to a fairly narrow soil layer. A combination of FN and SN would ensure that N continued to be taken up by plants more uniformly throughout the growing season. Soil N, alone, even at high amounts, may not be optimum for it might not supply the young palnts developing in the surface soil layer with sufficient "starter" N. This could be even more pronounced when SN is situated deeper in the soil profile.

The greater combined amounts of SN and FN required to achieve maximum profit as SN levels increased suggests that soil test FN recommendations should be modified. Soil test FN recommendations may be improved by using a FN recommendation model that does not have a fixed ceiling for SN and FN.

The smaller decrease in FN at maximum profit as SN increased in 1986, compared with 1985, indicated that depth of SN had some effect on the grain yield response to FN. This finding could affect FN recommendations for soft white wheat, once verified by further field studies.

Table 1. Marginal rate of substitution (MRS), at various combinations of fertilizer N and soil nitrate-N

	Soil NO_3-N	1985 fertilizer N 0	54	89	107	143	1986 fertilizer N 0	54	89	107	143
MRS[1]	71	1.20	1.55	2.13	2.74	10.5	0.30	0.21	NC[2]	NC	NC
	125	0.97	1.30	2.09	3.71	NC	0.47	0.51	0.69	NC	NC
	161	0.76	0.98	1.98	NC	NC	0.64	0.92	NC	NC	NC
	196	0.43	0.26	NC	NC	NC	0.85	1.94	NC	NC	NC
	250	NC	NC	NC	NC	NC					

[1]MRS = $(\delta y/\delta SN)/(\delta y/\delta FN)$

[2]Not calculated, since MRS values become unrealistic as $\delta y/\delta FN$ and $\delta y/\delta SN$ approach zero.

At the lowest SN level of 73 lb ac^{-1} the MRS increased in 1985 with increasing levels of FN but in 1986 the MRS decreased with increased FN. At the lowest FN level, the MRS decreased in 1985 as SN increased but in 1986 the MRS increased over the corresponding range of SN. The large difference in MRS values between years appeared to be influenced by the depth of SN. Lower grain yields in 1986 than in 1985 may have contributed to lower MRS values but they do not explain the increase in MRS as SN increased.

The variability of MRS values does not support the assumptions of a one-to-one substitution model for predicting FN requirements that the MRS is constant and equal to one. The large MRS values in 1985 were outside the range of MRS values (low to approximately 0.70) reported by Onken et al. (1985). In the present study there may have been a much greater fraction of SN in the 0- to 12-in soil layer.

The FN at maximum profit was calculated from the equations 3 and 5 and compared with the recommended FN based on the currently used one-to-one substitution model (Table 2). The FN at maximum profit in 1985 at the lowest SN level of 73 lb ac^{-1} and the recommended FN were very similar. The lower FN at maximum profit in 1986 than in 1985 at 73 lb ac^{-1} of SN could be attributed to lower grain yields in that year. However, the FN at maximum profit occurred at a greater combined amount of SN and FN for the higher SN levels in both years. These results were in constrast to the one-to-one substitution model, which assumes a constant amount of SN and FN at FN at maximum profit for every level of SN. Haby et al. (1983) found that by using a diminishing marginal rate of substitution model for predicting FN at maximum profit for dryland winter wheat, the combined

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