IRRIGATION SYSTEM EFFECTS ON SOIL CARBON AND NITROGEN UNDER SUGARBEET AND BARLEY IN NORTHERN GREAT PLAINS

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ABSTRACT

Irrigation system may influence the growth and yields of sugarbeet (*Beta vulgaris* L.) and malt barley (*Hordeum vulgaris* L.), amount of their residue returned to the soil, and soil C and N levels. The effect of two irrigation systems [low energy precision application (LEPA) and mid-elevation spray application (MESA)] was examined on the amount of biomass (stems + leaves) residue returned to the soil from conventional till sugarbeet (CTSB), strip till sugarbeet (STSB), and conventional till malt barley (CTMB), and soil organic C, total N, NH_4-N and NO_3-N levels at the 0 to 35 cm depth in eastern Montana in 2004. Irrigation system did not influence biomass yield, residue cover, and soil C and N levels. Biomass yield, C content, and residue cover were higher in CTMB than in CTSB and STSB. Soil organic C and total N were similar between cropping systems. The NH_4-N content was higher in CTSB than in CTMB but NO_3-N was higher in CTMB than in CTSB and STSB. Although irrigation system did not influence crop biomass yields and soil properties, increased N uptake probably reduced soil NO_3-N in sugarbeet than in malt barley. Greater biomass residue returned to the soil and its higher C:N ratio likely increased residue cover in malt barley compared with sugarbeets.

INTRODUCTION

The semiarid MonDak region at the confluence of Yellowstone and Missouri rivers in eastern Montana and western North Dakota has abundant supply of high quality water that can be used for irrigation and increase crop production. About 100,000 ha of land in this region are currently being irrigated using self-propelled surface irrigation system. However, with the use of appropriate irrigation system, as much as 200,000 ha of dryland can be brought under irrigation. Because of the increased competition of water use among municipalities, industries, and farm producers and decreased soil and water qualities due to increased erosion and chemical contamination, improved soil and water management systems are needed to use water efficiently, improve environmental quality, and sustain irrigated crop production.

Sugarbeet and malt barley are important irrigated cash crops grown in the rotation in this region. Intensive tillage used for planting, weed control, and harvest, followed by increased rate of N fertilization have reduced soil and water qualities by increasing soil erosion, organic matter mineralization, and N leaching. Studies have shown that soil organic matter mineralization increases with increased intensity of tillage (Franzluebbers et al., 1999; Sainju et al., 2005). Therefore, research is needed to examine if conservation tillage along with improved irrigation system can be used to maintain or increase soil organic matter, reduce soil erosion and N leaching, and sustain crop yields.

Little is known about the use of conservation tillage, such as strip till, in sugarbeet production. Halvorson and Hartman (1984) found that strip till produced sugarbeet yields similar to or greater than that did by conventional till. Sainju et al. (2005) found that strip till increased soil organic C compared with chisel till and also maintained cotton and sorghum yields. Similarly, Al-Kaisi and Licht (2004) reported that strip till maintained corn yield and N uptake similar to no-till and chisel till and reduced NO_3-N build-up in the soil profile at the 0 to 1.2 m depth compared with chisel till. Strip till disturbs the soil in a narrow zone of 15 to 20 cm wide in the cropping rows to a depth of 20 cm, leaving the areas between rows undisturbed. It also provides an opportunity to prepare seed bed and fertilization in one tillage operation. As a result, strip till may reduce energy requirement, improve soil and water qualities, and sustain crop yields compared with conventional till.

The mid-elevation spray application (MESA) is a commonly used sprinkler irrigation system in the MonDak region. It primarily applies water above or to the plant canopy of low growing crops, part of which could be lost due to evapo-transpiration. In contrast, the low energy precision application (LEPA) system applies water near the ground directly to plant roots. As a result, water can be used more efficiently by crops using LEPA, which can increase crop yields and biomass production. Since aboveground biomass (leaves + stems) of sugarbeet and malt barley are returned to the soil after beet and grain harvest, we hypothesized that LEPA can increase soil C and N levels better than MESA because of increased biomass residue returned to the soil. We also hypothesized that soil C and N levels will be higher in strip till sugarbeet (STSB) than in conventional till sugarbeet (CTSB) because of reduced soil disturbance. Our objective was to examine the effects of two irrigation methods (MESA and LEPA) on the amount of biomass residue returned to the soil and soil organic C, total N, NH_4-N, and NO_3-N levels in CTSB, STSB, and conventional till malt barley (CTMB).

