Tillage practices and nitrogen rates influenced wheat and sorghum yield and nitrogen use efficiency in long-term dryland wheat-sorghum rotation system

by

Mosaed Abdullah Majrashi

B.S., King Saud University, 2005
M.S., Kansas State University, 2018

An Abstract of a Dissertation

submitted in partial fulfillment of the requirements for the degree

Doctor of Philosophy

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2020

Abstract

A major challenge for agronomists is developing cropping systems that exhibit superior performance across variable environmental conditions. Long-term field research trials provide a direct measure of the effect of environmental conditions within the context of treatment effects. Winter wheat (*Triticum aestivum* L.) is the most widely grown base crop in dryland systems of the semiarid central Great Plains, but grain yields are limited by nitrogen (N) and soil water availability. The goal of this research was to assess long-term cropping systems of winter wheat-grain sorghum-fallow in dryland. The focus was to determine the effect of three tillage practices and rates of N fertilization rates effects on the efficiency of the management system and grain yields for 2015-2018, and evaluate the yield stability for both crops in a 53-year-old crop rotation and fertility experiment.

In the first study we evaluated the long-term effects of three different tillage practices and four N fertilizer rates on grain yield, protein content, and N use efficiency indices of winter wheat and grain sorghum in 2015-2018. The experiment was conducted on a long-term plot initiated in 1965 in Hays, KS as a split-split-plot arrangement of rotation, tillage, and N fertilizer treatments with four replications in a randomized complete block design. The main plots were the crop phase (winter wheat, grain sorghum, or fallow), sub-plots were three tillage treatments [conventional tillage (CT), reduced tillage (RT), and no-tillage (NT)]. The sub-sub-plots were four N rates (0, 22, 45, and 67 kg N ha^{-1}) later modified in the 2015 growing season to 0, 45, 90, and 134 kg ha^{-1}.

Results showed tillage × N rate interaction had no significant ($P = 0.608$) effect on grain yield. Year × tillage and year × N rate had significant ($P < 0.0001$) effect on grain yield. Across N rates, grain yield, NAE and ANR were more in soils under NT compared with CT or RT.

Grain yield under NT increased by 8 kg ha^{-1} for every mm of growing season precipitation compared with 4 kg ha^{-1} with CT or RT. Nitrogen application significantly ($P < 0.05$) increased grain yield and protein concentration, but NAE and ANR decreased beyond 45 kg N ha^{-1}. Our results showed NT is the best management practice to increased grain sorghum yields, N use indices and sustainability in dryland systems.

Winter wheat yield with CT was greater than RT or NT, but tillage had no significant effect on ANR, NAE or N utilization efficiency (NUtE, kg grain/ kg total N uptake) averaged across the four-years. Grain yield, protein content, total N uptake, and NUtE of winter wheat increased with increasing N rates. But the NAE and RAN decreased at higher N rates. Tillage systems had little effect on the total N uptake and NUE indices. The benefits of NT can be realized with appropriate N fertilization. However, the extent of that benefit and the appropriate N fertilization rate depends on the amount and timing of precipitation during the growing season. That benefit also depends on the effectiveness of weed control practices.

A second study was conducted to evaluate the long-term effects of three different tillage practices in four N fertilizer rates on yield of winter wheat and grain sorghum, yield trend, and yield stability from 1975 to 2014. We hypothesized that yield would be higher, more stable, and increase more over time in i) NT practices compared to most intensive tillage CT and RT systems, and ii) highest N fertilizer rate compared to unfertilized control and 20 kg N ha^{-1}. The stability analysis showed grain yield with each tillage practice was more stable with increasing N fertilizer rates. The data created from this long-term experimental study of winter wheat-grain sorghum- fallow production systems showed temporal variability in yield for both crops, which was evident with all treatment combinations. An analysis of variances was shown that practices were a significant factor for predicting yield in 24 out of 31 years (77% of years) for winter wheat in 17 out 30 years (57% of years) for grain sorghum. N fertilizer rate was a significant factor for predicting yield in 31 out of 31 years (100% of years) for winter wheat in 27 out 30 years (90% of years) for grain sorghum during the study periods at significant level of 0.05. Yield stability analysis indicated yields under NT responded poorly in winter wheat or equally in grain sorghum in low-yielding environments compared to the more intensive tillage practices of CT or RT. In high-yielding environments CT and RT produced greater yields than NT. In general, N fertilizer application resulted in more stable yields compared to unfertilized controls. This effect was more pronounced in low yielding environments for both crops. When fertilized, NT production in low yielding environments generated yields comparable to CT or RT treatments. The amount and distribution of precipitation throughout the growing season or during the fallow period preceding crop planting were the most important factors influencing yields of both crops, though that impact was influenced by N fertilization rate. Overall, yield stability analysis indicated that the use of RT or CT along with adequate N fertilization produced higher wheat yields across all yield environments compared to NT.

Tillage practices and nitrogen rates influenced wheat and sorghum yield and nitrogen use efficiency in long-term dryland wheat-sorghum rotation system

by

Mosaed Abdullah Majrashi

B.S., King Saud University, 2005
M.S., Kansas State University, 2018

A Dissertation

submitted in partial fulfillment of the requirements for the degree

Doctor of Philosophy

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2020

Approved by:

Co-Major Professor
Dr. Augustine Obour

Approved by:

Co-Major Professor
Dr. Colby Moorberg

Copyright

Abstract

A major challenge for agronomists is developing cropping systems that exhibit superior performance across variable environmental conditions. Long-term field research trials provide a direct measure of the effect of environmental conditions within the context of treatment effects. Winter wheat (*Triticum aestivum* L.) is the most widely grown base crop in dryland systems of the semiarid central Great Plains, but grain yields are limited by nitrogen (N) and soil water availability. The goal of this research was to assess long-term cropping systems of winter wheat-grain sorghum-fallow in dryland. The focus was to determine the effect of three tillage practices and rates of N fertilization rates effects on the efficiency of the management system and grain yields for 2015-2018, and evaluate the yield stability for both crops in a 53-year-old crop rotation and fertility experiment.

In the first study we evaluated the long-term effects of three different tillage practices and four N fertilizer rates on grain yield, protein content, and N use efficiency indices of winter wheat and grain sorghum in 2015-2018. The experiment was conducted on a long-term plot initiated in 1965 in Hays, KS as a split-split-plot arrangement of rotation, tillage, and N fertilizer treatments with four replications in a randomized complete block design. The main plots were the crop phase (winter wheat, grain sorghum, or fallow), sub-plots were three tillage treatments [conventional tillage (CT), reduced tillage (RT), and no-tillage (NT)]. The sub-sub-plots were four N rates (0, 22, 45, and 67 kg N ha^{-1}) later modified in the 2015 growing season to 0, 45, 90, and 134 kg ha^{-1}.

Results showed tillage × N rate interaction had no significant ($P = 0.608$) effect on grain yield. Year × tillage and year × N rate had significant ($P < 0.0001$) effect on grain yield. Across N rates, grain yield, NAE and ANR were more in soils under NT compared with CT or RT.

Grain yield under NT increased by 8 kg ha^{-1} for every mm of growing season precipitation compared with 4 kg ha^{-1} with CT or RT. Nitrogen application significantly ($P < 0.05$) increased grain yield and protein concentration, but NAE and ANR decreased beyond 45 kg N ha^{-1}. Our results showed NT is the best management practice to increased grain sorghum yields, N use indices and sustainability in dryland systems.

Winter wheat yield with CT was greater than RT or NT, but tillage had no significant effect on ANR, NAE or N utilization efficiency (NUtE, kg grain/ kg total N uptake) averaged across the four-years. Grain yield, protein content, total N uptake, and NUtE of winter wheat increased with increasing N rates. But the NAE and RAN decreased at higher N rates. Tillage systems had little effect on the total N uptake and NUE indices. The benefits of NT can be realized with appropriate N fertilization. However, the extent of that benefit and the appropriate N fertilization rate depends on the amount and timing of precipitation during the growing season. That benefit also depends on the effectiveness of weed control practices.

A second study was conducted to evaluate the long-term effects of three different tillage practices in four N fertilizer rates on yield of winter wheat and grain sorghum, yield trend, and yield stability from 1975 to 2014. We hypothesized that yield would be higher, more stable, and increase more over time in i) NT practices compared to most intensive tillage CT and RT systems, and ii) highest N fertilizer rate compared to unfertilized control and 20 kg N ha^{-1}. The stability analysis showed grain yield with each tillage practice was more stable with increasing N fertilizer rates. The data created from this long-term experimental study of winter wheat-grain sorghum- fallow production systems showed temporal variability in yield for both crops, which was evident with all treatment combinations. An analysis of variances was shown that practices were a significant factor for predicting yield in 24 out of 31 years (77% of years) for winter

wheat in 17 out 30 years (57% of years) for grain sorghum. N fertilizer rate was a significant factor for predicting yield in 31 out of 31 years (100% of years) for winter wheat in 27 out 30 years (90% of years) for grain sorghum during the study periods at significant level of 0.05. Yield stability analysis indicated yields under NT responded poorly in winter wheat or equally in grain sorghum in low-yielding environments compared to the more intensive tillage practices of CT or RT. In high-yielding environments CT and RT produced greater yields than NT. In general, N fertilizer application resulted in more stable yields compared to unfertilized controls. This effect was more pronounced in low yielding environments for both crops. When fertilized, NT production in low yielding environments generated yields comparable to CT or RT treatments. The amount and distribution of precipitation throughout the growing season or during the fallow period preceding crop planting were the most important factors influencing yields of both crops, though that impact was influenced by N fertilization rate. Overall, yield stability analysis indicated that the use of RT or CT along with adequate N fertilization produced higher wheat yields across all yield environments compared to NT.

Table of Contents

List of Figures xiii
List of Tables xv
Acknowledgements xviii
Dedication xx
Chapter 1 - Introduction and Literature Review 1
  Introduction 1
  Literature Review 5
    Effects of Soil Management Practices on Soil Water and Nitrogen 5
    Effects of Soil Management Practices 6
      Soil Water Storage 9
    Nitrogen, Plant Growth, and Crop Production 10
    Soil Nitrogen Losses, Nitrogen Mineralization, and Soil Management 14
      Denitrification 15
      Leaching 17
      Volatilization 19
      Surface Runoff 21
      Mineralization, Immobilization, and Mineralization-Immobilization 22
    Nitrogen Use Efficiency 24
      Factors influencing NUE 25
    Yield Stability 29
    Summary 34
  References 35
Chapter 2 - Long-Term Tillage and Nitrogen Rates Influenced Sorghum Yield in Dryland Wheat-Sorghum Rotation 62
  Abstract 62
  Introduction 63
  Materials and Methods 65
    Site Description and Experimental Design 65
    Sorghum Crop Yield 67

Calculations of Nitrogen use Efficiency Indices ... 67

Statistical Analysis Methods ... 68

Results ... 69

Grain Sorghum Yield ... 69

Nitrogen Use Efficiency ... 72

Discussion ... 73

Conclusion ... 78

References ... 85

Chapter 3 - Long-Term Tillage and Nitrogen Rates Influenced Winter Wheat Yield in Dryland Wheat-Sorghum Rotation ... 92

Introduction ... 93

Materials and Methods ... 95

Site Description and Experimental Design ... 95

Wheat crop yield and Biomass ... 97

Calculations of Nitrogen use efficiency indices ... 98

Statistical Analysis ... 98

Results ... 99

Winter Wheat Yield ... 99

Winter Wheat Protein Content ... 100

Winter Wheat Total N Uptake ... 101

N use efficiency indicators ... 101

Discussion ... 104

Conclusion ... 108

References ... 115

Chapter 4 - Crop Yield Stability as Affected by Long-Term Tillage and Nitrogen Fertilizer Rates in Dryland Wheat and Sorghum Production Systems ... 124

Abstract ... 124

Introduction ... 125

Materials and Methods ... 129

Site Description and Experimental Design ... 129

Weather Influence on Crop Yields ... 130

Wheat and grain sorghum crop yield ... 131
Statistical Analysis Methods ... 131
Analyses of Variance (ANOVA) ... 131
Stability Analysis of both Crop Yields ... 133
Results and Discussion ... 134
Yield Response ... 134
Stability Analysis ... 137
Conclusion and Summary ... 141
References ... 158

List of Figures

Figure 2.1 Grain sorghum yield variability as affected by tillage × N fertilizer rates (a); years of study (2015 through 2018) (b), tillage practice (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT) (c), and N fertilizer rate (d) in Hays, KS. Means followed by same letter (s) are not different using Tukey's Honest Significant Difference Test at $P < 0.05$ ... 83

Figure 2.2 Sorghum grain protein concentration as affected by tillage (a) and N fertilization rates (b) over four study years in Hays, KS. Tillage and N rate means followed by same uppercase letter (s) within a given year are not different. Lowercase letters represent tillage and N rate comparisons across years. All mean comparisons done using Tukey's Honest Significant Difference Test at $P < 0.05$ ... 84

Figure 4.1 Selected precipitation periods during fallow period (PF), in the growing season (PG), and sum of March to May, January to March (PWinter) and April (PApril) of each given year for winter wheat (A) and grain sorghum (B) in Hays, KS ... 143

Figure 4.2 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by tillage practices across N fertilizer rates in Hays, KS, 1975-2014 ... 144

Figure 4.3 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by N fertilizer rates across tillage practices in Hays, KS, 1975-2014 ... 145

Figure 4.4 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by tillage practices at N fertilizer rate of 0 kg ha^{-1} in Hays, KS, 1975-2014 ... 146

Figure 4.5 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by tillage practices at N fertilizer rate of 22 kg ha^{-1} in Hays, KS, 1975-2014 ... 147

Figure 4.6 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by tillage practices at N fertilizer rate of 45 kg ha^{-1} in Hays, KS, 1975-2014 ... 148

Figure 4.7 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by tillage practices at N fertilizer rate of 67 kg ha^{-1} in Hays, KS, 1975-2014 149

List of Tables

Table 2.1 Average monthly precipitation and temperature over four grain sorghum growing seasons at Hays, KS 79

Table 2.2 Sorghum grain yield and grain N removal (GNR, kg ha^{-1}) influenced by tillage (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and N fertilizer rates over four growing seasons at Hays, KS 80

Table 2.3 Multiple linear regression analysis of grain sorghum yields as a function of N fertilizer rate (N rate, kg N ha^{-1}), total fallow precipitation (PF, mm, from January through May) and growing season precipitation (PG, mm, from June through September) for each tillage practices (CT, RT, and NT) over four growing seasons at Hays, KS 81

Table 2.4 Means of sorghum grain nitrogen agronomic efficiency (NAE, kg grain /kg applied N) and applied N recovery (ANR,%) influenced by years of study (2015, 2016, 2017, and 2018), tillage (T) practices (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and N fertilizer rates (0, 45, 90, and 134 kg N/ha) 82

Table 3.1 Total and average monthly and growing season periods of precipitation and temperature of winter wheat growing season for 2015, 2016, 2017, and 2018 at Hays, KS 110

Table 3.2 Means of winter wheat yield and grain protein concentration influenced by years of study (2015, 2016, 2017, and 2018), tillage (T) practices (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and N fertilizer rates (0, 45, 90, 134, kg N/ha), and their interaction 111

Table 3.3 Linear regression analysis over 4-yr study periods (2015 through 2018) of winter wheat yields as a function of N fertilizer rate (N rate, Kg N ha^{-1}), PFall (Oct. through Dec.), PWinter (Jan. through March) by each tillage practices (CT, RT, and NT) 112

Table 3.4 Means of winter wheat total N uptake (TNUp, kg ha^{-1}) and N utilization efficiency (NUtE, kg grain/ kg N applied) influenced by years of study (2015, 2016, 2017, and 2018), tillage (T) practices (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and N fertilizer rates (0, 45, 90, 134, kg N/ha) and their interaction 113

Table 3.5 Means of winter wheat nitrogen agronomic efficiency (NAE, kg grain /kg applied N) and applied N recovery (ANR,%) influenced by years of study (2015, 2016, 2017, and

2018), tillage (T) practices (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and N fertilizer rates (0, 45, 90, and 134 kg N/ha) and their interaction.................... 114

Table 4.1 The analysis of variance for winter wheat yield and grain sorghum of 404 plots in Hays, KS, with three different constant tillage practices (conventional tillage, reduced tillage, and no-tillage) nested with four nitrogen (N) fertilizer rates (0, 22, 45, and 67 kg N/ ha) 150

Table 4.2 Analysis of variance summary of the effects of tillage (TILL), N fertilizer rate (NR), and their interactions on winter wheat grain yield at each year from 1975 to 2014 (Noted: data are missing from 2004 2012 for winter wheat) 151

Table 4.3 Analysis of variance summary of the effects of tillage (TILL), N fertilizer rate (NR), and their interactions on winter wheat grain yield (kg/ha) at each year from 1975 to 2014 (Noted: data are missing from 2003 2012 for grain sorghum) 152

Table 4.4 Linear regression analysis of grain yield stability of winter wheat on environment index in 404 plots in Hays, KS, with three different constant tillage practices (CT, RT, and NT) nested with four nitrogen rates (NR) (0, 22, 45, and 67 kg N/ ha), and their interaction 153

Table 4.5 Linear regression analysis of grain yield stability of grain sorghum (Mg ha^{-1}) on environment index in 404 plots in Hays, KS, with three different constant tillage practices (CT, RT, and NT) nested with four nitrogen rates (NR) (0, 22, 45, and 67 kg N/ ha), and their interaction 154

Table 4.6 Differences in slopes and intercepts for treatment of tillage practices (CT, RT, and NT), N fertilizer rates (NR) (0, 22, 45, and 67 kg N/ ha) regression equations of winter wheat for 31 years and grain sorghum for 30 year of the study periods; in 404 plots in Hays, KS 155

Table 4.7 Linear regression analysis over 31-yr study periods (1975 through 2014) of winter wheat yields as a function of N fertilizer rate (N rate, Kg N ha^{-1}), total precipitation of fallow (PF, from Nov. to September) and through growing season precipitation of PWinter (Jan. through March) and PApril (summed of April.),by each tillage practices (CT, RT, and NT).. 156

Table 4.8 Linear regression analysis over 30-yr study periods (1975 through 2014) grain sorghum yields as a function of N fertilizer rate (N rate, kg N ha^{-1}), total fallow precipitation

(PF, mm, from March through May) and growing season precipitation (PG, mm, from June through October) for each tillage practices (CT, RT, and NT) over four growing seasons at Hays, KS 157

Acknowledgements

Praise is due to Allah whose worth cannot be described by speakers, whose bounties cannot be counted by calculators and whose claim (to obedience) cannot be satisfied by those who attempt to do so, whom the height of intellectual courage cannot appreciate, and the diving of understanding cannot reach; He for whose description no limit has been laid down, no eulogy exists, no time is ordained, and no duration is fixed. May peace and blessings of Allah Almighty be upon His all Prophets, including Muhammad (peace be upon him), His last messenger, who is the fountain of knowledge and guidance for the salvation of mankind in this world and the hereafter.

