LONG-TERM TILLAGE WITH WINTER WHEAT GRAIN YIELD IN DRYLAND CROPPING SYSTEM

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ABSTRACT

Long-term studies are important to improve our understanding and evaluate the sustainability of management practices while mitigating climate change. This study evaluated the winter-wheat grain yield stability under long-term tillage practices. Yield stability was assessed using squared deviation from regression (S^2d). This study of winter wheat-fallow rotation was established in 1970 within the High Plains Agricultural Laboratory (HPAL) near Sidney, Nebraska (NE) on Duroc loam soil with slope of ≤ 1%. Wheat grain yield will be presented from 1972 to 2010, with seven years of missing data, under three tillage intensity practices, no-tillage (NT), stubble mulch (SM), and moldboard plow (MP). Throughout the years, average wheat grain yield was about 2.60 Mg ha^{-1} with NT and 2.63 Mg ha^{-1} for MP and SM practices. Tillage did not significantly influence wheat yield ($P = 0.88$) except for six years out of 32 years where tillage had a significant ($P \leq 0.04$) effect on wheat yield. The years and year × tillage interaction significantly influenced wheat grain yield ($P < 0.01$). The influence of years and their interaction with tillage was mostly related to environmental factors (precipitation and temperature) associated with each year within the study period. The stability analysis (yield vs. environment) showed that changes in yield will not be influenced by small changes in environment. The SM practice demonstrates a possibility of yield stability (S^2d = 0.03 that was not significant than zero) under different environments compared with NT and MP practices. In general, SM practice that maintains surface residues could enhance land sustainability and improve yield resiliency under different environmental conditions in dryland cropping systems.

INTRODUCTION

Long-term studies are essential for evaluating the effect of management decisions on sustainable land production (Peterson et al., 2012) while mitigating climate change. In dryland cropping system, water is the most limiting factor for crop production. The wheat-fallow (WF) cropping systems was adapted at the central Great Plain region to improve soil water storage during the fallow period for subsequent wheat crops (Peterson et al., 1998). In this region, the WF system is predominantly associated with specific forms of tillage, either conventional tillage (CT) or moldboard plow (MP). The MP completely inverses and displace the soil surface layer and buries the crop residues in MP furrows, thus depriving the surface soil from its crop residue. In present time, there are multiple tillage practices are being implemented in which can conserve surface residue and reduce soil erosion due to the herbicides availability such as no-tillage (NT), strip, ridge, stubble mulch (SM), and minimum tillage (Reicosky, 2015). With changing climate, it became evident that the agricultural system that can produce stable yield across different environmental conditions could be preferable than the system that is unstable as the environment changes (Kiboi et al., 2017). The stable system is the one that can withstand changes with changing the environment (Raun et al., 1993). Yield stability is defined as the plant's ability to produce yield with less variability under different environmental conditions.

Yield stability analysis was considered useful to interpret the significant year × treatment interaction associated with long-term study where the same treatments were being implemented for several years (Raun et al. (1993). In the last few decades, the concept of yield stability has been used with soil nutrients management (Grover et al., 2009). Recently, Xu et al. (2019) reported that NT and subsoiling exhibit yield stability potential compared with conventional tillage system. In general, the influence of tillage on yield stability is being researched with some uncertainties and more research is yet to be done. Specifically, research regarding yield stability under different tillage practices in dryland cropping system is not extensively studied. Therefore, this research is evaluating the stability of long-term winter wheat grain yield under different tillage practices in dryland cropping system.