MATERIALS AND METHODS

The experiment was conducted at the Eastern Agricultural Research Center, Montana State University farm in Sidney, MT in 2004. The soil is savage silty clay loam (fine, montmorillonitic Typic Argiborolls) with sand content of 209 g kg^{-1}, silt 463 g kg^{-1}, and clay 328 g kg^{-1} soil, pH 7.8, organic C 8.9 g kg^{-1}, and total N 0.65 g kg^{-1} at the 0 to 20 cm depth. Growing season average monthly air temperature from April to September 2004 ranged from 7 to 21^{o}C and total rainfall 191 mm. Previous crops were malt barley and spring wheat (*Triticum aestivum* L.).

The treatments included two irrigation systems (MESA and LEPA). The nozzles in the MESA system were suspended at a height of 1.2 m above the ground, separated at 3.0 m apart, and delivered water each at 24.4 L min^{-1}. Similarly, nozzles in the LEPA system were suspended at a height of 0.2 to 0.5 m above the ground, separated at 1.2 m apart, and delivered water each at 9.4 L min^{-1}. Although water flow rates were different, both irrigation systems applied similar amount of water (232 mm) at the same time during dry periods from April to September. The different distance between nozzles in the two irrigation systems was designed to distribute water evenly among plants throughout the plot.

The response crops used were CTSB, STSB, and CTMB. In August 2003, plots for CTSB were prepared by tilling the soil with a ripper (Case IH, Racine, WI) to a depth of 23 cm, followed by mulcher (Brillion Inc., Brillion, WI), and leveler (Eversman, Denver, CO). Similarly, plots for STSB were tilled by using a custom built strip tiller (Schlagel Mfg., Torrington, WY) to a depth of 20 cm in crop rows which were 30 cm wide and 60 cm apart. The areas between rows were left undisturbed. The surface tilled zone is leveled by coulters and crows foot packer wheels behind the subsoiler. For CTMB, seedbeds were prepared by using disc harrow (Kongskilde Mfg., Soro, Denmark) to a depth of 8 cm and leveled with a S-tine harrow (Kongskilde Mfg., Soro, Denmark). At the time of seedbed preparation, N and P fertilizers (as urea and monoammoniun phosphate), based on the soil test and crop requirement, were applied at 130 kg N ha^{-1} and 105 kg P ha^{-1} for CTSB and STSB and at 122 kg N ha^{-1} and 55 kg P ha^{-1} for CTMB, respectively. Fertilizers were broadcast in CTSB and CTMB and banded to a depth of 20 cm in STSB during the fall tillage.

In April 2004, sugarbeet (cv. ACH 927 Large bare, American Crystal Co., Eden Prairie, MN) was seeded at 135,000 seeds ha^{-1} (60 cm row spacing) to a depth of 2.5 cm with a Heath unit planter (Arts-Way Mfg. Co., Armstrong, IA) for CTSB and STSB. Similarly, malt barley (cv. Certified Tradition, Busch Agricultural Resources, West Fargo, ND) was seeded at 90 kg ha^{-1} (20 cm row spacing) to a depth of 3.8 cm using the planter for CTMB. Both sugarbeet (in CTSB and STSB) and malt barley (in CTMB) were applied with appropriate herbicides and pesticides before planting, during growth, and after harvest to control weeds and pests. In July 2004, malt barley was hand harvested from an area of 1 × 1 m^2 for determining biomass (stems + leaves) yield after removing grains. Grain yield was determined from an area of 6.1 × 1.5 m^2 with a combine harvester (John Deere, Moline, IL). Similarly, in October 2004, sugarbeets were hand harvested from an area of 1.5 x 1.2 m^2 for determining beet and aboveground biomass yields. After harvesting the rest of malt barley grains with the combine harvester and sugarbeet with the sugarbeet harvester (John Deere, Moline, IL), all aboveground biomass (stems + leaves) of both malt barley and sugarbeet were returned to the soil.