I feel a paucity of words and phrases to express my deepest and eternal gratitude to my supervisors, Dr. Augustine Obour and Dr. Colby Moorberg, Professor, Department of Agronomy, Kansas State University, Manhattan, KS. They were very kind and generous in their auspicious help, scholarly guidance, great encouragement, and affectionate support that was a colossal source of inspiration and solace for me in the quest of my Ph.D. program. At the same time, I don`t have words to utter for Dr. Jaun Du and Dr. Romulo Lollato for their consistent, supportive, dedicative, and suggestive research and analysis.

Likewise, I am thankful to Dr. Maysoon Mikha, Research Soil Scientist at USDA-ARS Central Great Plains Research, Akron, Colorado for allowing me to use her laboratory for plant samples analysis for Nitrogen & carbon. Furthermore, I am thankful for Dr. Maysoon and Yared Assefa for the statistic discussion and improve SAS coding.

I am thankful to the research support staff at the Kansas State University Western Kansas Agricultural Research Center, Hays, Kansas. The Technicians at the Soils Lab in Hays, Mr. Joe Kimzey and Tanner Yohe, helped with planting, harvesting, and soil sampling. I'll extend my

sincere thanks to my respectable colleagues Dr. Eric Obeng and Morgan Pearman for their help during planting, harvesting, and plant and soil sampling.

I owe a heartfelt debt of gratitude to my very close friends, Dr. Zafer Alasmary, Dr. Raghavendra Amachawadi, Dr. Mohammad Almutari, and Omar Alqahtani, who endured all the strains and stress during my study while their hearts were beating with prayers for my success.

I am grateful to the Department of Agronomy at Kansas State University for offering the Ph.D.'s admission, which helped to pursue my Ph.D. program after I finished my master's degree. I can't forget to thank king Saud University, which is represented by SACM, for the scholarship offers, which helped to ease my financial burden during the course of my studies

Dedication

I dedicate this dissertation to parents, brothers, sisters, and my wife and three children (the fourth one on the way) for motivating me and keeping my morale high as well as the most affectionate supportive people. Also, everyone who has contributed to being successful in my education. May Allah (Almighty) infuses me with the energy to fulfill their inspirations and expectations and modify my competence. May Allah bless them all with lives full of happiness and contentment.

Chapter 1 - Introduction and Literature Review

Introduction

Western Kansas and the western Great Plains are a productive region for winter wheat (*Triticum aestivum* L.) and grain sorghum (*Sorghum bicolor* (L.) Moench ssp. *Bicolor*), among other crops. However, the region recieves limited, highly variable amounts of rainfall. Success of rain-fed (dryland) crop production in the region requires careful management of soil moisture, which is acomplished with a focus on tillage intensity, residue management, and soil fertility.

Variability in precipitation and poor soil fertility are the major factors limiting the productivity in dryland farming regions around the world due to the sensitively of crops to water and nutrient deficits during critical growth stages (Nawaz and Farooq, 2016; Fahad et al., 2017; Zhang et al., 2018). These dryland regions account for more than 40% of land area on Earth (Turner et al. 2011). Water limitation accounts for about 30-70% loss of productivity of field crops during the crop growth period (Kumaraswamy and Shetty, 2016; Lilliane and Charles, 2020). Water deficiencies can result from low or unpredictable precipitation, as well as inefficient precipitation storage in the soil during fallow periods (Unger et al., 1997). There is growing interest in increasing productivity of dryland farming operations. Adoption of agronomic practices that increase productivity from rainfall is a critical aspect in the intensification of dryland farming, particularly in semiarid regions where water limitations are severe (Koohafkan and Stewart, 2008).

Fahad et al., (2017) stated that wheat is impacted by drought stress and high temperature stress during all growth stages, but grain formation and the reproductive stage are the most critical stages. Wheat yield can decrease 1-30% during mild drought stress at post-anthesis, and yield can decrease up to an additional 90% under prolonged mild drought stress at flowering and grain formation (Araus et al., 2002; de Oliveira et al., 2013). Improvement in precipitation use efficiency is of crucial importance for crop productivity in drylandagricultural systems. The term "water use efficiency" is often employed to quantify water productivity (Nielsen and Vigil, 2010; Zhang et al., 2018; Sun et al., 2019).

A common cropping system in the central Great Plains is winter wheat-summer crop-fallow with no-till (NT) (Halvorson et al., 2004). However, there have been limited long-term nitrogen (N) fertilization studies conducted in this region. Nitrogen fertilizer applications are a key component in increasing agricultural production, and long-term studies are necessary to observe changes in nutrient dynamics in order to develop strategies for sustainable productivity and improving nitrogen use efficiency (NUE) and soil health (Antil and Raj, 2020). This would help avoid over- or under-applying N fertilizer, and will maintain soil health (Fageria et al., 1991; Havlin et al., 2005). The N mineralization process is a key component of the soil N cycle, and is influenced by the crop production system, tillage practices, type of fertilizer, and fertilizer application method. N mineralization is mediated mainly by microbes, and involves the transformation of organic N into plant-available mineral forms - primarily nitrate and ammonium (Sainju et al., 2007; Montemurro, 2009). The availability of N from fertilizer depends on the placement and sources of fertilizer (Malhi et al., 1996), which, in turn, vary based on tillage practice. Several researchers have found that conservation agriculture (CA) systems (e.g., NT and reduced tillage, RT) and placement of N fertilizer were more important than the timing of fertilizer applications to reduce N fertilizer losses resulting from immobilization and volatilization (Malhi et al. 2001; Ladha et al. 2005; Grahmann et al. 2013). Additionally, N fertilizer application increases the production of dry matter of wheat crop production (Soon et al., 2008), but over application of N fertilizer could decrease crop NUE (Habbib et al., 2017) .

Increased efficiency is vital for the economic sustainability of crop production systems (Yadav et al., 2017). Accorrding to Omara et al., (2019), winter wheat producers in the central Great Plains of the US currently practicing conventional tillage (CT) could improve the efficiency of surface-applied fertilizer N and farm profitability by adopting NT. However, N fertilizer, subject to many different transformations, can cause challenges to environmental management such as soil denitrification, volatilization, leaching, surface runoff, plant uptake, immobilization, and gaseous plant emissions (Halvoson and Rule, 1994; Fageria and Baligar, 2005).

Nitrogen is an essential nutrient for all plants, and is the main nutrient that limits agricultural production in arid and semiarid regions (Kant et al., 2011; and Wu et al., 2019). Due to chemical, physical, and biological soil properties, the form and quantity of N in the soil regularly fluctuates (Grahmann et al., 2013), which, in turn, effects N use by crops. Nitrogen management has become a critical part of sustainable agriculture (Goulding et al., 2008). Mineralization of N from soil organic matter and applied N by fertilizer are the most important sources to meet the N requirement of crops (Yadav et al., 2017). However, the proportion that comes from mineralization is less than that from most fertilizers due to slow rate of N mineralization, which in turn is due to many factors. Those factors include available moisture, soil temperature, aeration status, and microbial activity (Giller et al., 2004; and Yadav et al., 2017); whereas those factors would effect by tillage practices and then nutrients availability particularly N (Silgram and Shepherd, 1999).

Tillage practices greatly affect soil moisture and temperature, which in turn affect soil N dynamics (Torbet and Woods, 1992; Nadelhoffer et al., 1991). For example, N availability from mineralization can be reduced due to low soil moisture with mild temperature (Giller et al., 2004; and Yadav et al., 2017). Conversely, higher temperatures enhanced N uptake by plants by increasing the availability of soil N (Sardans and Peñuelas, 2012). Instead, a higher temperature regularly results in a decline of plant N use efficiency (NUE, because higher temperatures increase plant-microbial competition for N and lead to more N becoming immobilized in microorganisms (Kuzyakov and Xu, 2013). The C:N ratio is an indictor of NUE; according to Zhang et al. (2020), reported that, plants with a higher C:N ratio promote NUE under strong N-limited conditions to ensure survival priority, when compared to plants with a lower C:N ratio. In nature, larger proportion of species with a high C:N ratio enabled communities to inhabit more N-limited conditions. This would lead to a reduction of N utilization by crops and depresses yields (Rathke et al., 2006). Higher temperatures also increase the risk of N losses due to increasing N_2O efflux (Ma et al., 2010) and decreasing NUE and crop biomass (Liu et al., 2013).

The NUE can be defined and calculated in many ways (Goulding et al., 2008). The NUE and its components are indirect measurements of the sustainability of production systems (Pourazari et al., 2015; Yadav et al., 2017). Consequently, a strong emphasis is being placed on NUE in wheat production systems (Raun and Johnson,1999). Therefore, there is a need for new strategies aiming for higher crop NUE in combination with fewer N fertilizer inputs (Wu et al., 2019). Long-term field research with nutrient management is critical to determine the complex soil-plant-climate interactions with possible benefits for improving NUE (Powlson et al., 2011). Measuring NUE is challenging because of the number of different ways in which the data can be presented and analyzed in combination with the inherent statistical issues associated with these measurements. There were a many definitions of NUE. NUE components, N uptake efficiency (NUpE), and N utilization efficiency (NUtE) have been typically used for characterizing newly developed cereal genotypes and are primary component of NUE (Moll et al., 1982; Samonte et al., 2006). However, those testing the N efficiency of agronomic practices have used other NUE-associated components due to a change in strategy targeting higher crop NUE in combination with the application of less N fertilizer (Wu et al., 2019). For example, about 88% of the yield difference was due to NUtE with high rate of applied N (Huggins and Pan, 1993). However, increasing doses of N fertilizer did not show a different increase in wheat N utilization; the N rate of 120 kg N ha^{-1}showed the same values of N utilization indices as compared to 180 kg N ha^{-1} (Montemurro et al., 2007). Measuring the N agronomic efficiency (NAE), crop applied N recovery (ANR), and physiological efficiency of applied N (PEN) are recommended by Dobermann (2005) and Ladha et al. (2005). The AEN is the product of the recovered N by the plant, multiplied by the efficiency with which this N is converted into the crop´s part of economic interest (grain, for cereals). In general, these N ratios have shown a tendency to decrease as the N inputs were increased (Halvorson et al., 2004).

Literature Review

This literature review will cover important contributions to the scientific literature related to sorghum and wheat production in two parts. It begins with soil management, tillage intensity, and nitrogen dynamics - concepts that directly influence carbon, nitrogen, and water dynamics in all agricultural systems, but that are particularly important in the central Great Plains. The review concludes with a focus on yield stability, which is influenced by many factors such as crop rotation, tillage practices, and N fertilization with different sources.

Effects of Soil Management Practices on Soil Water and Nitrogen

Recent increased intensity of agriculture has raised the question of the long-term sustainability of agro-ecosystems (Liebig et al., 2004; Frison et al., 2011). Long-term experiments provide insight to sustainability of intensive production systems (Rasmussen et al., 1998; Takahashi, and Anwar, 2007). Problems associated with intensification of agricultural systems such as extreme weather events, drought, pollution, demand for plant biomass for biofuel production each are amplified at the regional to global scales. (Kozai, 2013). In addition, certain growing conditions for small grains can result in varying yield and grain quality. Such growing conditions are influenced by local climate, weather conditions, and soil properties such as available water-holding capacity, pH, and bulk density (Wilson et al., 1992; Hobbs et al., 2008; López-Fando and Pardo, 2009). Cultivated soils are exposed to additional agronomic or environmental risks. Examples include increased use of chemical inputs that increase pollution; erosion leading to loss of topsoil, organic matter, and fertility; and soil compaction resulting in decreased infiltration and aeration (Aktar et al., 2009; Michael et al., 2020). These risks can be reduced through the incorporation of soil management practices such as NT, which has been shown to provide significantly increased crop yields, increased nutrient use efficiency, with decreased environmental risk (Zhang et al., 2011). The original intent of NT systems in the United States was to reduce erosion (Logan et al., 1991). However, climate change has brought increasing attention to carbon (C) storage in soils, because NT systems are known to increase C sequestration (Balesdent et al., 2000; Freibauer et al., 2004; Abbas et al., 2020).

Effects of Soil Management Practices

Continuous research is critical in identifying superior soil and nutrient management practices for the limited water environments of the Great Plains, a region valued for wheat and sorghum production. The adoption of conservation tillage practices (NT and RT) led to reduced erosion, increased soil organic matter (SOM), and increased precipitation storage in the US Great Plains (Logan et al., 1991; Thomas et al., 2007; Triplett and Dick, 2008). Conservation agriculture practices also reduced the use of pesticides while increasing crop intensification and diversification (Anderson, 2009; Cochran et al., 2006; Hansen et al., 2015; and Hansen et al., 2016). In semi-arid regions intensifying the frequency of cropping systems is another conservation approach that led to higher yield performance (Halvorson et al., 2001). No-tillage and RT practices of ten years or longer are known to match or exceed wheat yields in CT systems (Pittelkow et al., 2015). However, integrating NT and RT practices in some systems has led to a reduction in crop quality and yield when compared with CT practices, which has been attributed to the effects of NT on N dynamics (Lundy et al., 2015; Pittelkow et al., 2015; Ruisi et al., 2016). Halvorson et al. (2001) reported that the residual NO_3^- within 0 to 150 cm soil profile is higher with CT and RT compared to NT. They also revealed that soil NO_3^- movement to the crop root zone tends to leach out with above-average precipitation. Additionally, Halvorson et al. (2001) noted that NT is a promising strategy for reducing residual soil NO_3^- available for leaching compared to CT and RT. After 16 years of establishing a long-term wheat experimental, available N (NO_3^-) was higher in upper 2.5 cm under NT compared to till plots, as mineralization of organic nutrients accumulates higher nutrients closer to the surface in the NT (Tracy et al., 1990). López-Fando et al., (2007) found higher available N with the NT system compared to CT or RT in semi-arid Central Spain for the study examining different tillage practices with crop rotations.

Continuous adoption of tillage management systems (as a long-term practice of NT or RT) must be used to influence the soil properties (physical, chemical, and biological) (Tarkalson et al., 2006; Van Eerd et al., 2014; Obour et al., 2017). Conservation tillage practices (e.g., NT) were noted for increasing soil water storage (Anderson, 2009; López-Fando and Pardo, 2009; Obour et al., 2015) and improvements in water and fertilizer use efficiencies (Triplett and Dick, 2008). Furthermore, the most significant issues with the tillage practices were soil compaction and the related loss of structure, increase in bulk density, and a decrease in porosity. These changes, in turn, result in reduced permeability to water and air and changes to overall root growth and development (Batey and McKenzie, 2006).

Conservation tillage, including NT, improves aggregate stability and vertical macropore connectivity, which enhances water infiltration rates (Strudley et al., 2008). The increased concentration of organic matter/organic C in the soil is considered a result of different interacting factors (Fageria, 2012). These factors lead to a decrease in temperature at the soil's surface, enhanced residue return, less soil disturbance, and an increase in moisture content (Logan et al., 1991; Blevins and Frye, 1993). Intense crop rotation, coupled with NT systems, significantly reduces the loss of organic matter in the soil and works at an optimal rate by limiting soil disturbance (West et al., 2002). There was a widespread system of root channels and macrospores in the soil due to different crop rotations that combined with minimal soil disturbance (Hobbs et al., 2008; Wright et al., 1999). Advantages of combinations of RT systems with reduced fallow frequency include more soil microbial biomass, potentially mineralizable N, water-stable aggregates, and higher total glomalin, which has been linked to higher soil C and better soil structure due to increased prevalence of arbuscular mycorrhiza (AM) fungi (Wright et al., 1999). While NT practice, combined with intense crop rotations, might have more impact on maintaining and increasing SOM (Liebig et al., 2006), AM fungi benefit soil by improving soil structure, soil aggregation, decreased erosion rates, and water infiltration because of increased residue on the soil surface (Frey et al., 1999; Hobbs et al., 2008).

In dryland regions the variability of rainfall, low fertility of soils, and low availability of nutrients are major biophysical factors limiting crop productivity as it causes crop sensitivity to water and nutrient deficits throughout different critical stages (Fahad et al., 2017; Nawaz and Farooq, 2016). These dryland regions account for more than 40% of the earth's total surface land area (Turner et al., 2011). Choosing the correct cropping management system can make a significant impact, especially if there is a water limitation, such as the case of the semiarid Great Plains. Water deficiencies can result from low or unpredictable precipitation, inefficient precipitation storage in the soil during fallow periods, or soil factors such as texture, profile depth, pH, fertility (Unger et al., 1997; Tarkalson et al., 2006). Long-term field research of nutrient management is critical to determine the complex soil-plant-climate interactions with possible benefits for improving NUE and decreasing nitrous oxide emission (Powlson et al., 2011). Short-term studies determining the effect of treatments would not assist in improving and developing soil management practices as applied to the global food chain production, stability, and sustainability of agriculture. The purpose of long-term experiments is to provide a measurement of the effects crop management practices have on the environment over time, with consistent treatments.