MATERIALS AND METHODS

The study was established in 1970 within the High Plains Agricultural Laboratory, Sidney, NE . The soil type is Duroc loam (fine-silty, mixed, superactive, mesic Pachic Haplustolls) with 0–1% slope. The crop rotation consist of winter wheat-fallow (WF), each phase of the rotation was present each year. Tillage practices consist of three levels of tillage intensity and frequencies, no tillage (NT), stubble mulch (SM), and moldboard plow (MP). Stubble mulch tillage accomplished by tilling the soil to a depth of 10–15 cm using 90–150 cm V-Blades with the operation performed two to four times but with a decrease in tilling depth for each subsequent operation. A rotary rod weeder was also used to perform one or two operations. This process maintains soil surface residues. Moldboard plowing was done in the spring at a depth of 15 cm depth followed by two or three operations using a field cultivator and one or two more operations using a rotary rod weeder. The study design was randomized complete block design with three replications with Each experimental unit's area of 8.5 × 45.5 m. Winter wheat was planted in early September. More detailed descriptions of research management were reported by Fenster (1961), Fenster and Peterson (1979), and Peterson et al. (2012). Weather data (precipitation and ambient temperature) from 1970 to 2010 were obtained from the weather station near the experimental site. Throughout the study period, tillage practices and study duration effects on grain yield were tested with F-tests by fitting a linear mixed model appropriate for a randomized complete block design using PROC MIXED procedure (SAS version 9.3). All results were considered significantly different at $P < 0.05$. The yield stability analysis was performed in R. The regression coefficients (βi) and squared deviation from regression (S^2d) were evaluated. The S^2d was used as a measure of dispersion around the regression line to provide an estimate of predictability and repeatability of performance of each tillage practice throughout the study period, represent as an environments. Coefficient of variation (CV) was also used for assessing grain yield variability among the different tillage practices. Detailed description of gain stability analysis is reported in (Aula et al., 2022).

RESULTS AND DISCUSSION

Throughout the study period, wheat grain yield was significantly influenced by study period (years) and by tillage × year interaction ($P < 0.0001$), but not by tillage practices. This indicate that the weather pattern (Precipitation and Temperature) within each year influenced the grain year in combination of tillage. The influence of weather pattern and tillage wheat yield were presented within each tillage practice (Fig. 1). The

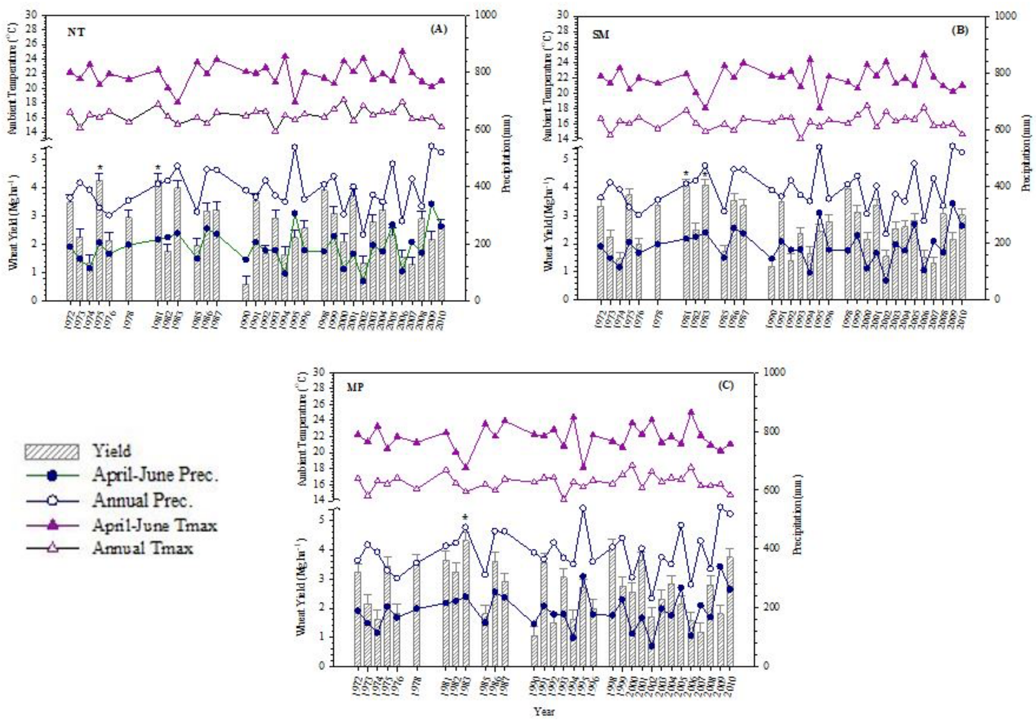

Figure 1. Wheat yield (bars) from 1972 to 2010 influenced by No-tillage, NT; stubble mulch, SM; and moldboard plow, MP tillage practices and by environmental condition, precipitation (blue line with circle symbols) and maximum ambient temperature (purple line with triangle symbols), from April to July. (A) represents wheat yield under NT; (B) represents wheat yield under SM; and C) represents wheat yield under MP. The error bars represent the standard errors of the mean. The filled symbols represent April to June precipitation and maximum temperature while the open symbols represent the annual precipitation and maximum temperature within each year. (*) represents the highest yield observed from 1970 to 2010 within each tillage practice.