After harvest in October 2004, crop residue cover was measured by using the USDA-NRCS point-method of counting 100 points per plot by a 15 m long string with each point at 0.15 m spacing (Shelton et al., 1993). Soil samples were collected with a hydraulic probe (5 cm i.d.) from 0 to 35 cm depth from five places in the middle rows of the plot. These were separated into 0 to 5 and 5 to 35 cm depths, composited within a depth, air-dried, sieved to 2 mm. Carbon and N concentrations in the biomass residue of sugarbeet and malt barley were analyzed by the high induction C and N analyzer (LECO Co., St Joseph, MI). Similarly, organic C and total N in soil samples were determined by using the C and N analyzer after pretreating the soil with 5% (v/v) H_2SO_3 to remove inorganic C. The NH_4-N and NO_3-N concentrations were determined by using the autoanalyzer (Lachat Instrument, Loveland, CO).

Data for plant biomass, residue cover, and soil C and N contents were analyzed using the MIXED procedure of SAS (Littell et al., 1996). Treatments contained two irrigation methods and three cropping systems arranged in a factorial design with eight replications. Means were separated by using the least square means test when treatments and interaction were significant. Statistical significance was evaluated at $P \leq 0.05$, unless otherwise stated.

RESULTS AND DISCUSSION

Crop Biomass Yields and Carbon and Nitrogen Contents

Irrigation method and its interaction with the cropping system were not significant for biomass yields of sugarbeet and malt barley returned to the soil, their C and N contents, and residue cover (Table 1). Biomass yield was higher but C and N concentrations were lower in CTMB than in CTSB and STSB. As a result, C content was higher but N content was lower in CTMB than in CTSB and STSB. Because of lower N concentration, N content was also lower in STSB than in CTSB. The C/N ratio of biomass was higher in CTMB than in CTSB and STSB. Similarly, residue cover was higher in CTMB than in CTSB and STSB.

Table 1. Effects of irrigation method and cropping system on biomass (stems + leaves) yields and C and N contents in sugarbeet and malt barley.

Treatment	Biomass Yield	Concentration C	Concentration N	Content C	Content N	C/N Ratio	Residue Cover
	Mg ha^{-1}	-------g kg^{-1}------		------kg ha^{-1}-----			%
Irrigation method†							
LEPA	6.45a‡	368a	18.0a	2275a	106a	20.4a	20.2a
MESA	6.40a	372a	18.3a	2314a	108a	20.3a	19.9a
Cropping system§							
CTSB	5.82b	394a	24.1a	2250b	140a	16.3b	4.8b
STSB	5.24b	396a	22.7b	2034b	120b	17.4b	5.2b
CTMB	8.20a	318b	7.6c	2599a	61c	41.8a	50.0a

† Irrigation methods are LEPA, low energy precision application; and MESA, mid-elevation sprinkler application.

‡ Numbers followed by same letter within a treatment are not significantly different by the least square means test at $P \leq 0.05$.

§ Cropping systems are CTMB, conventional till malt barley; CTSB, conventional till sugarbeet; and STSB, strip till sugarbeet.

Since the amount of water applied by the two irrigation methods were equal, water held by plant canopy and its evapo-transpiration from these sites in the MESA system had little effect in influencing the biomass yields and C and N contents of sugarbeet and malt barley and residue cover compared with the LEPA system. However, biomass yield, C and N contents, and residue cover varied with cropping system. Higher biomass yield increased C content and residue cover in CTMB but higher N concentration increased N content in CTSB and STSB. As a result, C/N ratio was higher in CTMB than in CTSB and STSB. Lower N concentration and content in STSB than in CTSB was probably a result of difference in N fertilization methods between the two cropping systems. Band application may have decreased N content in aboveground biomass in STSB compared with broadcast in CTSB. Greater residue cover in CTMB than in CTSB and STSB suggests that soil erosion will be less in this treatment.