Soil Water Storage

The drought is usually more severe in dryland farming areas due to 85% or more is used for transpiration or 70% in more favorable regions resulting in evaporation losses (Stewart and Peterson, 2015). However, in dryland areas crop yield is determined by the effectiveness and distribution of precipitation during the growing season, rather than the total amount (Stewart and Peterson, 2015; Stewart and Liang, 2015). Conservation tillage practices minimized soil disturbance and reduced the rate of evaporation because of the surface residue influence, resulting in greater soil moisture conservation (Bhatt and Khera, 2006). Bhatt (2017) notes that this is also likely due to enhanced water infiltration rates resulting from long-term NT.

In a comparison of CT, RT, and NT effects on evaporation, the NT plots had the lowest rates of evaporation resulting in greater soil moisture content (Bhatt, 2017). Arshad et al. (1999) recorded a linear relationship between soil water storage and infiltration rate comparing NT to CT, which was a result of the redistribution of pore size classes into more small pores. Also, higher soil water storage was found when crop residue was retained (Liu et al., 2013). The results of soil tillage practice and retained crop residues practices on soil hydraulic conductivity infiltration was higher in NT with residue retention compared to CT and NT without retained residues (Verhulsta et al., 2010). Improvements in soil water storage in NT increased crop water use efficiency and crop productively (Sainju et al., 2009; Awale et al., 2018).

Nitrogen, Plant Growth, and Crop Production

Understanding the characteristics and reactions of N in the soil is essential to understand crop production management better. Due to the chemical, physical, and biological soil properties, the form and quantity of N in the soil regularly fluctuates (Grahmann et al., 2013). Although total plant-available N is present in a small amount, and greatly depends on the quality and quantity of soil organic matter (Sheaffer and Moncada, 2012). Plants absorb nitrate (NO_3^-) and ammonium (NH_4^+), as well as small quantities of organic N, but not including amino acids, proteins, and amino sugars present in the soil (Grahmann et al., 2013); however, plants cannot use these organic N compounds, preventing N from being lost (Sheaffer and Moncada, 2012; Grahmann et al., 2013). Both inorganic forms of available NO_3^- and NH_4^+ are present in soil solution and bound to soil particles, respectively; NO_3^- is more affected by leaching (Grahmann et al., 2013). Other forms of N found in soil and atmosphere are insoluble in water, and thus unavailable for plants. Some insoluble, unavailable N can be converted through fixation (by taking gaseous N_2 and fixing it at NH_3), ammonification, nitrification, and/or biological fixation to make available N for plant usage (Sheaffer and Moncada, 2012).

Halverson and Reule (1994) demonstrated that increased N supply resulted in increased wheat yield, dry matter grain production, and water use efficiency in dryland production systems. There are several ways to increase residual N in the soil. One strategy to increase residual N is to reduce N losses. According to Sainju et al. (2009), reducing N losses through erosion, leaching, volatilization, surface runoff, and green gaseous N emissions (e.g., NO, NO_2, or N_2) are necessary for reducing N loss. Increasing SOM is another strategy to increase residual N (Grahmann et al., 2013), though the ability to increase SOM is influenced by soil properties and climatic factors (Fageria el at, 1991) and management practices (Sainju et al., 2009). Increasing SOM can take years to decades particularly in dryland systems (Schmidt et al., 2011). In addition, SOM is not always available to plants, as microbes facilitating mineralization require warm soil temperatures and adequate moisture (Ju and Li, 1998) to convert it to usable forms for plant uptake. Due to soil aeration, water content, and NH_4^+ quantity from both soil and fertilizers, which could be quickly transformed into NO_3^- was more important compared to NH_4^+ in regard to supplying N to plants/crop, especially in dryland region (Li et al., 2009). Many researchers reported that the nitrification rate was linearly correlated with soil volumetric water content from 12% to 27%, revealing that nitrification reached the maximum. While with water content ranged from 50% to 70% of field capacity, that it is limited by oxygen when water is above or below these water content (Malhi and McGill 1982; Flower and Challagha, 1983; Ju and Li, 1998; Li et al., 2009).

The synthetic fertilizers contribute most likely just over two-fifths of all inputs N, and it is a fifth most abundant element in our solar system (Smil, 1991 and 2001), and composes 78% of the atmosphere (Canfield et al., 2010). However, N is a limiting nutrient in cereal grain production due to the limited availability of N fixed in plant-available forms (Rahimizadeh et al., 2010).

Researchers and farmers have sought N fertilizer since the early 1800s. In the 1820s, vast deposits of sodium nitrate, known as Chilean nitrates, were discovered in the arid highlands of northern Peru (Follett, 2008). Similarly, dried bird excrements located off the west coast of South America were imported to Europe as an N fertilizer, though the source was exhausted by 1890 (Smil, 2001). By the latter half of the 1800s, sights were set on developing a synthetic N fertilizer. Smil (2001) described the development of the Haber-Bosch process, beginning first in 1909 with Fritz Haber successfully fixing atmospheric N (N_2) into ammonia. The process was later scaled to industrial-scale production by Carl Bosch and termed the Haber-Bosch Process. The Haber-Bosch process was credited as one of the most important discoveries of the 20th century due to the impact on agricultural productivity and N fertilization (Smil, 1991).

Delogu et al. (1998) demonstrated both grain yield and crop quality are directly related to N uptake. However, there is a need for further research examining the significant effect of N on plant growth, productivity, and grain quality. In addition, excess nitrogen can have environmental impacts. Increased use of N fertilizer led to dramatic yield gaps of the major cereal crops (Krupnik et al., 2004) as well as increasing crop yield and enhancing drought resistance of crops in arid and semiarid regions (Liu et al., 2013). However, excessive application of N fertilizers resulted in environmental impacts (e.g., greenhouse gas emission, water pollution, soil quality degradation, and accumulation of soil NO_3^- in soil profile) and significantly lower NUE (Malhi et al., 1996; Huang et al., 2015; Zhang et al., 2015).

As a cereal crop, grain sorghum needs substantial amounts of N; however, sorghum is also considered a "low input crop" in comparison to other crops. Thus, N management for grain sorghum production has received less attention, which has consequently limited yields (Panhwar et al., 2019). Nutrient uptake from soil is highly dependent on the growth and development of the plant root system. Application of the right amount of N fertilizer at the proper depth, along with adequate water supply to the crop, will have a significant impact on the development of the crop's root system due to increased root density and water uptake (Plett et al., 2020). Correspondingly, Halvorson and Reule. (1994), reported that wheat receiving adequate N was able to remove water efficiently from the soil at a higher N rate or sufficient available N than this crop that did not have N fertilizer applied. López-Bellido et al. (1996), reported there was not N fertilizer respond in wheat when rainfall was below 450 millimeter over the growing season. This is due to N being acquired by mass flow, which requires sufficient soil moisture (Panhwar et al., 2019). Robertson and Vitousek (2009) also noted that synthetic N sustained and increased crop yields as a universal and fundamental feature of modern crop management.

Plant N-absorption is affected significantly during its growth stage through plant-available N in the soil and water (Mokhele et al., 2012). Li et al. (2012) showed that heavy N application might not be necessary during the early stages of plant growth. This implies that N is required uniformly throughout the various stages of crop growth and development to achieve the best yield/results. Li et al. (2012) support that increasing N fertilizer application during middle and later stages of plant growth directly impact its absorption and uptake, thereby increasing grain yield. Reforming N management practices by decreasing initial N application rates in wheat crop and then applying N fertilizer at jointing can increase ear-bearing tillers by up to 60%, where this amount was reduced by 25% when N fertilizer application was increased in the early stage of the crop's growth cycle (Li et al., 2012). Excessive yield largely depended on dry matter and N accumulations after heading.

The average N recovery efficiency for cereal production is approximately 33%, and the unaccounted 67% represented approximately $15.9 billion annual loss of N fertilizer as of 1999 (Raun and Johnson, 1999). Erosion and leaching on agricultural lands with excess fertilizer cause surface and groundwater pollution (Aulakh et al., 1992). For this reason, efficient management of N through accurate application using agronomic rates is both economically and environmentally beneficial.

Soil Nitrogen Losses, Nitrogen Mineralization, and Soil Management

Nitrogen loss can encourage adjustments to N fertilizer rates and timing in tillage and cropping systems. Nitrogen cycling in the soil is complex and can involve relatively rapid conversion from one N form to another, each with different characteristics (Scharf, 2015). Simultaneously, when organic and synthetic N fertilizer are applied the nitrogen rapidly undergoes chemical transformations and is exposed to different loss pathways, making N management in any crop a challenge (Wychoff, 2012). These dynamics are further complicated by tillage practices which vary in how each practice redistributes plant residues and changes the physical, chemical, and biological soil quality (Verhulst et al., 2010; Grahmann et al., 2013). Urea of synthetic N is exceptionally susceptible to N loss when exposed on or near the soil surface, which has many advantages and disadvantages. Urea N loss rate might vary from 50-90% of the total Urea N within 48 hours after surface application (Hefley, 2016). Thus, understanding the potential losses of N throughout the process and transformation (leaching, surface runoff, and volatilization) (Raun and Johnson, 1999) and immobilization by microorganisms into the system of agricultural soil is essential for the development of a soil test for available N (Dahnke and Vasey, 1973) and efficient N management (Wychoff, 2012). In reducing the intensity of tillage (e.g., NT or spring till), N loss (e.g., leaching, volatilization, or denitrification) decreased compared to a CT system (e.g., spring till wheat-fallow). It also increased soil surface residue N, N storage, and potential N mineralization (Sainju et al., 2009).

Denitrification

The definition of soil denitrification is the nitrogen oxides. Gayon and Dupetit (1882) noted that denitrification occurs when a microbial activity (denitrification) or a nitrite chemical reaction (chemodenitrification) reduces nitrate (NO_3^-) or nitrite (NO_2) to nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2), and/or N gas (dinitrogen, N_2) (Hefley, 2016). Denitrification is an opposing biological process to biological fixation in which NO_3^- and NO_2 are reduced to NO, N_2O, NO_2, or N_2 by reductase enzymes and then form gaseous oxides (Grahmann et al., 2013). This process can also be a mechanism of significant loss of fertilizer and soil N from agricultural fields (Scharf, 2015).

Both nitric oxide and nitrous oxide produced during the denitrification process are considered significant greenhouse gasses which contribute to global warming (Snyder et al., 2009). Therefore, decreasing soil denitrification would also benefit the environment. Tillage systems have been shown to have a less significant effect on N_2O emissions compared to crop rotation and N fertilizer rate, where N_2O emission from N fertilizer application ranged from 0.30% to 0.75% of N applied (Halvorson et al., 2008). Additionally, within one month after N fertilizer in the sorghum phase nearly 50% of the total emissions occurred. Preza-Fontes et al. (2020) proposed cover crops after harvesting winter wheat was a potential strategy to reduce emissions of N_2O, especially when residual N accumulation and N_2O emissions are expected to be high. However, they found that emissions of N_2O were significantly higher in sorghum following cover crops than that of sorghum following fallow. In a meta-analysis of cover crop management practices, Basche et al. (2014) noted that N_2O emissions from the soil surface were reduced when nonlegume cover crop species were used and residues were not incorporated into the soil.

Various models and approaches for estimating denitrification significantly depend on soil characteristics such as pH, soil texture, organic matter or organic C, cation exchange capacity, mineral N supply, soil oxygen (O_2), soil water status, and soil temperature (Mosier et al., 2002; Huang et al., 2011). These characteristics may be considered complex and difficult to manage under field conditions because of their potential interactions. Generally, denitrification rates will be higher in warm and wet soils because the microorganisms regulate the reactions and are temperature- and pH-sensitive. For example, most denitrifying bacteria have optimum growth in alkaline soils where pH ranges between 6 and 8 and are more active in warm soils than in cold soils (Aulakh et al., 1992). Therefore, the main factors affecting soil denitrifications are soil oxygen content and microbial activity in the soil (Wychoff, 2012). Hilton et al. (1994); Raun and Johnson, (1999) reported that denitrification rates of 10-22% for the application of N fertilizers in corn. Aulakh et al. (1982); and Raun and Johnson, (1999) noted that as much as 9.5% of N losses occurred in winter wheat because of denitrification.

One strategy to limit denitrification that is growing in popularity is to use nitrification and urease inhibitors, which control nitrification of converting ammonium in soils is to nitrate by impeding the metabolism of Nitrosomonas bacteria (Coyne et al., 2018). Nitrification and urease inhibitors are proposed as a means to reduce N losses, thereby increasing crop nitrogen use efficiency. But the effect of nitrification and urease inhibitors on crop yield is inconsistent (Abalos et al., 2014).

On the other hand, there is not a clear positive or negative response or impact for the mitigation of greenhouse gas emissions using conservation (e.g., RT or NT) practices compared to conventional tillage. Production systems using RT or NT rather than CT in some regions benefit from increased SOM and carbon storage to a greater degree than any potential increase in N_2O emissions (Snyder et al., 2009). Malhi et al. (2006), reported the amount of N lost as N_2O was greater from CT than NT. Similarly, Venterea et al. (2005) reported emissions of N_2O were higher under NT compared to CT, especially when N was applied post-emergence as broadcast urea, but completely different tillage effects occurred when N was applied pre-plant as either injected anhydrous ammonia or broadcast urea–ammonium nitrate. Therefore, different N fertilizer source and tillage interactions could result from differences in soil water content and bulk density, differences in soil nitrate accumulation among N sources, and may depend on whether nitrification or denitrification dominates in the crop and soil system (Venterea and Stanenas, 2008; and Snyder et al., 2009). Generally, N_2O emission was highly variable and depend on a complex interaction of soil properties (Soane et al., 2012).

Leaching

Soil NO_3^- leaching is defined as percolated excess NO_3^- in soil solution through the soil profile and out of reach by plant roots by water percolation and flows (Grahmann et al., 2013). Leaching occurs when there is an imbalance between the supply and demand in a cropping system (Teixeira et al., 2016). Since the 1970s, NO_3^- leaching from croplands has become a significant concern because of its direct impact on water quality (Rivett et al., 2008). In environments where precipitation exceeds evapotranspiration, the excess water will percolate down through the soil profile, thereby moving NO_3^- to groundwater, drainage tile lines, or nearby drainage ditches and streams, typically leaching ranged from 10 to 30% of the total applied N input (Meisinger and Delgado, 2002; Delgado et al., 2010; Scharf, 2015). Quemada et al. (2013) states that excessive water application in irrigated agriculture increases NO_3^- leaching. This can result in low crop N availability necessitating higher N fertilizer rates, thus increasing the probability of groundwater pollution.

The NO_3^- leaching from agricultural soils is a complex process that depends on many factors, such as soil properties (e.g., soil texture), climatic variables (e.g., precipitation), and management aspects (e.g., timing of N fertilizer application) (Dinnes et al., 2002; Plaza-Bonilla et al., 2015). More leaching is expected on coarse-textured soils, soils with low SOM, and irrigated soils (Zhou and Butterbach-Bahl, 2014). Keeney and Follet (1991) reported that in most cases where N fertilizer causes NO_3^- pollution, it is due to excessive application or poor management practices. According to Power and Peterson (1998) and Grahmann et al., (2013), NO_3^- leaching could be potentially reduced with NT due to higher soil moisture and snow preservation causing slower nitrification, mineralization, and immobilization rates during fallow periods. This is due to lower soil temperature, slower soil warming, and slower microbial activity in spring and winter fallow time (Grahmann et al., 2013).

It is also important to consider seasonal precipitation. Williams and Kissel (1991) described a dryland system where precipitation was less than 406 mm and reported an analysis of soil hydrology and N loss interactions revealed leaching of NO_3^- was zero or very minimal. Quemada et al. (2013) observed that adjusting water application to crop needs reduced NO_3^- leaching by 40%, and noted the best relationship between yield and leaching of NO_3^- was obtained when the recommended N fertilizer rate was applied. According to Delgado et al. (2010), the loss of NO_3^- due to leaching during the corn growing season differs depending on the timing of the precipitation. They noted minimal N losses (< 15 NO_3^- ha^{-1} y^{-1}) when most of the precipitation occurred during the growing season, and significant increase of N losses (> 85 NO_3^- ha^{-1} y^{-1}) when most of the precipitation occurred before planting. Reducing the potential leaching of available NO_3^- during the winter months can lead to decreased exposure (Meisinger and Delgad, 2002; Delgado et al., 2010).

A meta-analysis of NO_3^- leaching from corn and wheat cropping systems by Zhou and Butterbach-Bahl, (2014), revealed that area-scaled NO_3^- leaching losses for corn cropping systems were approximately two times higher than those found in wheat cropping systems. The higher NO_3^- leaching losses from corn cropping systems were driven mainly by increased N fertilizer application, and the wetter and warmer natural climate conditions during corn 's growing seasons. On average, 15% and 22% of the N fertilizer applied to corn and wheat cropping systems worldwide is leached in the form of NO_3^-, respectively. The average area-scaled NO_3^- leaching loss for corn (57 kg N ha^{-1}) was close to two times higher than the loss for wheat (29 kg N ha^{-1}). However, when scaled to crop yields, the average yield scaled NO_3^- losses were comparable between corn (5.40 kg N Mg^{-1}) and wheat (5.41 kg N Mg^{-1}) systems. The lowest yield-scaled NO_3^- leaching losses were observed at slightly suboptimal fertilization rates, corresponding to 90% and 96% of maximum corn or wheat yields, respectively, when compared across all sites (Zhou and Butterbach-Bahl, 2014). Thus, controlling N input and improving NUE reduces the potential leaching of NO_3^- (Wychoff, 2012).

Volatilization

Ammonia is a gas at atmospheric pressure and exists in equilibrium with NH_4^+ in the soil. Ammonia can be lost from the soil to the atmosphere through NH_3 volatilization, which can occur rapidly since NH_3 is in a gaseous state (Fageria and Balinger, 2005). The proportion of N lost from urea-based N fertilizers due to NH_3 volatilization may range from one percent to more than 50%, depending on fertilizer type, fertilizer incorporation, environmental conditions (temperature, wind speed, and rain), and soil chemical properties (clay content, calcium content, cation exchange capacity, and pH) (Sommer et al., 2004; Wychoff, 2012). Scharf (2015) notes that when urea from animal urine or a urea-based fertilizer is applied to the soil surface, the first reaction breaks down urea into NH_4HCO_3 and then the urease enzyme, and then produces NH_3. Conditions such as high winds and temperatures, moist surface soil, and low plant cover height lead to increased NH_3 volatilization (Chien et al., 2009). Volatilization rates can also be elevated with high soil pH, presence of crop residue, and initially wet soils followed by drying (Grahmann et al., 2013). Volatilization rates can also be elevated when there is a high proportion of NH_3 gas in the equilibrium between NH_3 and NH_4^+, especially when urea-based fertilizers are applied at the soil surface and not incorporated by tillage, precipitation, or irrigation (Scharf, 2015).