highest ($P < 0.001$) wheat yield with NT were recorded in 1975 and 1981 with an average of 4.3 Mg ha^{-1} and the lowest yield was recorded in 1990 with an average of 0.6 Mg ha^{-1} (Fig. 1A). In SM has the highest yield in 1981, 1983, and 1998 with an average of 4.1 Mg ha^{-1} and the lowest yield was in 1990 with an average of 1.2 Mg ha^{-1} (Fig. 1B). Whereas the highest yield for MP management were in 1983 with an average of 4.3 Mg ha^{-1} and lowest yield 1990 with an average of 1.0 Mg ha^{-1} (Fig. 1C). The highest yield varied depending on the individual tillage practices interaction with the weather. Indicating that the weather could influence wheat yield depending on the type of tillage implemented. The lowest yield was reported in 1990 regardless of tillage practices which was probably not related to the precipitation that was not the lowest throughout the study period or to the ambient temperature that was almost like the previous and subsequent years. The low yield was probably related to other factors that we are not accounting for in this study such as rain intensity and temperature fluctuation between day and night during wheat critical growth stage. The quantity of rainfall may not be the restraining factor rather its extreme variability such as high rainfall intensity, uneven spatial or temporal distribution of the few rainy days (Hatibu et al., 2003) and temperatures fluctuations (Zampieri et al., 2020) could affect crop yield in dryland cropping system.

Principal component analysis (PCA) was performed to evaluate the relationship between study parameters (Fig. 2). Our data showed that yield was positively correlated to precipitation while negatively influenced by ambient temperature, indicating that the increase in precipitation will lead to yield increase while increasing in ambient temperature will cause a reduction in wheat yield. The length of the precipitation variables, represented by arrows, (prec. summer and prec. seasonal) has the same length indicating that both variables have equal contribution to the yield increased. However, the length of the temperature variable Tmax. Summer was longer than the variable Tmax. seasonal indicating that the negative influence of Tmax. Summer is more influential on wheat yield than Tmax. Seasonal. In addition, the ambient temperature from April to June, the critical wheat growth stage, is more important than the seasonal temperature.

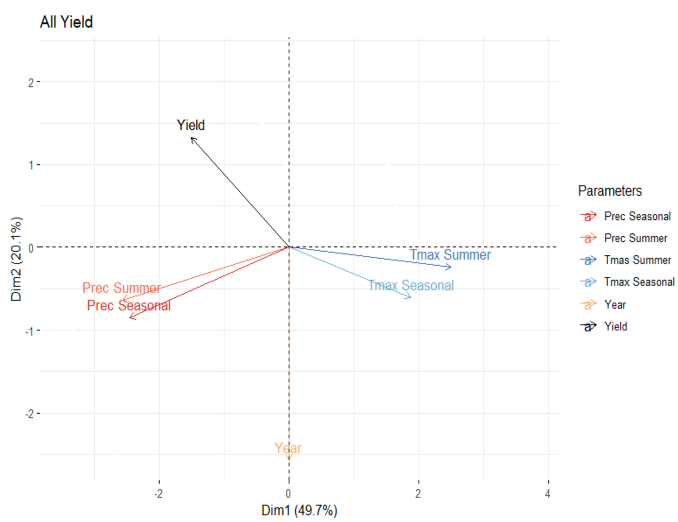

Figure 2. Wheat yield throughout the study period influence by summer (April to June) and seasonal precipitation (mm) and ambient temperature (℃) throughout the wheat growing season from 1972 to 2010. The Prec. Summer and Tmax. summer, represent the period from April to June and prec. seasonal and Tmax. Seasonal represent the wheat growing season within each year of the study. The principal component analysis (PCA): arrows indicate correlation of parameters with the principal component. Percentage refer to variability explained by the principal component.