Soil Carbon and Nitrogen

Like crop biomass yield, irrigation method and its interaction with cropping system did not influence soil organic C, total N, NH_4-N, and NO_3-N contents (Tables 2 and 3). Similarly, organic C and total N were not influenced by cropping system (Table 2). The NH_4-N content at 0 to 5 cm was higher in CTSB than in STSB and CTMB and at 5 to 35 and 0 to 35 cm was higher in CTSB than in CTMB (Table 3). The NO_3-N content at 0 to 5 and 5 to 35 cm was higher in CTMB than in CTSB and STSB.

Table 2. Effects of irrigation method and cropping system on soil organic C and total N contents at the 0 to 35 cm depth (footnotes similar to Table 3).

	Soil organic C at depth (cm)			Soil total N at depth (cm)		
Treatment	0 to 5	5 to 35	0 to 35	0 to 5	5 to 35	0 to 35
	--Mg ha^{-1}-----------------------------------					
Irrigation method†						
LEPA	8.6a‡	54.3a	62.9a	0.73a	6.09a	6.82a
MESA	8.7a	55.3a	64.0a	0.73a	4.44a	5.17a
Cropping system§						
CTSB	8.6a	56.3a	64.9a	0.75a	7.05a	7.80a
STSB	8.8a	53.1a	61.9a	0.72a	4.21a	4.93a
CTMB	8.6a	55.0a	63.6a	0.72a	4.54a	5.26a

Table 3. Effects of irrigation method and cropping system on soil NH_4-N and NO_3-N contents at the 0 to 35 cm depth.

	Soil NH_4-N at depth (cm)			Soil NO_3-N at depth (cm)		
Treatment	0 to 5	5 to 35	0 to 35	0 to 5	5 to 35	0 to 35
	--kg ha^{-1}-----------------------------------					
Irrigation method†						
LEPA	0.95a‡	7.10a	8.05a	4.92a	15.65a	20.57a
MESA	0.93a	7.05a	7.98a	4.20a	17.32a	21.52a
Cropping system§						
CTSB	0.97a	7.21a	8.18a	3.88b	13.43b	17.31b
STSB	0.92b	7.13ab	8.05ab	1.93b	12.98b	14.81b
CTMB	0.92b	6.90b	7.82b	7.88a	23.13a	31.01a

† Irrigation methods are LEPA, low energy precision application; and MESA, mid-elevation sprinkler application.
‡ Numbers followed by same letter within a treatment are not significantly different by the least square means test at $P \leq 0.05$.
§ Cropping systems are CTMB, conventional till malt barley; CTSB, conventional till sugarbeet; and STSB, strip till sugarbeet.

It was not surprising to observe the non-significant effect of irrigation method on soil C and N levels because biomass yields and their C and N contents as the source of C and N inputs returned to the soil were not different between the methods. Even with various biomass yields and C and N contents between crops and tillage systems, such as in CTSB vs. STSB, soil organic C and total N were not different between cropping systems. It takes more than 5 years to obtain the significant impact of tillage and cropping system on soil organic C and N under irrigated crops in the Great Plains (Peterson et al., 1998; Halvorson et al., 2002). However, lower soil NO_3-N content in CTSB and STSB than in CTMB (Table 3) could have resulted from higher N uptake by sugarbeet than in malt barley because N content in aboveground biomass was higher in CTSB and STSB than in CTMB (Table 1). Probably sugarbeet requires a higher amount of N or is more efficient in N uptake than malt barley. The higher NH_4-N content in CTSB than in

CTMB indicates that increased N content in sugarbeet was probably a result of greater uptake of NO_3-N than NH_4-N from the soil.

CONCLUSIONS

The impact of irrigation method on soil C and N levels could be related more with the biomass production of crops returned to the soil than with C and N mineralization, since the amount of water applied by both methods is the same. However, quality (such as C/N ratio) and quantity of biomass residue returned to the soil in different cropping systems, followed by various tillage system, such as in CTSB vs. STSB, could influence residue cover and soil C and N by influencing on C and N mineralization. Results of this study indicate that it will take more than a year to measure the effects of irrigation and cropping system on soil C and N storage. However, soil inorganic N level varied between cropping systems probably due to greater N requirement for sugarbeet than for malt barley.

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