Regardless of the cropping system process and natural or synthetic N fertilizer usage, the process of NH_3 volatilization poses problems for producers. NH_3 volatilization is highest when N fertilizer is applied in a broadcast/surface and unincorporated manner, and then left with little or no irrigation or accumulation of proper precipitation (Sanz-Cobena et al., 2011). According to Keller and Mengel (1986), more than 30% of N loss by volatilization of NH_3 occurs when granular urea N fertilizer is applied to the soil surface of NT corn cropping with nearly 60% of the soil surface covered by corn residues. Additionally, the occurrence of rainfall in the first five days after fertilization was a factor lead to decreasing N losses in the summer (Viero et al., 2014). In cold-weather conditions such as those in Montana, Engel and Wallander (2011) observed more than 40% N losses in winter wheat by NH_3 volatilization occurs when urea is surface-applied to frozen soils. Further, Palma et al. (1998) noted slightly higher NH_3 volatilization loss was reported under NT (12%) compared to CT (9%) of broadcast urea and cropped by corn in dry seeded time. In that study, cumulative NH_3 volatilization was three times higher under the NT system than the CT system with the application of solution urea-ammonium nitrate. However, this solution urea-ammonium nitrate application reduced N infiltration and leaching because of crop residues in the soil surface of NT systems (Al-Kanani and Mackenzie, 1992). When two different N sources were used, urea and urea ammonium nitrate, along with two practices of residue management (retained and burned), they found that three to four weeks after both N sources were applied, the average seasonal soil NH_3 volatilization was significantly higher under urea plots. The urea plots had at least two times greater volatilization loses compared to the urea ammonium nitrate plots (2.4 to 5.6% vs. 1.2 to 1.7%).

Surface Runoff

Delgado et al. (2010) defined soil surface runoff as a transportation process caused by excess irrigation or intense precipitation into a cropping system, in which soil particles, SOM, organic N, and clay-bound N or N dissolved in water can be transported off-site and lost from the system. Shaver et al. (2002) stated that improved soil structure and increased residue in NT crop systems exhibit increased infiltration and decreased runoff (Shaver et al., 2002). Hansen et al. (2012) also noted a decrease in the runoff of NT management systems as residue cover increased. Endale et al. (2015) noted that CT watersheds exhibited a greater proportion of rainfall lost as runoff compared to NT watersheds in a 39-year experiment. The CT watersheds averaged 19% of rainfall being lost as runoff compared to 7% from NT watersheds. However, for a 10-year experiment in the northwestern Corn Belt, Lindstrom and Onstad (1984) reported that NT decreased rainfall infiltration and increased runoff. There is some disagreement in the literature though. Norvell et al. (2008) showed nearly the same annual runoff from both CT and NT production systems in an eastern Colorado example. Jones et al. (1994) observed an increase in runoff and reduced infiltration with NT management under semiarid dryland conditions revealed in a 10-year wheat-sorghum-fallow rotation study in Bushland Texas. Nevertheless, more precipitation was stored as soil water content when NT residue management was used rather than CT management.

Mineralization, Immobilization, and Mineralization-Immobilization

Soil mineralization and immobilization are important components of the N cycle. They are generally considered separate transformations rather than coupled transformations (Keeney and Hatfield, 2008). Mineralization is the microbially-mediated conversion of organic N to mineral N (Mahal et al., 2019). Through mineralization, microbes transform organic N from SOM, crop residue, and organic fertilizer (e.g., manure) into inorganic N, namely NH_4^+ and NO_3^- (Grahmann et al., 2013; Chen et al., 2014).

The immobilization process consists of soil microorganism removing available inorganic N from the soil solution or exchangeable N (Wychoff, 2012; Grahmann et al., 2013; Chen et al., 2014). That N is incorporated into the cells of microbes and other soil organisms as they decompose low quality (high C:N ratio) substrates (Grahmann et al., 2013). According to Chen et al. (2014), mineralization occurs when C:N ratios range from 9.4 to 22 as a result of the plant residue decay, including green manure, leguminous crops, and vegetables. Typically, only plant residues with C:N ratios under 24 increased the inorganic N concentration compared to soils without plant residues (Chen et al., 2014).

Chen et al. (2014) note three processes that determine the effects of returning plant residue in soils using NT or RT management: (i) immobilization, (ii) immobilization-mineralization, (iii) and mineralization. These processes are differentiated based on the duration and occurrence of net immobilization over time. No net immobilization occurs in the mineralization process. In contrast, net immobilization occurs during the early stages of the immobilization-mineralization process, followed by net mineralization finishing the process. The immobilization-mineralization process is characterized by net mineralization occurring at the end of the experiment following a long period of net immobilization at the beginning. No net mineralization occurs in the immobilization process. Wood et al. (1990) reported decreasing NO_3^- content in the soil profile was due to an increase in cropping systems intensity, resulting in greater N immobilization. The immobilization-mineralization and immobilization processes occur when plant residues have C:N ratios of 30-136 and 47-99, respectively. For example, a wheat residue with a C:N ratio of 79, which results in an immobilization process demand if there is a shortage of inorganic N in the system (Mohanty et al. 2010). However, a wheat residue with a C:N ratio of 136 results in an immobilization-mineralization process demand (Hadas et al. 2004). When there is more N in the plant residues than the N demand of the microbial population during plant residue decomposition, N mineralization becomes dominant. Inversely, if the N concentrations in the plant residues are low, all the inorganic N will be used by the microorganisms, and microbial immobilization becomes dominant (Chen et al., 2014).

Tillage systems determine the placement of crop residues. When CT is used, crop residues are incorporated into the soil. In contrast, crop residues remain on the soil surface when using NT and RT, which influences the chemical, physical, and biological soil processes, and thereby enhances the biological activity, improves physical properties, and increases nutrients' availability (Hadas et al., 2004; Nunes et al., 2020). Usually, incorporating plant residues into the soil with tillage accelerates and stabilizes C and N mineralization compared to removed residues by making SOM within the macroaggregates more available to microorganisms and by retaining only 30 to 50% of the organic residues (Lichter et al., 2008). Soil organic C is significant similar in CT to NT when crop residues were removed but when crop residues were retained, NT was greater compared to CT (Dendooven et al., 2012). Instead, when residues stay on the surface of the soil, it is less likely to be broken down by microbes. Microbial growth is limited after crop residues with low N concentrations (C:N >30) cause temporary net N immobilization into the end of the growing season because of potential C mineralization is increased to faster rates under CT compared to NT after harvest of each crop (Franzluebbers et al., 1995). Franzluebbers et al. (1995), investigated the C and N dynamics in CT versus NT for residue retention in monoculture wheat, sorghum, and soybean. In the CT plots, the authors found temporary N immobilization and stated that seasonal changes in the soil N pool; this may be caused by rhizodeposition in combination with residue incorporation. These changes were smaller under NT, and therefore, the N dynamics were more stable. In the initial years of conversion from CT to NT or RT, short-term N immobilization can be compensated for by increasing the application of N fertilizer.

Nitrogen Use Efficiency

The NUE was initially defined as the inverse of N concentration in the plant tissue (Chapin, 1980). Moll et al. (1982) later defined NUE as the weight of grain yield per unit of available N in the soil. More recently, Johnston and Poulton (2009) define NUE as the ratio between the amount of N removed from the field by the crop and the initial quantity of N contained in the soil as well as the amount of fertilizer N application applied. Raun and Johnson (1999) derived the equation for calculating NUE as the difference of N uptake in the treated plot(s) and N uptake in the untreated plot(s) divided by the total applied N rate. However, there are numerous other definitions and methods used to estimate, calculate, and compute NUE (Barraclough et al., 2010). In the late 1990s, the average of NUE was about 50% and as low as 33% for various cereal crops grain of receiving applied N fertilizer (Raun and Johnson, 1999). NUE can also decrease as N fertilizer rates increased (Raun and Johnson, 1999). Additionally, higher N fertilizer application can lead to decrease in NUE because of N losses through volatilization and leaching, which, in turn, is responsible for environmental contamination (Meisinger and Delgad, 2002; Delgado et al., 2010).

Factors influencing NUE

Loss of N fertilizer through gaseous emissions, soil denitrification, surface runoff, volatilization, and leaching cause decreased NUE. Similarly, conservation agriculture, such as reduction of tillage intensity and increased crop residue, can also result in N loses through immobilization (Grahmann et al., 2013; Awale et al., 2018). Increased cereal NUE is unlikely unless the system uses high harvest index, incorporated NH_4^+ fertilizer, application of prescribed rates consistent within-field variability using sensor-based systems within production fields, low N rates applied at flowering, or forage production systems (Raun and Johnson, 1999; Wychoff, 2012; Chen et al., 2014; Scharf, 2015). NUE increases can also come from changes in fertilizer management practices, time delay between N application and N plant uptake, , avoiding excess N fertilizer applications, and using N source reduce losses (e.g., nitrification and urease inhibitors) (Smith et al., 2008; Abalos, et al., 2014).

Increasing N application rates enhances crop yields and water use efficiency, but it can also result in excess biomass production, which uses up stored soil water needed for grain production (Halvorson et al., 2004; Nielsen and Halvorson, 1991). This would cause a need for increased precipitation use efficiency (PUE) when N rates are more than 56 kg ha^{-1} (Halvorson et al., 2004). However, more often, it merely increases N loss, especially with overdose fertilizer application rates (Zhou and Butterbach-Bahl, 2014). Therefore, the improvement of NUE in agricultural systems is more than just a matter of using more or less fertilizer and knowing the type of N fertilizer; it requires a deep understanding on how nutrients, plants, and soil interact in a cropping system with different tillage practices to avoid losses. For example, increasing the N fertilizer rate from 84 kg N ha^{-1} to 112 kg N ha^{-1} did not show any yield benefits in a study conducted in the Great Plains, while more than 84 kg N ha^{-1} showed higher rates of NO_3^- leaching (Halvorson et al., 2004).

There was significant impact on NUE when increasing N rate (Grahmann et al., 2013). Therefore, the extreme dependence on inorganic/organic fertilizers resulted in environmental degradation issues such as NO_3^- leaching to groundwater and gaseous loss through NH_3 volatilization, in addition to denitrification and immobilization within the soil system. The difficulties in soil nutrition management in organic cropping systems often result in lower, variable yields, and lower NUE because of the limits on plant uptake. The utilization of beneficial soil microorganisms is fundamental to optimize the availability of soil N. Estimates of SOM mineralization made by prediction models may be useful to enhance NUE, if the models are calibrated for target environments (Sparks, 2012; Sparks and Banwart, 2017). However, the applied N fertilizer is often used as available N because of the difficulties associated with measuring available plant N from mineralization through soil microbial activities (Kubota et al., 2018). For example, Baker and Saxton (2007) and Baker et al., (1996) describe snow retention by residues resulting in higher winter soil temperatures in temperate zones. Since soil temperature influences the activity of soil microbes, this additional residue and snow catch contributed to changes in the rate of N fertilizer mineralization and immobilization, and plant uptake of nitrogen. Instead, it was shown that N mineralization rate increased as organic N uptake exceeded microbial growth demand (Zhang et al., 2019). Consequently, microbial populations controlling soil N mineralization are affected by wetting and drying cycles (Borken and Matzner, 2009; Zhang et al., 2019). Mineralization rates and N uptake were commonly reduced under temperate conditions compared to tropical (Baker et al. 1996). However, microbial activity and formation of mineralizable N rate were enhanced with high soil moisture (Borken and Matzner, 2009)

The type/amount of crop residue left by the previous crops in the soil can also affect NUE (Rahimizadh et al., 2010). Rahimizadh et al. (2010) found that wheat grown following a non-wheat crop increases NUE up to 24% compared to wheat following another wheat crop. This suggests that crop rotation plays a pivotal role in increasing grain yields by increasing NUE.

The N losses can be reduced with better management of N application by matching N availability to crop uptake patterns, paying attention to crop uptake needs under stress, and the ability to obtain soil N at low concentration (Dawson et al., 2008). For example, Fatima et al. (2018) demonstrated that splitting N into three applications was successful for all of the selected winter wheat and summer cereals. According to Rosolem et al. (2017), a majority of annual crops take up less than 5% of their N at the seedling stage, between 70 to 80% during the vegetative stage, and 15 to 25% in the reproductive stage. Commonly, the N uptake rate is at its maximum from 35-40 to 80-90 days after plant emergence. Thus, having excess N early in the cycle or during the reproductive stage will result in transporting nitrates farther down in the soil profile and increasing the chances of NO_3^- leaching. Conversely, if not enough N is available during the vegetative stage when the uptake rate is at its maximum, there will be a decreased crop yield. For example, mineral N fertilizer is applied during peak N demand of the plant, immobilization and losses from the soil-plant system are reduced, and NUE is increased (Torbert et al., 2001; Verachtert et al., 2009; Rosolem et al., 2017).

Delgado and Fellett (2002) recommended that C management should be an integral part of nutrient management because of its positive effects on porosity, available water holding capacity, cation exchange capacity, and ability to reduce toxicities from certain elements. The management of N and C is critical because of the effects they can have on increasing SOM. Management practices that increase SOM also reduce the amount of required N input because of the higher NUE generated by the increase in N cycling, which overall reduces the potential for NO_3^- leaching and N losses. Additionally, SOM is essential as it contributes to favorable soil physical and chemical characterizations, improving soil productivity and nutrient use efficiency (Triplett and Dick, 2008; Anderson, 2009; López-Fando & Pardo, 2009). For example, on average, N mineralization was about 45 kg N ha^{-1} for every one percent of SOM; therefore, if the SOM content increased from one to three percent, then N release would increase from 45 to 135 kg N ha^{-1} (Vigil et al., 2002). This increase in SOM would increase the amount of N available for crop uptake and reduce the need for N input (Delgado et al., 2010). Both cropping systems and NT and RT would increase SOM-C and SOM-N by reducing soil erosion (Havlin et al., 1990). However, according to Grahamnn et al. (2013), their results showed an inconsistent effect on NUE by NT and RT managements. Instead, after analyzing the rotation of winter wheat-summer crop-fallow with proper N fertilization in a long-term NT system, soil available N plus fertilizer N level of 124 to 156 kg N ha^{-1} was found, which was sufficient to optimize winter wheat yields in most years in both rotations (wheat- sorghum or corn-fallow) (Halvorson et al., 2004). Correspondingly, low crop NUE and yields reduced were clearly shown with increased of crop residues, which caused a high C/N ratio (e.ge., < 80 for wheat straw) more often than would immobilize inorganic N from both fertilizer N applied and available N at soil (Rasmussen et al., 1980; Halvorson et al., 2002; Awale et al., 2018).

Yield Stability

A system that is deemed "stable" exhibits the least changes in response to changes in environmental conditions (Lightfoot et al., 1987). Stability analyses can be useful for continuous-site experiments where treatments are applied to the same-plot location year-to-year (Ruan et al., 1993). Assessment of the effectiveness of sustainable agriculture practices requires long-term field and laboratory experiments, capable of determining the complex soil-plant-climate management interactions. Long-term field experiments play an essential role in understanding the complex plant-soil-climate interactions and potential effects on crop yields (Army and Kemper, 1991). Compared to other kinds of research, agricultural studies are usually based on short-term studies, but sustainable agriculture practices requires long-term field experiments to determine complex soil-plant-climate management interactions and important tools to help to understand the agronomic treatment effects on yield stability and sustainability of such as wheat in different cropping systems (Karlen et al. 2013; Van Eerd et al., 2014; Macholdt and Honermeier, 2019; Han et al., 2020). Long-term field experiments play an essential role in understanding plant-soil-climate interactions and their effect on crop yields (Army and Kemper, 1991).

Stability analysis is regularly used in plant breeding studies to evaluate the yield stability of cultivars or genotypes as well as it is carried out at several locations, or in many of study years, (Yates and Cochran, 1938; Eberhart and Russel 1966; Piepho, 1998). Eberhart and Russel (1966) utilized the popular methodology of regression to estimate the treatment stability), which they estimated the coefficient (b) by placing treatment means onto an environmental index, which was estimated as the mean of all the treatments in a test year. Coefficients (β_i) approach unity (1.0) that were above unit indicate treatments with greater specific adaptability in high yielding test years, while the coefficient values below 1.0 describe better specific adaptability in low-yielding test years. Finlay and Wilkinson (1963) suggested that slopes played a role in adaptation; those with $\beta_i < 1.0$ would better adapt to poor environments, while those with $\beta_i > 1.0$ grow best in superior environments. There is a random, unpredictable element in the performance of the crop system, just as the notion of stability implies.

The bigger the random component is, the smaller the stability of the system. The two main parameters that describe the response of a cropping system are the mean or systematic effect and the variance or random effect (Piepho, 1998).

Lin and Binns (1988) discovered that using traditional analysis of variance is difficult to do on long-term experiments due to the complex factors that influence the environment; however, they noted that the data could be interpreted easily using stability analysis. Treatment-by-environment interactions can be divided into two sections: variation associated with the site (fixed variation) and variation related to yearly differences within a location (random variation). Treatments at locations with less variation over time are deemed more stable.

Raun et al. (1993) analyzed the stability of long-term wheat and corn yield using the linear regression technique on the location/year, environment, and mean yield. The Magruder plots from the wheat data showed that bovine manure applications (269 kg N ha^{-1}) had poor performance compared to nitrogen-phosphorus-potassium (NPK) applications if environmental means were low (< 2.0 Mg ha^{-1}) or high (> 2.0 Mg ha^{-1}). Similarly, Berzsenyi et al. (2000)'s long-term crop rotation experiment studied the yield stability of corn-corn and wheat. In using both stability analysis and conventional analysis of variance procedures, the study found that crop rotation increased the yields in both corn corn-corn and wheat compared to monoculture. The higher the level of NPK fertilization, the higher the yields were, especially where the proportion of corn-corn or wheat was 50% or higher. The stability of various crop sequences differs significantly from those of monoculture, as shown by the regression method of stability analysis. This difference is mainly attributed to the difference between the intercepts. According to Berzsenyi et al. (2000), reported stability analysis is a suitable method for the interpretation of the environment and treatment interactions observed in analysis of variance models of long-term crop rotation experiments. The stability of experimental treatments in various environments is found using both variance and regression methods.