Wheat yield stability could provide a direct approach in evaluating the influence of the temporal changes on land sustainability (Raun et al., 1993).The regression coefficient, β_i and square deviation from regression, $\delta^2 d_i$ (Table 1), were used to evaluate the performance and the suitability of each tillage, regarding wheat yield, under different environments throughout the 39 years. Our data suggested that different tillage practices (NT, SM, and MP) exhibit average yield stability due to the β_i's that were not significant (P = 0.43) from zero and β_i's values of ~ 1.0 (Table 1). Indicating that all tillage practices were equally adequate to be implemented. The regression line (Fig. 3) of each tillage practice was not different that the regression line of the environmental mean (black line). Indicating that minor changes in the environment have no influence on changing in grain yield among different tillage practices.

Table 1. Wheat yield stability parameters (mean yield, m_i; regression coefficient, β_i; square deviation from regression, $\delta^2 d_i$; and Coefficient of variation CV influenced by No-tillage, NT; stubble mulch, SM; and moldboard plow, MP tillage practices. Table adapted from Aula et al., (2022).

Tillage	$Yield_{(mean)}$	$Yield_{(differences)}$[a]	β_i	$\delta^2 d_i$	CV
	------------ Mg ha^{-1} ------------				%
NT	2.60	– 0.02	1.04†	0.063*	37.6
SM	2.63	0.01	0.97	0.027	33.9
MP	2.63	0.01	0.99	0.075**	36.3

[a] Yield difference was computed as yield associated with a particular tillage practice minus population average yield (2.62 Mg ha^{-1}).; * Significant at the $P \leq 0.05$. ** Significant at the $P \leq 0.01$; † ns, not significant at $P = 0.43$

The influence of different tillage practices on yield stability could be evaluated using $\delta^2 d_i$, square deviation from regression. For this parameter, $\delta^2 d_i$, the zero value represents high yield stability while the significant deviation from zero represents low yield stability. In our study, the $\delta^2 d_i = 0.03$ was associated with SM practice (Table 1) and was not significant than zero indicating higher yield stability under different environments. While the NT showed the $\delta^2 d_i = 0.063$ and MP had the $\delta^2 d_i = 0.075$ that were significantly different than zero (Table 1), indicating that NT and MP are suitable in specific environments. The NT with $\beta_i = 1.04$ (> 1.0) indicate that NT could perform well in high-yielding environments while MP with $\beta_i = 0.99$ (< 1.0) may perform well in low-yielding environments (Fig. 3). The MP performed well in low-yielding environment could be related to no nutrient addition to this study site since the 1970. We believe that the MP practice of mixing crop residue with soil could provide nutrients for crop through residue decomposition relative to NT practice.

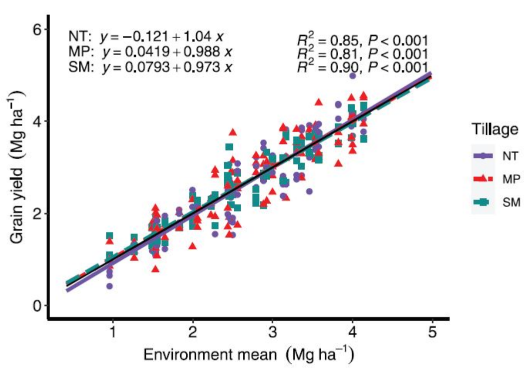

Figure 3. Wheat yield stability analysis throughout the study period 1972-2010 influenced by tillage practices, no-tillage, NT; moldboard plow, MP; and stubble mulch, SM. The solid line represents the population mean. Figure adapted from Aula et al., (2022).

Our observation regarding the $\delta^2 d_i$ relation to yield stability was supported by the Coefficient of variation (CV) valued (Table 1). The CV of 33.9% was associated with SM compared with NT of 37.6% and MP of 36.3% indicate that the variability of the β_i and the intercept of SM practice was low (Fig 3).This study showed that the stability of long-term wheat yield was influenced by different tillage practices in the dryland cropping. Significant grain yield stability was associated with the SM which could be related improvement of soil properties that was not associated with NT or MP practices. Further research regarding soil properties need to be examined to relate soil properties and nutrients dynamics to yield stability under different tillage practices.

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