Blaise et al. (2006) conducted an experiment from 1985–1986 and again in 2002–2003 on vertosols under rain-fed conditions to evaluate the long-term effects, trends, and stability analyses of various cropping systems, application of fertilizers, and manure may have on seed cotton yield. The highest mean yield (1218 kg ha^{-1}) resulted from the combined application of manure and fertilizer coupled with a high slope. Also, in the manure-added plots, a more considerable nutrient status imparted a higher degree of yield stability. The study also showed that when compared to trend analysis, stability analysis is more sensitive in recognizing treatment × environment interaction. Similarly, Ming- De et al. (2007) used regression and stability analysis to investigate the effects of long-term chemical fertilizer applications on wheat yields and the yield stability on the Loess Plateau. Results showed that in the unfertilized control or N-only or Phosphorus (P)-only applications, though not statistically significant, wheat yields declined. Together stability analysis and trend analysis showed that to increase and sustain the productivity of rain-fed winter wheat, integrated use of N and P fertilizer was preferable to the individual application.

Researches documented that climate change was predicted to cause temporal fluctuation in crop yields (Dai et al, 2001; Lightfoot and Tayler 2008). It is possible that plants such as wheat can exploit the prevailing growing conditions better and be more resilient to environmental stress specially under conditions of sufficient plant-available N supply and higher accumulated soil N content with related higher mineralization rates (St-Martin et al., 2017; Macholdt et al., 2020). The stability of any agricultural system in response to environmental changes can be evaluated by crop yield as influenced by the temporal changes (Lightfoot and Tayler 2008; Chen et al, 2018). Where the stable agricultural system has less yield variations in response to the environmental changes compared with an unstable system (Lightfoot and Tayler 2008; Romero-Perezgrovas et al, 2014; Chen et al, 2018). Guretzky et al. (2010) studied the effects of fertilizer rates on the stability of Midland Bermuda grass in southern Oklahoma. Stability analysis revealed that yields responded positively to N fertilization during favorable weather conditions and negatively during adverse weather conditions. The best yield stability and mean annual forage yield of the treatments was with the application of 112 kg N ha^{-1}.

Ma et al. (2012) studied the effects of varying nutrient management, rainfall, and crop rotation on corn yields and stability. Findings revealed that under nutrient absence conditions, recycled manure improved yield stability. Yield stability was also substantially improved with crop rotation. The typical environment in this region includes an arid index ranging from 1.08 to 1.16, with high, stable yields obtained during that time. The recommended fertility regimen for this region is recycled manure, as it achieved high and stable yields. Micskei (2012) discovered that the yields produced from the farmyard manure (FYM) plus NPK fertilizer combination did not differ significantly from that of NPK fertilizer alone. Yield stability was the smallest for the control treatment and the high dose of NPK fertilizer alone, while it was most significant for the low fertilizer rates and 70 Mg ha^{-1} FYM.

Srdan Seremesic et al. (2013) used stability analysis to determine year-by-year treatment interaction by comparing selected treatments versus yield differences of specific cropping systems. Stability analysis showed that the corn yield had a significant response to the agro-ecological mean yield if linear regression was applied. There was the inversely proportional ratio for the corn yields from crop rotation and corn yields in sequence. Relative stability revealed that corn monoculture had higher yield sensitivity to favorable climatic conditions ($r = 0.76$). Unfertilized rotations showed a decreasing yield trend as the mean agro-ecological yield increased. The results also showed that stability analysis could help the selection of corn technology and the interpretation of the environment and treatment interaction observed in long-term experiments.

Nevertheless, previous research on yield stability analysis primarily focused on crop genotypes across environments and their interaction (Yate and Cochran, 1938; Finlay and Wilkinson, 1963; Eberhart and Russel, 1966). However, stability analysis is becoming more commonly used in long-term fertility experiments. Raun et al. (1993) conducted two long-term experiments on wheat and corn fertility trials using stability analyses to determine that wheat responded poorly to beef manure (338 kg N/ha) as an N source compared to a chemical fertilizer treatment. They also used stability analysis in an irrigated corn experiment to determine that side-dressing with anhydrous ammonia resulted in higher yield compared to side-dressing or pre-planting with urea-ammonium nitrate (Raun et al., 1993). Daigh et al. (2018) examined long-term tillage management and crop rotations in multiple locations in the Midwest. Using stability analysis, they concluded there is no significant difference in yield between chisel-plow (CP) and NT managed corn/soybean. Further, yield stability analysis of environmental conditions showed no differences between CP and NT yield stabilities over time (Daigh et al., 2018). In a 24-year study, Nielson and Vigil (2018) reported that wheat yield stability was more stable for NT wheat-fallow when compared to CT wheat-fallow, and both NT wheat-fallow and CT wheat-fallow were more stable than more intensive crop rotations.

Summary

Conservation tillage practices (e.g., NT or RT) have shown great potential for increasing SOM and conserving soil moisture. This is due to improvements in soil chemical, physical, and biological properties. It is clear that N management is an important consideration for successfully implementing conservation tillage in the Central Great Plains. Conservation tillage practices have the potential to reduce N losses and enhance N utilization by reducing N losses and increasing NUE. More research is required as NUE with regard to long-term experiments using CT, RT, and NT practices combined with varying N fertilizer rates is rarely documented in the literature. Therefore, a study examining the long-term effects of these three tillage practices overlaid with varying nitrogen rates can be a valuable tool to gain understanding of these agricultural practices common to the Central Great Plains. Further, as the world population increases it stresses the efficiency, safety, and sufficiency of our food production systems. Effective use of inorganic fertilizers is required to optimize crop yield and quality while minimizing environmental damage. As N is the nutrient most limiting crop production in vast areas of the world, its efficient use is essential for the long-term sustainability and stability of crop production. The overall efficiency of applied N has been approximately <50% and our understanding of enhancing NUE in various ecosystems and management is still deficient. Reducing N losses due to volatilization, immobilization, denitrification, and leaching will lead to improved productivity of N use by crops. The effects of tillage intensity and nitrogen fertilizer application rates on grain sorghum and winter wheat yields and NUE will be a focus of Chapters 2 and 3 respectively.

In addition, research is needed to increase our understanding of tillage intensity and N fertilizer application on the yield stability of winter wheat and grain sorghum yields as cropping systems production rotation in the Central Great Plains. This will be the focus of Chapter 3, in which annual yield, precipitation, and its impact on yield of both crops data will be used to explore the yield stability from 1975 to 2014 years study period. That will be accomplished using linear regression of yield and environments index and then separating the treatments response as a function of different environments/years throughout the study period.

References

Abalos, D., Jeffery, S., Sanz-Cobena, A., Guardia, G., and Vallejo, A. 2014. Meta-analysis of the effect of urease and nitrification inhibitors on crop productivity and nitrogen use efficiency. Agriculture, Ecosystems & Environment, 189, 136-144.

Abbas, F., Hammad, H. M., Ishaq, W., Farooque, A. A., Bakhat, H. F., Zia, Z., and Cerdà, A. 2020. A review of soil carbon dynamics resulting from agricultural practices. *Journal of environmental management*, *268*, 110319.

Aktar, W., Sengupta, D., and Chowdhury, A. 2009. Impact of pesticides use in agriculture: their benefits and hazards. *Interdisciplinary toxicology*, *2*(1), 1-12.

Al-Kanani, T., and MacKenzie, A. F. 1992. Effect of tillage practices and hay residues on ammonia losses from urea-ammonium nitrate solutions. *Can. J. Soil Sci*, *72*, 145-157.

Anderson, R. L. 2009. Rotation design: A critical factor for sustainable crop production in a semiarid climate: A review. In *Organic Farming, Pest Control and Remediation of Soil Pollutants* (pp. 107-121). Springer, Dordrecht.

Antil, R. S., and Raj, D. 2020. Integrated Nutrient Management for Sustainable Crop Production and Improving Soil Health. In *Nutrient Dynamics for Sustainable Crop Production* (pp. 67-101). Springer, Singapore.

Araus, J. L., Slafer, G. A., Reynolds, M. P., and Royo, C. 2002. Plant breeding and drought in C3 cereals: what should we breed for?. *Annals of botany*, *89*(7), 925-940.

Army, T. J., and Kemper, W. D. 1991. Support for Long-Term Agricultural Research. *Agronomy Journal*, *83*(1), 62-65.

Arshad, M. A., Franzluebbers, A. J., and Azooz, R. H. 1999. Components of surface soil structure under conventional and no-tillage in northwestern Canada. *Soil and Tillage Research*, *53*(1), 41-47.

Aulakh, M. S., Doran, J. W., and Mosier, A. R. 1992. Soil denitrification—significance, measurement, and effects of management. In *Advances in soil science* (pp. 1-57). Springer, New York, NY.

Awale, R., Machado, S., and Rhinhart, K. 2018. Soil carbon, nitrogen, pH, and crop Yields in winter wheat–spring pea systems. *Agronomy Journal*, *110*(4), 1523-1531.

Baker, C. J., and Saxton, K. E. 2007. *No-tillage seeding in conservation agriculture*. CAB international.

Baker, C. J., Saxton, K. E., and Ritchie, W. R. 1996. No-tillage seeding: science and practice. CAB international.

Balesdent, J., Chenu, C., and Balabane, M. 2000. Relationship of soil organic matter dynamics to physical protection and tillage. *Soil and tillage research*, *53*(3-4), 215-230.

Barraclough, P. B., Howarth, J. R., Jones, J., Lopez-Bellido, R., Parmar, S., Shepherd, C. E., and Hawkesford, M. J. 2010. Nitrogen efficiency of wheat: genotypic and environmental variation and prospects for improvement. *European journal of agronomy, 33*(1), 1-11.

Basche, A. D., Miguez, F. E., Kaspar, T. C., and Castellano, M. J. 2014. Do cover crops increase or decrease nitrous oxide emissions? A meta-analysis. *Journal of Soil and Water Conservation, 69*(6), 471-482.

Batey, T., and McKenzie, D. C. 2006. Soil compaction: identification directly in the field. *Soil Use and Management*, *22*(2), 123–131.

Berzsenyi, Z., Győrffy, B., and Lap, D. 2000. Effect of crop rotation and fertilisation on maize and wheat yields and yield stability in a long-term experiment. *European Journal of Agronomy*, *13*(2-3), 225-244.

Bhatt, R. 2017. Zero tillage impacts on soil environment and properties. *J Environ Agri Sci*, *10*, 01-19.

Bhatt, R., and Khera, K. L. 2006. Effect of tillage and mode of straw mulch application on soil erosion in the submontaneous tract of Punjab, India. *Soil and Tillage Research, 88*(1-2), 107-115.

Blaise, D., Ravindran, C. D., and Singh, J. V. 2006. Trend and Stability Analysis to Interpret Results of Long-Term Effects of Application of Fertilizers and Manure to Cotton Grown on Rainfed Vertisols. *Journal of agronomy and crop science, 192*(5), 319-330.

Blevins, R. L., and Frye, W. W. 1993. Conservation tillage: an ecological approach to soil management. *Advances in Agronomy, 51*, 33-78.

Borken, W., and Matzner, E. 2009. Reappraisal of drying and wetting effects on C and N mineralization and fluxes in soils. *Global change biology*, *15*(4), 808-824.

Camara, K. M., Payne, W. A., and Rasmussen, P. E. 2003. Long-term effects of tillage, nitrogen, and rainfall on winter wheat yields in the Pacific Northwest. Agronomy journal, 95(4), 828-835.

Canfield, D. E., Glazer, A. N., and Falkowski, P. G. 2010. The evolution and future of Earth's nitrogen cycle. *science*, *330*(6001), 192-196.

Chapin III, F. S. 1980. The mineral nutrition of wild plants. *Annual review of ecology and systematics*, *11*(1), 233-260.

Chen, B., Liu, E., Tian, Q., Yan, C., and Zhang, Y. 2014. Soil nitrogen dynamics and crop residues. A review. *Agronomy for Sustainable Development*, *34*(2), 429-442.

Chen, H., A. Deng, W. Zhang, W. Li, Y. Qiao, T. Yang, C. Zheng, C. Cao, and F. Chen. 2018. Long-term inorganic plus organic fertilization increases yield and yield stability of winter wheat. The Crop J. 6:589-599.

Chien, S. H., Prochnow, L. I., and Cantarella, A. H. 2009. Recent developments of fertilizer production and use to improve nutrient efficiency and minimize environmental impacts. *Advances in agronomy*, *102*, 267-322.

Cochran, V., Danielson, J., Kolberg, R., and Miller, P. 2006. Dryland cropping in the Canadian prairies and the US northern Great Plains. *Dryland agriculture*, *23,* 293-339.

Coyne, M. S., Lal, R., and Stewart, B. A. 2018. Denitrification in soil. *Soil nitrogen uses and environmental impacts*, 95-139.

Dahnke, W. C., Vasey, E. H., Walsh, L. M., and Beaton, J. D. 1973. Testing soils for nitrogen. *Soil testing and plant analysis. SSSA, Madison, WI*, 97-114.

Dai, A., T.M.L. Wigley, B.A. Boville, J.T. Kiehl, and Buja, L.E. 2001. Climaties of the Twentieth and Twenty-First Centuries Simulated by the NCAR Climate System Model. J. Clim. 14:485-519.

Daigh, A.L.M., Dick, W.A., Helmers, M.J., Lal, R., Lauer, J.G., Nafziger, E., Pederson, C.H., Strock, J., Villamil, M., and Mukherjee, A. 2018. Yield and yield stability of no-till and chisel-plow fields in the Midwestern US corn belt. Field Crop Res. 218:243-253.

Daigh, A.L.M., Dick, W.A., Helmers, M.J., Lal, R., Lauer, J.G., Nafziger, E., Pederson, C.H., Strock, J., Villamil, M., and Mukherjee, A. 2018. Yield and yield stability of no-till and chisel-plow fields in the Midwestern US corn belt. Field Crop Res. 218:243-253.

Dawson, J. C., Huggins, D. R., and Jones, S. S. 2008. Characterizing nitrogen use efficiency in natural and agricultural ecosystems to improve the performance of cereal crops in low-input and organic agricultural systems. *Field Crops Research*, *107*(2), 89–101.

de Oliveira, E. D., Bramley, H., Siddique, K. H., Henty, S., Berger, J., and Palta, J. A. 2013. Can elevated CO2 combined with high temperature ameliorate the effect of terminal drought in wheat?. Functional Plant Biology, 40(2), 160-171.

Delgado, J. A., and Follett, R. F. 2002. Carbon and nutrient cycles. *Journal of Soil and Water Conservation*, *57*(6), 455-464.

Delgado, J. A., Gross, C. M., Lal, H., Cover, H., Gagliardi, P., McKinney, S. P., and Shaffer, M. J. 2010. A new GIS nitrogen trading tool concept for conservation and reduction of reactive nitrogen losses to the environment. In *Advances in agronomy* (Vol. 105, pp. 117-171). Academic Press.

Delogu, G., Cattivelli, L., Pecchioni, N., De Falcis, D., Maggiore, T., and Stanca, A. M. 1998. Uptake and agronomic efficiency of nitrogen in winter barley and winter wheat. *European Journal of Agronomy*, *9*(1), 11-20.

Dendooven, L., Patiño-Zúñiga, L., Verhulst, N., Luna-Guido, M., Marsch, R., and Govaerts, B. 2012. Global warming potential of agricultural systems with contrasting tillage and residue management in the central highlands of Mexico. *Agriculture, Ecosystems & Environment*, *152*, 50-58.

Diacono, M., Rubino, P., and Montemurro, F. 2013. Precision nitrogen management of wheat. A review. *Agronomy for Sustainable Development*, *33*(1), 219-241.

Dinnes, D. L., Karlen, D. L., Jaynes, D. B., Kaspar, T. C., Hatfield, J. L., Colvin, T. S., and Cambardella, C. A. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. *Agronomy journal*, *94*(1), 153-171.

Dobermann, A. 2005. Nitrogen use efficiency—state of the art. IFA Int. Workshop 1, 28–30.

Eberhart, S. t, and Russell, W. A. 1966. Stability parameters for comparing varieties 1. Crop Science, 6(1), 36–40.

Endale, D. M., Schomberg, H. H., Fisher, D. S., and Jenkins, M. B. 2015. Curve numbers from conventional and no-till cropping: A 39-year dataset from a small Georgia piedmont watershed. *Transactions of the ASABE*, *58*(2), 379-391.

Engel, R., Jones, C., and Wallander, R. 2011. Ammonia volatilization from urea and mitigation by NBPT following surface application to cold soils. *Soil Science Society of America Journal*, *75*(6), 2348-2357.

Fageria, N. K. 2012. Role of soil organic matter in maintaining sustainability of cropping systems. Communications in Soil Science and Plant Analysis, 43(16), 2063-2113.

Fageria, N. K., and Baligar, V. C. 2005. Enhancing nitrogen use efficiency in crop plants. *Advances in agronomy*, *88*, 97-185.

Fageria, N. K., V. C. Baligar., and C. A. Jones., 1991. Growth and mineral nutrition of field crops. *Books in soils, plants, and the environment (USA).*

Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A., and Ihsan, M. Z. 2017. Crop production under drought and heat stress: plant responses and management options. *Frontiers in plant science*, *8*, 1147.

Fatima, Z., Abbas, Q., Khan, A., Hussain, S., Ali, M. A., Abbas, G., and Nadeem, M. 2018. Resource use efficiencies of C3 and C4 cereals under split nitrogen regimes. *Agronomy*, *8*(5), 69.

Finlay, K. W., and Wilkinson, G. N. 1963. The analysis of adaptation in a plant-breeding programme. *Australian journal of agricultural research*, *14*(6), 742-754.

Flowers, T. H., and O'Callaghan, J. R. 1983. Nitrification in soils incubated with pig slurry or ammonium sulphate. *Soil Biology and Biochemistry*, *15*(3), 337-342.

Follett, R. F. 2008. Transformation and transport processes of nitrogen in agricultural systems. In *Nitrogen in the Environment* (pp. 19-50). Academic Press.

Franzluebbers, A. J., Hons, F. M., and Saladino, V. A. 1995. Sorghum, wheat and soybean production as affected by long-term tillage, crop sequence and N fertilization. *Plant and Soil*, *173*(1), 55-65.

Freibauer, A., Rounsevell, M. D., Smith, P., and Verhagen, J. 2004. Carbon sequestration in the agricultural soils of Europe. *Geoderma*, *122*(1), 1-23.

Frey, S. D., Elliott, E. T., and Paustian, K. 1999. Bacterial and fungal abundance and biomass in conventional and no-tillage agroecosystems along two climatic gradients. Soil Biology and Biochemistry, 31(4), 573-585.

Frison, E. A., Cherfas, J., and Hodgkin, T. 2011. Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. *Sustainability, 3*(1), 238-253.

Giller, K. E., Chalk, P., Dobermann, A., Hammond, L., Heffer, P., Ladha, J. K., and Freney, J. 2004. Emerging technologies to increase the efficiency of use of fertilizer nitrogen. *Agriculture and the nitrogen cycle: assessing the impacts of fertilizer use on food production and the environment*, *65*, 35-51.

Goulding, K., Jarvis, S., and Whitmore, A. 2008. Optimizing nutrient management for farm systems. *Philosophical Transactions of the Royal Society B: Biological Sciences, 363*(1491), 667-680.

Grahmann, K., Verhulst, N., Buerkert, A., Ortiz-Monasterio, I., and Govaerts, B. 2013. Nitrogen use efficiency and optimization of nitrogen fertilization in conservation agriculture. *CAB Reviews, 8*(053), 1-19.

Grahmann, K., Verhulst, N., Dittert, K., Govaerts, B., and Buerkert, A. 2018. High N fertilizer application to irrigated wheat in Northern Mexico for conventionally tilled and permanent raised beds: Effects on N balance and short term N dynamics. *Journal of Plant Nutrition and Soil Science*, *181*(4), 606-620.

Guretzky, J., Kering, M., Mosali, J., Funderburg, E., and Biermacher, J. 2010. Fertilizer rate effects on forage yield stability and nutrient uptake of midland bermudagrass. *Journal of plant nutrition, 33*(12), 1819-1834.

Habbib, H., Hirel, B., Verzeaux, J., Roger, D., Lacoux, J., Lea, P., and Tétu, T. 2017. Investigating the combined effect of tillage, nitrogen fertilization and cover crops on nitrogen use efficiency in winter wheat. Agronomy, 7(4), 66.

Hadas, A., Kautsky, L., Goek, M., and Kara, E. E. 2004. Rates of decomposition of plant residues and available nitrogen in soil, related to residue composition through simulation of carbon and nitrogen turnover. *Soil Biology and Biochemistry*, *36*(2), 255-266.

Halvin, J. L., Beaton, J. D., Tisdale, S. L., and Nelson, W. L. 2005. Soil fertility and fertilizers: an introduction to nutrient management. 7th ed. *Pretice Hall, New Jersey*.

Halvorson, A. D., and Reule, C. A. 1994. Nitrogen fertilizer requirements in an annual dryland cropping system. *Agronomy Journal*, *86*(2), 315-318.

Halvorson, A. D., Del Grosso, S. J., and Reule, C. A. 2008. Nitrogen, tillage, and crop rotation effects on nitrous oxide emissions from irrigated cropping systems. *Journal of Environmental Quality*, *37*(4), 1337-1344.

Halvorson, A. D., Nielsen, D. C., and Reule, C. A. 2004. Nitrogen fertilization and rotation effects on no-till dryland wheat production. *Agronomy Journal*, *96*(4), 1196-1201.

Halvorson, A. D., Wienhold, B. J., and Black, A. L. 2001. Tillage and nitrogen fertilization influence grain and soil nitrogen in an annual cropping system. *Agronomy Journal*, *93*(4), 836–841.

Halvorson, A. D., Wienhold, B. J., and Black, A. L. 2002. Tillage, nitrogen, and cropping system effects on soil carbon sequestration. *Soil science society of America journal*, *66*(3), 906-912.

Han, X., Hu, C., Chen, Y., Qiao, Y., Liu, D., Fan, J., and Zhang, Z. 2020. Crop yield stability and sustainability in a rice-wheat cropping system based on 34-year field experiment. *European Journal of Agronomy*, *113*, 125965.

Hansen, N. C., Allen, B. L., Anapalli, S., Blackshaw, R. E., Lyon, D. J., and Machado, S. 2016. Dryland Agriculture in North America. In Innovations in Dryland Agriculture (pp. 415–441). Springer.

Hansen, N. C., Allen, B. L., Baumhardt, R. L., and Lyon, D. J. 2012. Research achievements and adoption of no-till, dryland cropping in the semi-arid US Great Plains. *Field Crops Research*, *132*, 196-203.

Hansen, N. C., Tubbs, S., Fernandez, F., Green, S., Hansen, N. E., and Stevens, W. B. 2015. Conservation agriculture in North America. In Conservation Agriculture (pp. 417–441). Springer.

Havlin, J. L., Kissel, D. E., Maddux, L. D., Claassen, M. M., and Long, J. H. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. *Soil Science Society of America Journal*, *54*(2), 448-452.

Hefley, C. S. 2016. *Nitrogen Content of Wheat and Corn in Response to the Application of Urea and the Urease Inhibitor N-(n-butyl thiophosphorictriamide)* (Doctoral dissertation).

Hilton, B. R., Fixen, P. E., and Woodard, H. J. (1994). Effects of tillage, nitrogen placement, and wheel compaction on denitrification rates in the corn cycle of a corn-oats rotation. *Journal of plant nutrition*, *17*(8), 1341-1357.

Hobbs, P. R., Sayre, K., and Gupta, R. 2008. The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *363*(1491), 543–555.

Huang, M., Liang, T., Wang, L., and Zhou, C. 2015. No-tillage and fertilization management on crop yields and nitrate leaching in North China Plain. *Ecology and evolution*, *5*(6), 1143-1155.

Huang, P., Li, Y., and Sumner, M. 2011. Handbook of Soil Sciences: Resource Management and Environmental Impacts. (Eds.), CRC Press, Boca Raton, Florida.

Huggins, D. R., and Pan, W. L. 1993. Nitrogen efficiency component analysis: an evaluation of cropping system differences in productivity. *Agronomy Journal*, *85*(4), 898-905.

Johnston, A. E., and Poulton, P. R. 2009. Nitrogen in agriculture: an overview and definitions of nitrogen use efficiency. In *Proceedings-International Fertiliser Society* (No. 651). International Fertiliser Society.

Jones, O. R., Hauser, V. L., and Popham, T. W. 1994. No-tillage effects on infiltration, runoff, and water conservation on dryland. *Transactions of the ASAE*, *37*(2), 473-479.

Ju, X. T., and Li, S. X. 1998. The effect of temperature and moisture on nitrogen mineralization in soils. *Plant Nutr. Fertil. Sci*, *4*(1), 37-42.

Kant, S., Bi, Y. M., and Rothstein, S. J. 2011. Understanding plant response to nitrogen limitation for the improvement of crop nitrogen use efficiency. *Journal of experimental Botany*, *62*(4), 1499-1509.

Karlen D.L., E.G. Hurley, S.S. Andrews, C.A. Cambardella, D.W. Meek, M.D. Duffy, and Mallarino, A. P. 2013. Crop rotation effects on soil quality at three northern corn/soybean belt locations. Agron. J. 98: 484-495.

Keeney, D. R., and Follett, R. F. 1991. Managing nitrogen for groundwater quality and farm profitability: Overview and introduction. *Managing nitrogen for groundwater quality and farm profitability*, 1-7.

Keeney, D. R., and Hatfield, J. L. 2008. The nitrogen cycle, historical perspective, and current and potential future concerns. In *Nitrogen in the Environment* (pp. 1-18). Academic Press.

Keller, G. D., and Mengel, D. B. 1986. Ammonia volatilization from nitrogen fertilizers surface applied to no-till corn. *Soil Science Society of America Journal*, *50*(4), 1060-1063.

Koohafkan, P., and Stewart, B. A. 2008. Water and cereals in drylands. Earthscan.

Kozai, T. 2013. Resource use efficiency of closed plant production system with artificial light: Concept, estimation and application to plant factory. *Proceedings of the Japan Academy, Series B*, *89*(10), 447-461.

Krupnik, T. J., Six, J., Ladha, J. K., Paine, M. J., and Van Kessel, C. 2004. An assessment of fertilizer nitrogen recovery efficiency by grain crops. In:Mosier A.R., Syers K.J. and Freney J.R. (eds), *Agriculture and the nitrogen cycle, The Scientific Committee Problems of the Environment*. Island Press, Covelo, California, USSA. pp. 193-207.

Kubota, H., Iqbal, M., Quideau, S., Dyck, M., and Spaner, D. 2018. Agronomic and physiological aspects of nitrogen use efficiency in conventional and organic cereal-based production systems. *Renewable Agriculture and Food Systems*, *33*(5), 443-466.

Kumaraswamy, S., and Shetty, P. K. 2016. Critical abiotic factors affecting implementation of technological innovations in rice and wheat production: A review. *Agricultural Reviews*, *37*(4), 268-278.

Kuzyakov, Y., and Xu, X. 2013. Competition between roots and microorganisms for nitrogen: mechanisms and ecological relevance. *New Phytologist*, *198*(3), 656-669.

Ladha, J. K., Pathak, H., Krupnik, T. J., Six, J., and van Kessel, C. 2005. Efficiency of fertilizer nitrogen in cereal production: retrospects and prospects. *Advances in agronomy*, *87*, 85-156.

Li, L. P., Liu Y. Y., Luo, S. G., and Peng, X. L. 2012. Effects of nitrogen management on the yield of winter wheat in cold area of northeastern China. *Journal of Integrative Agriculture*, *11*(6), 1020-1025.

Li, S. X., Wang, Z. H., and Stewart, B. A. 2013. Responses of crop plants to ammonium and nitrate N. In *Advances in agronomy* (Vol. 118, pp. 205-397). Academic Press.

Li, S. X., Wang, Z. H., Malhi, S. S., Li, S. Q., Gao, Y. J., and Tian, X. H. 2009. Nutrient and water management effects on crop production, and nutrient and water use efficiency in dryland areas of China. *Advances in Agronomy*, *102*, 223-265.

Lichter, K., Govaerts, B., Six, J., Sayre, K. D., Deckers, J., and Dendooven, L. 2008. Aggregation and C and N contents of soil organic matter fractions in a permanent raised-bed planting system in the Highlands of Central Mexico. *Plant and Soil*, *305*(1-2), 237-252.

Liebig, M. A., Tanaka, D. L., and Wienhold, B. J. 2004. Tillage and cropping effects on soil quality indicators in the northern Great Plains. *Soil and Tillage Research*, *78*(2), 131-141.

Liebig, M., Carpenter-Boggs, L., Johnson, J. M. F., Wright, S., and Barbour, N. 2006. Cropping system effects on soil biological characteristics in the Great Plains. *Renewable Agriculture and Food Systems*, *21*(1), 36–48.

Lightfoot, C.W.F., and Tayler, R. S. 2008. Intercropping Sorghum with Cowpea in Dryland Farming Systems in Botswana. I. Field Experiments and Relative Advantages of Intercropping. Exp. Agric. 23:425-434.

Lightfoot, C.W.F., K.B.G. Dear, and Mead, R. 1987. Intercropping sorghum with cowpea in dryland farming system in Botswana. II. Comparative stability of alternative cropping system. Exp. Agric. 23:435-442.

Liliane, T. N., and Charles, M. S. 2020. Factors Affecting Yield of Crops. *Agronomy-Climate Change & Food Security*, 9.

Lin, C. S., and Binns, M. R. 1988. A method of analyzing cultivar x location x year experiments: a new stability parameter. *Theoretical and Applied Genetics*, *76*(3), 425-430.

Liu, L., Chen, T., Wang, Z., Zhang, H., Yang, J., and Zhang, J. 2013. Combination of site-specific nitrogen management and alternate wetting and drying irrigation increases grain yield and nitrogen and water use efficiency in super rice. *Field Crops Research*, *154*, 226-235.

Logan, T. J., Lal, R., and Dick, W. A. 1991. Tillage systems and soil properties in North America. *Soil and Tillage Research*, *20*(2-4), 241-270.

López-Fando, C., and Pardo, M. T. 2009. Changes in soil chemical characteristics with different tillage practices in a semi-arid environment. *Soil and Tillage Research*, *104*(2), 278–284.

López-Fando, C., Dorado, J., and Pardo, M. T. 2007. Effects of zone-tillage in rotation with no-tillage on soil properties and crop yields in a semi-arid soil from central Spain. *Soil and Tillage Research*, *95*(1–2), 266–276.

Lundy, M. E., Pittelkow, C. M., Linquist, B. A., Liang, X., Van Groenigen, K. J., Lee, J., and Van Kessel, C. 2015. Nitrogen fertilization reduces yield declines following no-till adoption. *Field Crops Research*, *183*, 204–210.

Ma, B. L., Wu, T. Y., Tremblay, N., Deen, W., Morrison, M. J., McLaughlin, N. B., and Stewart, G. 2010. Nitrous oxide fluxes from corn fields: on-farm assessment of the amount and timing of nitrogen fertilizer. *Global Change Biology*, *16*(1), 156-170.

Ma, Q., Wang, Y. L., Zhou, H., Xu, Y. G., Jiang, C. M., and Yu, W. T. 2012. Corn yield and yield stability under varying nutrient management, crop rotation, and rainfall. *International Journal of Plant Production*, *6*(1), 73-92.

Macholdt, J., and Honermeier, B. 2019. Stability analysis for grain yield of winter wheat in a long-term field experiment. *Archives of Agronomy and Soil Science*, *65*(5), 686-699.

Macholdt, J., Piepho, H. P., Honermeier, B., Perryman, S., Macdonald, A., and Poulton, P. 2020. The effects of cropping sequence, fertilization and straw management on the yield stability of winter wheat (1986–2017) in the Broadbalk Wheat Experiment, Rothamsted, UK. *The Journal of Agricultural Science*, *158*(1-2), 65-79.

Mahal, N. K., Osterholz, W. R., Miguez, F. E., Poffenbarger, H. J., Sawyer, J. E., Olk, D. C., and Castellano, M. J. 2019. Nitrogen fertilizer suppresses mineralization of soil organic matter in maize agroecosystems. *Frontiers in Ecology and Evolution*, *7*, 59.

Malhi, S. S., and McGill, W. B. 1982. Nitrification in three Alberta soils: effect of temperature, moisture and substrate concentration. *Soil Biology and Biochemistry*, *14*(4), 393-399.

Malhi, S. S., Grant, C. A., Johnston, A. M., and Gill, K. S. 2001. Nitrogen fertilization management for no-till cereal production in the Canadian Great Plains: a review. *Soil and Tillage Research*, *60*(3-4), 101-122.

Malhi, S. S., Lemke, R., Wang, Z. H., and Chhabra, B. S. 2006. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. *Soil and Tillage Research, 90*(1-2), 171-183.

Malhi, S. S., Nyborg, M., and Solberg, E. D. 1996. Influence of source, method of placement and simulated rainfall on the recovery of 15N-labelled fertilizers under zero tillage. *Canadian Journal of Soil Science*, *76*(1), 93-100.

Meisinger, J. J., and Delgado, J. A. 2002. Principles for managing nitrogen leaching. *Journal of soil and water conservation*, *57*(6), 485-498.

Michael, O. K., Hogarh, J. N., and Van den Brink, P. J. 2020. Environmental risk assessment of pesticides currently applied in Ghana. *Chemosphere*, 126845.

Micskei, G. 2012. *Comparative studies on the effect of farmyard manure and mineral fertilizers on the growth of maize in long-term experiments*. Ph.D. Thesis, Szent Istvan University.

Ming-De, H. A. O., Jun, F. A. N., Quan-Jiu, W. A. N. G., Ting-Hui, D. A. N. G., Sheng-Li, G. U. O., and Ji-Jun, W. A. N. G. 2007. Wheat grain yield and yield stability in a long-term fertilization experiment on the Loess Plateau. *Pedosphere*, *17*(2), 257-264.

Mohanty, M., Probert, M. E., Reddy, K. S., Dalal, R. C., Rao, A. S., and Menzies, N. W. 2010. Modelling N mineralization from high C: N rice and wheat crop residues. In *19th World Congress of Soil Science* (pp. 1-6).

Mokhele, B., Zhan, X., Yang, G., and Zhang, X. 2012. Nitrogen assimilation in crop plants and its affecting factors. *Canadian Journal of Plant Science*, *92*(3), 399-405.

Moll, R. H., Kamprath, E. J., and Jackson, W. A. 1982. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization 1. *Agronomy journal*, *74*(3), 562-564.

Montemurro, F. 2009. Different nitrogen fertilization sources, soil tillage, and crop rotations in winter wheat: effect on yield, quality, and nitrogen utilization. Journal of plant nutrition, 32(1), 1-18.

Montemurro, F., Convertini, G., and Ferri, D. 2007. Nitrogen application in winter wheat grown in Mediterranean conditions: effects on nitrogen uptake, utilization efficiency, and soil nitrogen deficit. Journal of plant nutrition, 30(10), 1681-1703.

Mosier, A. R., Doran, J. W., and Freney, J. R. 2002. Managing soil denitrification. *Journal of soil and water conservation*, *57*(6), 505-512.

Nadelhoffer, K. J., Giblin, A. E., Shaver, G. R., and Laundre, J. A. 1991. Effects of temperature and substrate quality on element mineralization in six arctic soils. *Ecology*, *72*(1), 242-253.

Nawaz, A., and Farooq, M. 2016. Weed management in resource conservation production systems in Pakistan. *Crop Protection, 85*, 89-103.

Nielsen, D. C., and Halvorson, A. D. 1991. Nitrogen fertility influence on water stress and yield of winter wheat. *Agronomy journal*, *83*(6), 1065-1070.

Nielsen, D. C., and Vigil, M. F. 2010. Precipitation storage efficiency during fallow in wheat-fallow systems. *Agronomy Journal*, *102*(2), 537–543.

Nielsen, D. C., and Vigil, M. F. 2018. Wheat yield and yield stability of eight dryland crop rotations. Agronomy Journal, 110(2), 594-601.

Norvell, K., Hansen, N., Westfall, D., and Ahuja, L. 2008. Runoff and erosion estimates for Great Plains dryland agroecosystems. *Hydrology Days*.

Nunes, M. R., Karlen, D. L., Moorman, T. B., and Cambardella, C. A. 2020. How does tillage intensity affect chemical soil health indicators? A United States meta-analysis. *Agrosystems, Geosciences & Environment*, *3*(1), e20083.

Obour, A. K., Mikha, M. M., Holman, J. D., and Stahlman, P. W. 2017. Changes in soil surface chemistry after fifty years of tillage and nitrogen fertilization. Geoderma, 308, 46–53.

Obour, A. K., Stahlman, P. W., and Thompson, C. A. 2015. Wheat and Grain Sorghum Yields as Influenced by Long-term Tillage and Nitrogen Fertilizer Application. Int. J. Soil Plant Sci., 7, 19–28.

Omara, P., Aula, L., Oyebiyi, F., Nambi, E., Dhillon, J. S., Carpenter, J., and Raun, W. R. 2019. No-tillage Improves Winter Wheat (Triticum Aestivum L.) Grain Nitrogen Use Efficiency. *Communications in Soil Science and Plant Analysis*, *50*(19), 2411-2419.

Palma, R. M., Saubidet, M. I., Rimolo, M., and Utsumi, J. 1998. Nitrogen losses by volatilization in a corn crop with two tillage systems in the Argentine Pampa. *Communications in soil science and plant analysis*, *29*(19-20), 2865-2879.

Panhwar, Q. A., Ali, A., Naher, U. A., and Memon, M. Y. 2019. Fertilizer management strategies for enhancing nutrient use efficiency and sustainable wheat production. In *Organic Farming* (pp. 17-39). Woodhead Publishing.

Piepho, H. P. 1998. Methods for comparing the yield stability of cropping systems. *Journal of Agronomy and Crop Science*, *180*(4), 193-213.

Pittelkow, C. M., Liang, X., Linquist, B. A., Van Groenigen, K. J., Lee, J., Lundy, M. E., and van Kessel, C. 2015. Productivity limits and potentials of the principles of conservation agriculture. *Nature*, *517*(7534), 365.

Plaza-Bonilla, D., Arrúe, J. L., Cantero-Martínez, C., Fanlo, R., Iglesias, A., and Álvaro-Fuentes, J. 2015. Carbon management in dryland agricultural systems. A review. *Agronomy for Sustainable Development*, *35*(4), 1319-1334.

Plett, D. C., Ranathunge, K., Melino, V. J., Kuya, N., Uga, Y., and Kronzucker, H. J. 2020. The intersection of nitrogen nutrition and water use in plants: new paths toward improved crop productivity. *Journal of Experimental Botany*.

Power, J. F., and Peterson, G. A. 1998. Nitrogen transformations, utilization, and conservation as affected by fallow tillage method. *Soil and Tillage Research*, *49*(1-2), 37-47.

Powlson, D. S., Gregory, P. J., Whalley, W. R., Quinton, J. N., Hopkins, D. W., Whitmore, A. P., and Goulding, K. W. 2011. Soil management in relation to sustainable agriculture and ecosystem services. *Food Policy*, *36*, S72–S87.

Preza-Fontes, G., Tomlinson, P. J., Roozeboom, K. L., Warren, J., and Ruiz Diaz, D. A. 2020. Nitrogen fertilization offsets the N_2O mitigating effects of cover-crops and double-crop soybean in a wheat–sorghum system. *Agronomy Journal*, *112*(2), 772-785.

Quemada, M., Baranski, M., Nobel-de Lange, M. N. J., Vallejo, A., and Cooper, J. M. 2013. Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yield. *Agriculture, ecosystems & environment*, *174*, 1-10.

Rahimizadeh, M., Kashani, A., Zare-Feizabadi, A., Koocheki, A. R., and Nassiri-Mahallati, M. 2010. Nitrogen use efficiency of wheat as affected by preceding crop, application rate of nitrogen and crop residues. *Australian journal of crop science*, *4*(5), 363.

Rasmussen, P. E., Allmaras, R. R., Rohde, C. R., and Roager Jr, N. C. 1980. Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. *Soil Science Society of America Journal*, *44*(3), 596-600.

Rasmussen, P. E., Goulding, K. W., Brown, J. R., Grace, P. R., Janzen, H. H., and Körschens, M. 1998. Long-term agroecosystem experiments: assessing agricultural sustainability and global change. *Science*, *282*(5390), 893-896.

Rathke, G. W., Behrens, T., and Diepenbrock, W. 2006. Integrated nitrogen management strategies to improve seed yield, oil content and nitrogen efficiency of winter oilseed rape (Brassica napus L.): a review. *Agriculture, ecosystems & environment*, *117*(2-3), 80-108.

Raun, W. R., and Johnson, G. V. 1999. Improving nitrogen use efficiency for cereal production. *Agronomy journal*, *91*(3), 357-363.

Raun, W.R., H.J. Barreto, and Westerman, R. L. 1993. Use of stability for long-term soil fertility experiments. Agron. J. 85:159-167.

Rivett, M. O., Buss, S. R., Morgan, P., Smith, J. W., and Bemment, C. D. 2008. Nitrate attenuation in groundwater: a review of biogeochemical controlling processes. *Water research*, *42*(16), 4215-4232.

Robertson, G. P., and Vitousek, P. M. 2009. Nitrogen in agriculture: balancing the cost of an essential resource. *Annual review of environment and resources*, *34*, 97-125.

Romero-Perezgrovas, R., N.Verhulst, D.De La Rosa, V. Hernández, M. Maertens, J. Deckers, and Govaerts, B. 2014. Effects of tillage and crop residue management on maize yields and net returns in the central mexican highlands under drought conditions. Pedosphere 24:476-486.

Rosolem, C. A., Ritz, K., Cantarella, H., Galdos, M. V., Hawkesford, M. J., Whalley, W. R., and Mooney, S. J. 2017. Enhanced plant rooting and crop system management for improved N use efficiency. In *Advances in agronomy* (Vol. 146, pp. 205-239). Academic Press.

Ruisi, P., Saia, S., Badagliacca, G., Amato, G., Frenda, A. S., Giambalvo, D., and Di Miceli, G. 2016. Long-term effects of no tillage treatment on soil N availability, N uptake, and 15N-fertilizer recovery of durum wheat differ in relation to crop sequence. *Field Crops Research*, *189*, 51–58.

Sainju, U. M., Lenssen, A. W., Caesar-TonThat, T., and Evans, R. G. 2009. Dryland crop yields and soil organic matter as influenced by long-term tillage and cropping sequence. *Agronomy Journal*, *101*(2), 243-251.

Sainju, U. M., Singh, B. P., Whitehead, W. F., and Wang, S. 2007. Accumulation and crop uptake of soil mineral nitrogen as influenced by tillage, cover crops, and nitrogen fertilization. *Agronomy Journal, 99*(3), 682-691.

Samonte, S. O. P., Wilson, L. T., Medley, J. C., Pinson, S. R., McClung, A. M., and Lales, J. S. 2006. Nitrogen utilization efficiency: relationships with grain yield, grain protein, and yield-related traits in rice. *Agronomy journal*, *98*(1), 168-176.

Sanz-Cobena, A., Misselbrook, T., Camp, V., and Vallejo, A. 2011. Effect of water addition and the urease inhibitor NBPT on the abatement of ammonia emission from surface applied urea. *Atmospheric Environment*, *45*(8), 1517-1524.

Sardans, J., and Peñuelas, J. 2012. The role of plants in the effects of global change on nutrient availability and stoichiometry in the plant-soil system. *Plant physiology*, *160*(4), 1741-1761.

Scharf, P. C. 2015. Understanding Nitrogen. *Managing Nitrogen in Crop Production*, (managingnitroge2), 1-24.

Schmidt, M. W., Torn, M. S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I. A., and Nannipieri, P. 2011. Persistence of soil organic matter as an ecosystem property. *Nature*, *478*(7367), 49-56.

Šeremešić, S., Đalović, I., Milošev, D., Jocković, Đ., and Pejić, B. 2013. Maize (Zea mays L.) yield stability dependence on crop rotation, fertilization and climatic conditions in a long-term experiment on Haplic Chernozem. *Zemdirbyste-Agriculture*, *100*(2), 137-142.

Shaver, T. M., Peterson, G. A., Ahuja, L. R., Westfall, D. G., Sherrod, L. A., and Dunn, G. 2002. Surface soil physical properties after twelve years of dryland no-till management. *Soil Science Society of America Journal*, *66*(4), 1296-1303.

Sheaffer, C.C., and Moncada, K.M., 2012. Introduction to Agronomy: Food, Crops and Environment. 2nd edition. Delmar Cengage Learning, New York.

Silgram, M., and Shepherd, M. A. 1999. The effects of cultivation on soil nitrogen mineralization. In *Advances in agronomy* (Vol. 65, pp. 267-311). Academic Press.

Smil, V. 1991. Population growth and nitrogen: an exploration of a critical existential link. *Population and Development Review*, 569-601.

Smil, V. 2001. Enriching the Earth. P. xiii. Massachusetts Institute of Technology.

Smith, D. R., Livingston, S. J., Zuercher, B. W., Larose, M., Heathman, G. C., and Huang, C. 2008. Nutrient losses from row crop agriculture in Indiana. *Journal of Soil and Water Conservation*, *63*(6), 396-409.

Snyder, C. S., Bruulsema, T. W., Jensen, T. L., and Fixen, P. E. 2009. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. *Agriculture, Ecosystems & Environment*, *133*(3-4), 247-266.

Soane, B. D., Ball, B. C., Arvidsson, J., Basch, G., Moreno, F., and Roger-Estrade, J. 2012. No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. Soil and Tillage Research, 118, 66-87.

Sommer, S. G., Schjoerring, J. K., and Denmead, O. T. 2004. Ammonia emission from mineral fertilizers and fertilized crops. *Advances in agronomy*, *82*(557622), 82008-4.

Soon, Y. K., Malhi, S. S., Wang, Z. H., Brandt, S., and Schoenau, J. J. 2008. Effect of seasonal rainfall, N fertilizer and tillage on N utilization by dryland wheat in a semi-arid environment. Nutrient cycling in agroecosystems, 82(2), 149-160.

Sparks, D. L. 2012. *Advances in agronomy* (Vol. 118). Academic Press.

Sparks, D. L., and Banwart, S. A. 2017. Quantifying and Managing Soil Functions in Earth's Critical Zone: Combining Experimentation and Mathematical Modelling (Vol. 142). Academic Press.

Stewart, B. A., and Liang, W. L. 2015. Strategies for increasing the capture, storage, and utilization of precipitation in semiarid regions. *Journal of Integrative Agriculture*, *14*(8), 1500-1510.

Stewart, B. A., and Peterson, G. A. 2015. Managing green water in dryland agriculture. *Agronomy Journal*, *107*(4), 1544-1553.

St-Martin, A., Vico, G., Bergkvist, G., and Bommarco, R. 2017. Diverse cropping systems enhanced yield but did not improve yield stability in a 52-year long experiment. *Agriculture, Ecosystems & Environment*, *247*, 337-342.

Strudley, M. W., Green, T. R., and Ascough II, J. C. 2008. Tillage effects on soil hydraulic properties in space and time: State of the science. Soil and Tillage Research, 99(1), 4-48.

Sun, L., Wang, R., Li, J., Wang, Q., Lyu, W., Wang, X., and Zhang, X. 2019. Reasonable fertilization improves the conservation tillage benefit for soil water use and yield of rain-fed winter wheat: A case study from the Loess Plateau, China. *Field Crops Research*, *242*, 107589.

Takahashi, S., and Anwar, M. R. 2007. Wheat grain yield, phosphorus uptake and soil phosphorus fraction after 23 years of annual fertilizer application to an Andosol. *Field Crops Research*, *101*(2), 160-171.

Tarkalson, D. D., Hergert, G. W., and Cassman, K. G. 2006. Long-term effects of tillage on soil chemical properties and grain yields of a dryland winter wheat–sorghum/corn–fallow rotation in the Great Plains. Agronomy journal, 98(1), 26-33.

Teixeira, E. I., Johnstone, P., Chakwizira, E., de Ruiter, J., Malcolm, B., Shaw, N., and Fraser, P. 2016. Sources of variability in the effectiveness of winter cover crops for mitigating N leaching. *Agriculture, Ecosystems & Environment*, *220*, 226-235.

Thomas, G. A., Dalal, R. C., and Standley, J. 2007. No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. *Soil and Tillage Research*, *94*(2), 295-304.

Torbert, H. A., and Wood, C. W. 1992. Effects of soil compaction and water-filled pore space on soil microbial activity and N losses. *Communications in Soil Science and Plant Analysis*, *23*(11-12), 1321-1331.

Torbert, H. A., Potter, K. N., and Morrison, J. E. 2001. Tillage system, fertilizer nitrogen rate, and timing effect on corn yields in the Texas Blackland Prairie. Agronomy Journal, 93(5), 1119-1124.

Tracy, P. W., Westfall, D. G., Peterson, G. A., Elliott, E. T., and Cole, C. V. 1990. Carbon, nitrogen, phosphorus, and sulfur mineralization in plow and no-till cultivation. *Soil Science Society of America Journal*, *54*(2), 457-461.

Triplett Jr, G. B., and Dick, W. A. 2008. No-tillage crop production: A revolution in agriculture!. *Agronomy journal*, *100*, S-153.

Turner, N. C., Molyneux, N., Yang, S., Xiong, Y. C., and Siddique, K. H. 2011. Climate change in south-west Australia and north-west China: challenges and opportunities for crop production. *Crop and Pasture Science*, *62*(6), 445-456.

Unger, P. W., Schomberg, H. H., Dao, T. H., and Jones, O. R. 1997. Main content area Tillage and crop residue management practices for sustainable dryland farming systems. *Annals of Arid Zone*, *36*(3), 209–232.

Van Eerd, L. L., Congreves, K. A., Hayes, A., Verhallen, A., and Hooker, D. C. 2014. Long-term tillage and crop rotation effects on soil quality, organic carbon, and total nitrogen. *Canadian Journal of Soil Science*, *94*(3), 303-315.

Venterea, R. T., and Stanenas, A. J. 2008. Profile analysis and modeling of reduced tillage effects on soil nitrous oxide flux. *Journal of environmental quality*, *37*(4), 1360-1367.

Venterea, R. T., Burger, M., and Spokas, K. A. 2005. Nitrogen oxide and methane emissions under varying tillage and fertilizer management. *Journal of Environmental Quality*, *34*(5), 1467-1477.

Verachtert, E., Govaerts, B., Lichter, K., Sayre, K. D., Ceballos-Ramirez, J. M., Luna-Guido, M. L., and Dendooven, L. 2009. Short term changes in dynamics of C and N in soil when crops are cultivated on permanent raised beds. *Plant and soil*, *320*(1-2), 281-293.

Verhulst, N., Govaerts, B., Verachtert, E., Castellanos-Navarrete, A., Mezzalama, M., Wall, P., and Sayre, K. D. 2010. Conservation agriculture, improving soil quality for sustainable production systems. *Advances in soil science: food security and soil quality*, *1799267585*, 137-208.

Viero, F., Bayer, C., Fontoura, S. M. V., and Moraes, R. P. D. 2014. Ammonia volatilization from nitrogen fertilizers in no-till wheat and maize in Southern Brazil. *Revista Brasileira de Ciência do Solo*, *38*(5), 1515-1525.

Vigil, M. F., Eghball, B., Cabrera, M. L., Jakubowski, B. R., and Davis, J. G. 2002. Accounting for seasonal nitrogen mineralization: An overview. *Journal of soil and water conservation*, *57*(6), 464-469.

West, T. O., and Post, W. M. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. *Soil Science Society of America Journal*, *66*(6), 1930-1946.

Wilson, J. P., Gerhart, K. E., Nielsen, G. A., and Ryan, C. M. 1992. Climate, soil and crop yield relationships in Cascade County, Montana. *Applied Geography*, *12*(3), 261-279.

Wood, C. W., Westfall, D. G., Peterson, G. A., and Burke, I. C. 1990. Impacts of cropping intensity on carbon and nitrogen mineralization under no-till dryland agroecosystems. *Agronomy Journal*, *82*(6), 1115-1120.

Wright, S. F., Starr, J. L., and Paltineanu, I. C. 1999. Changes in aggregate stability and concentration of glomalin during tillage management transition. *Soil Science Society of America Journal*, *63*(6), 1825–1829.

Wu, W., Ma, B. L., Fan, J. J., Sun, M., Yi, Y., Guo, W. S., and Voldeng, H. D. 2019. Management of nitrogen fertilization to balance reducing lodging risk and increasing yield and protein content in spring wheat. *Field Crops Research*, *241*, 107584.

Wyckoff, M. R. 2012. *Evaluation of anhydrous ammonia applications in winter wheat* (Master thesis, Kansas State University).

Yadav, M. R., Kumar, R., Parihar, C. M., Yadav, R. K., Jat, S. L., Ram, H., and Ghosh, A. 2017. Strategies for improving nitrogen use efficiency: A review. *Agricultural Reviews*, *38*(1), 29-40.

Yates, F., and CocHRAN, W. G. 1938. The analysis of groups of experiments. *The Journal of Agricultural Science*, *28*(4), 556-580.

Zhang, F., Cui, Z., Fan, M., Zhang, W., Chen, X., and Jiang, R. 2011. Integrated soil–crop system management: reducing environmental risk while increasing crop productivity and improving nutrient use efficiency in China. *Journal of Environmental Quality*, *40*(4), 1051-1057.

Zhang, J., He, N., Liu, C., Xu, L., Chen, Z., Li, Y., and Chen, H. Y. 2020. Variation and evolution of C: N ratio among different organs enable plants to adapt to N-limited environments. *Global change biology*, *26*(4), 2534-2543.

Zhang, S., Zheng, Q., Noll, L., Hu, Y., and Wanek, W. 2019. Environmental effects on soil microbial nitrogen use efficiency are controlled by allocation of organic nitrogen to microbial growth and regulate gross N mineralization. *Soil Biology and Biochemistry*, *135*, 304-315.

Zhang, Y., Wang, H., Liu, S., Lei, Q., Liu, J., He, J., and Liu, H. 2015. Identifying critical nitrogen application rate for maize yield and nitrate leaching in a Haplic Luvisol soil using the DNDC model. *Science of the Total Environment*, *514*, 388-398.

Zhou, M., and Butterbach-Bahl, K. 2014. Assessment of nitrate leaching loss on a yield-scaled basis from maize and wheat cropping systems. *Plant and soil*, *374*(1-2), 977-991.

Chapter 2 - Long-Term Tillage and Nitrogen Rates Influenced Sorghum Yield in Dryland Wheat-Sorghum Rotation

Abstract

Winter wheat (*Triticum aestivum* L.) and grain sorghum (*Sorghum bicolor* (L.) Moench ssp. *Bicolor*) rotation are common in dryland farming operations in semi-arid regions. However, little is known about the long-term effects of tillage intensity and nitrogen (N) fertilization in this system. This study explored impacts of tillage intensity on grain yield, N agronomy efficiency (NAE), and applied N recovery (ANR) in the sorghum phase of the rotation, using a field experiment initiated in 1965 in Hays, KS. The experimental design was a split-split-plot arrangement of rotation, tillage, and N fertilizer treatments with four replications in a randomized complete block design. The main plots were the crop phase (winter wheat, grain sorghum, or fallow), sub-plots were three tillage treatments [conventional tillage (CT), reduced tillage (RT), and no-tillage (NT)]. The sub-sub-plots were four N rates (0, 22, 45, and 67 kg N ha^{-1}), which were later modified in the 2015 growing season to 0, 45, 90, and 134 kg ha^{-1}. Results showed tillage × N rate interaction had no significant ($P = 0.608$) effect on grain yield. Year × tillage and year × N rate had significant ($P < 0.0001$) effect on grain yield. Across N rates, grain yield, NAE and ANR were more in soils under NT compared with CT or RT. Grain yield under NT increased by 8 kg ha^{-1} for every mm of growing season precipitation compared with 4 kg ha^{-1} with CT or RT. Nitrogen application significantly ($P < 0.05$) increased grain yield and protein concentration, but NAE and ANR decreased beyond 45 kg N ha^{-1}. Our results showed NT is the best management practice to increased grain sorghum yields, N use indices and sustainability in dryland systems.

Introduction

Winter wheat (*Triticum aestivum* L.) and grain sorghum (GS) (*Sorghum bicolor* L. Moench ssp. *Bicolor*) rotation are common in rain-fed (dryland) production fields in the semiarid Great Plains of the USA, including western Kansas (Obour et al., 2017; Schlegel et al., 2018). Grain sorghum is an important crop in dryland crop rotations due to its drought and high-temperature tolerance (Torres et al., 2013). It is well adapted to most parts of the central and southern Great Plains, a region that exhibits high summer temperatures and low precipitation where other crops are more likely to fail or become unprofitable (Torrest et al., 2013; Mahama et al., 2016). Grain sorghum produces greater grain yield and economic advantage under dry and warm growing conditions than maize (*Zea mays*) in dryland systems because of better drought and high-temperature tolerance and is often grown in environments where water stress is anticipated (Staggenborg et al., 2008; Assefa et al., 2010).

Nitrogen (N) is one of the most limiting nutrients in crop production (Sinclair and Rufty, 2012) and its availability heavily influences the sustainability and economic viability of agriculture systems worldwide (Delgado et al., 2010). Nitrogen fertilizer application can increase grain sorghum yield by enhanced growth of aboveground biomass and increased drought resistance in semiarid regions (Tamang et al., 2011; Ding et al., 2018). Furthermore, Guarda et al. (2004) showed that both yield and quality are directly related to N uptake and effective partitioning by crops. Despite the aforementioned positive effects of N fertilizer to increase productivity, N immobilization in crop residues and volitilization losses can decrease N availability to crops resulting in lower yield (Jug et al., 2019; Sainju et al., 2020). The N use efficiency (NUE) of cereal grains are generally reduced by over application of N fertilizer causing undesirable environmental impacts. These include greenhouse gas emissions, pollution of surface and groundwater, accumulation of NO_3^- in the soil profile and soil acidification (Cassman et al., 2003; Sommer et al. 2004; Reay et al., 2012; Zhou et al., 2016; Obour et al., 2017; Sainju et al., 2020). Environmental concerns emanating from excess application of N fertilizer are urgent, and management practices aimed at increasing NUE is critical to improve the sustainability of agricultural systems while reducing N losses.

The adoption of conservation tillage practices such as no-tillage (NT) and reduced tillage (RT) can lead to reduced erosion, increased soil organic matter and increased precipitation storage efficiency in the Great Plains (Thomas et al., 2007; Obour et al., 2017). Although NT does not always out-yield conventional tillage (CT), recent meta-analysis suggested that the greatest advantage of NT occurred in dryland systems in semiarid regions (Pittelkow et al., 2015) which characterize the majority of grain sorghum growing regions. Previous research suggested that long-term use of NT improves the quality and productivity of soils under dryland cropping conditions (Thomas et al., 2007; Triplett and Dick, 2008; Blanco-canqui et al., 2011). However, in practice, farmers generally believe that high-yield cropping systems and conservation tillage practices require high amounts of N fertilizer and tend to apply more N to maximize yields (Cui et al., 2010). In the aspect of environmental and economic constraints, improvements in NUE rather than increased N fertilizer application are needed to increase food production while maintaining environmental stewardship (Matson et al., 1998; Tilman et al., 2002). Given the low NUE of major cropping systems (Raun and Johnson, 1999), devising fertilizer management practices and tillage systems that optimize N fertilizer application and crop residue retention to increase grain yield is warranted in dryland environments.

Grain sorghum can be managed with low fertilizer rates due to its high NUE, but grain yield could increase with greater fertilizer rates (Buah et al., 2012). Nevertheless, previous research showed that grain sorghum response to N fertilizer application varies because of soil N supply and differed with weather conditions or tillage practices (Muchow, 1998; Cui et al., 2010). Other studies in the Great Plains have compared the performance of cereal crops grown with CT and NT (Dickey et al., 1994; Stone and Schlegel, 2006; Tarkalson et al., 2006; Schlegel et al., 2018). However, few experiments have investigated the combined effects of tillage and N rate on grain sorghum yield and NUE indices in the semiarid regions of the Great Plains. These NUE indices would be influenced by management practices and environment factors such as temperture and or precipitation. Long-term experiments provide opportunity to improve and fine-tuned N fertilizer recommendations and soil management practices (e.g., Lollato et al., 2019), with the ultimate goal of increasing N uptake efficiency. The current study reports grain yield and NUE from 2015 to 2018 in this long-term experiment. The hypothesis of this study was that decreasing tillage intensity will increase grain sorghum yields and NUE compared with CT in a dryland winter wheat-grain sorghum-fallow (W-GS-F) rotation system. The objectives of this study were to i) quantify the relationship between tillage intensity and N fertilizer application on grain yield, protein content, and grain N removal; and ii) determine applied N recovery and N agronomy efficiency as influenced by tillage practices and N fertilizer rates in a W-GS-F rotation.

Materials and Methods

Site Description and Experimental Design

This research was conducted using long-term experimental plots initiated in the fall of 1965 at the Kansas State University Agricultural Research Center near Hays, Kansas (38°86′ N, 99°27′ W, 609.6 m elevation) to investigate tillage intensity (CT, RT, and NT) effects on crop yields in a W-GS-F crop rotation system. The soil at the study site was a Harney silt loam (fine, montmorillonite, mesic Typic Agriustoll) (Soil Survey Staff, 2010). The experiment was modified in 1975 by adding N fertilizer treatments in a split-split-plot arrangement of crop phase, tillage, and N application rates with four replications in a randomized complete block design. Each phase of the crop rotation and tillage treatment was present in each block in each year of the study. The main plots were the crop phase, which consisted of either winter wheat, grain sorghum, or fallow (sorghum stubble). Tillage practice was the subplot factor, and N rate was the sub-sub plot factor. Each block measuring (60.4 m × 30.5 m) contained the three tillage treatments (CT, RT, and NT plots). Each tillage practice (20.4 m × 30.5 m) was subdivided into six sub-plots (3.4 m × 30.5 m), that were assigned to four N fertilizer application rates (0, 22, 45, and 67 kg N ha^{-1}) with two unfertilized alleys between tillage treatments. The entire study site contained 144 plots. The N rates were increased to 0, 45, 90, and 134 kg N ha^{-1} starting in the 2015 growing season to reflect current N fertilizer amounts that growers apply to dryland winter wheat and grain sorghum across the central Great Plains. The entire study site has not been amended with lime or phosphorus fertilizer since its establishment in 1965. Specifics regarding field operations and crop management were presented previously in Thompson and Whitney (2000), and Obour et al., (2017).

Weather Influence on Grain Sorghum Yield

Weather data including precipitation and temperature across years and growing seasons (Table 1) were recorded from the Kansas State University weather station located approximately 2.4 km from the plots. The precipitation information was grouped into different periods of grain sorghum production; growing season precipitation (PG, precipitation from June through October), and total precipitation of the fallow period (PF, precipitation after wheat harvest through fallowing year June where grain sorghum was sowed).

Sorghum Crop Yield

The current study reports grain sorghum yield from 2015 to 2018. However, the plots and treatments have been going and maintained throughout the 53-yr study period (1965 through 2018). Grain sorghum yield was determind by harvesting an area of 1.7 m wide by 30.5 m long from the center of each plot using a Massey Ferguson 8XP small plot combine harvester (Massey Ferguson, Duluth, GA). The grain moisture content was determined using a DICKEY-john grain moisture tester (DICKEY-john Inc., Auburn, IL), and then grain yield adjusted to 13.5% moisture content. The grain samples were finely ground and analyzed for N concentration by dry combustion using a LECO CN analyzer (LECO Corporation, St. Joseph, MI). The crude protein content of grain samples was determined by multiplying the grain N concentration by a crop factor of 6.25 (Virupaksha and Sastry, 1968). Grain sorghum N removal (GNR, kg ha^{-1}) was estimated by multiplying the N concentration by the weight of grain yield for each plot.

Calculations of Nitrogen use Efficiency Indices

Nitrogen use efficiency indices were computed annually for each tillage and N rate treatment similar to previously reported (Lopez-Bellido and Lopez-Bellido, 2001) as follows:

$$\boldsymbol{NAE = (GY_{Nrate} - GY_{CK})/N\ rate} \quad \textbf{\textit{Eq 2.1}}$$

$$\boldsymbol{ANR = \left(\frac{\mathrm{GNR}_{Nrate} - \mathrm{GNR}_{CK}}{N\ rate}\right) * 100} \quad \textbf{\textit{Eq 2.2}}$$

Where, NAE is N agronomic efficiency (NAE, kg grain /kg N applied), and ANR is applied N recovery in percentage (%). GY_{Nrate} and GY_{CK} is grain yield for the N fertilizer treatment and unfertilized control, respectively, (kg ha^{-1}), GNR_{Nrate} and GNR_{CK} (kg ha^{-1}) represent the N removal at a particular N fertilizer rate and unfertilized control, respectively.

Statistical Analysis Methods

Statistical analysis to assess sorghum responses to tillage and N fertilizer application over the 5-yr study was performed using PROC MIXED procedure in SAS 9.4 (SAS Institute, 2017) with tillage, N rate and year as main plots, split, and split-split-plot, respectively. Tillage practices, N fertilizer rates, and years were modeled as fixed effects, and blocks (replications) along with the interactions were considered as random effects. The LSMEANS procedure in PROC MIXED along with adjusted Tukey was used for mean comparisons. Interactions and treatment effects were considered significant when F test P values were ≤ 0.05.

Furthermore, multiple linear regression analysis was performed with the Proc Reg procedure in SAS (SAS Institute., 2017) to investigate the relationship between grain yield and weather variables and N fertilizer rates for each tillage practice. The model to explain grain yield variability was generated by first screening and selecting relevant explanatory weather variables (including total HTC, fallow precipitation from June to October, January to April, growing season precipitation from June through August, June to September, June to October, and June to July) for potential inclusion in the model. Multicollinearity among the variables was explored using the VIF option in SAS (SAS Institute., 2017), and variables with high collinearity (variables with Variance Inflation Factor (VIF) > 5) were removed. Finally, the Mallows Cp statistic was used to select the best predictive equation (Cp < 5 as good model) for each tillage practice using “selection = CP” function in SAS (SAS Institute, 2017).

Results

Grain Sorghum Yield

Grain sorghum yield was significantly affected by a year × tillage interaction (Table 2.2). This interaction occurred because grain yield was significantly greater with NT compared to RT and CT in 2016. No significant differences were observed among tillage treatments in 2015, 2017, and 2018 (Table 2.2). Across tillage and N rates, sorghum grain yields varied by year with greatest yields in 2018 and least in 2015 (Table 2.2). These differences were mostly due to differences in growing season precipitation and temperature over the four-year study. For example, 2015 had the lowest growing season precipitation and the highest average air temperature compared to the rest of study years (Table 2.1). However, results from the multiple regression analysis showed grain sorghum yield response to growing season precipitation (PG) or fallow precipitation (PF) varied with tillage practice. For example, every mm increase in PG increased grain sorghum yields by 8.1, 4.3, and 4.4 kg ha^{-1} for sorghum under NT, RT, or CT, respectively, (Table 3). Futhermore, grain yields under NT increased by 6.7 kg ha^{-1} for every mm increase in PF. However, PF had no significant effect on sorghum grain yield under CT or RT (Table 2.3). Averaged across year and N rates, grain sorghum yields under NT was greater than CT or RT (Table

The N rate × year interaction had significant effect on GS yield (Table 2.2). Nitrogen fertilizer application had no effect on grain sorghum yield in 2015, possibly because of the limited precipitation over the growing season. In 2016, applying N fertilizer increased sorghum grain yields compared to the unfertilized control, but there were no differences in grain yield beyond 45 kg N ha^{-1} (Table 2.2). Nitrogen application effects were more evident in 2017. The 134 kg N ha^{-1} exhibited the greatest grain yield compared with other N rate treatments. Over the four-year study, increasing N fertilizer rates increased grain sorghum yield over the unfertilized control (Table 2.2). Averaged across tillage, grain yield ranged from 2.63 Mg ha^{-1} for the unfertilized control to 4.55 Mg ha^{-1} for 134 kg N ha^{-1}. Regression analysis of data across the four-year study showed differences in N fertilizer response under the different tillage practices (Table 2.3). Grain sorghum yeild response to N fertilizer was highly singnificant under NT (16 kg grain ha^{-1} for one kg N ha^{-1} added) compared to CT (13 kg grain ha^{-1} for one kg N ha^{-1} added) or RT (13 kg grain ha^{-1} for one kg N ha^{-1} added) (Table 2.3). The year-to-year variability in grain yield was mostly because of variations in growing season precipiation typical of semiarid regions of the Great Plains. However, grain yield variability was different among tillage and fertilizer regime. For example, grain yield response under NT was more variable at higher N rates compared to CT (Figure 2.1a). Across years and N rates, there was more yield variability under NT compared to more intensive (CT and RT) tillage treatments (Figure 2.1c). Likewise, addition of N fertilzer resulted in a linear increase in yield variability over the 4-yr study (Figure 2.1d). However, increasing growing season precipitation decreased grain yield variability. For instance, the 2015 growing season had the least total GP which resulted in signficant yield variability compared to the remianing years of the study (Figure 2.1b), because sorghum grain yield depends on both GP and N fertilizer fertilizer application irrespective of tillage practice (Table 2.3).

Sorghum Grain Protein and Grain N Removal

Sorghum grain protein content was significantly affected by year × tillage interaction (Figure 2.3a). Protein content was significantly less with NT compared to RT and CT in 2015, but no differences among tillage treatments were observed in 2016 and 2018 (Figure 2.3a). In 2017, grain sorghum protein content was the lowest with RT compared to CT and NT.

Regardless of N rates, grain protein content was highest in 2015 but least in 2018 for all the tillage practices (Figure 2.3a). N rate × year interaction had significant effect on grain protein content (Figure 2.3b). In 2015 and 2017, grain protein content was lowest for the unfertilized control (Figure 2.3b). However, in 2016 and 2018, protein content of the unfertilized control was not different from the 45 or 90 kg N ha^{-1} application rates. In general, the highest N rate of 134 kg N ha^{-1} exhibited the greatest grain protein content over the study period. Across the four-year study period, increasing N application rates increased grain protein content over the unfertilized control (Figure 2.3b). Averaged across tillage, grain protein content ranged from 9.5% for the unfertilized control to 13.6% for 134 kg N ha^{-1}.

Grain N removal was significantly affected by the year × tillage interaction (Table 2.2). The GNR with NT was less than RT and CT in 2015, but GNR in 2016 with NT was significantly greater compared to RT and CT (Table 2.2). Meanwhile, in 2017, GNR was the least with RT compared to NT, however the GNR was not different between CT and RT. Tillage had no effect on GNR in 2018 (Table 2.2). Nitrogen removal was not different among years, ranging from 66 kg ha^{-1} in 2017 to 73 kg ha^{-1} in 2018. Similarly, the N rate × year interaction had significant effect on GNR (Table 2.2). Nitrogen fertilizer application increased GNR in 2015 but no differences beyond 45 kg N ha^{-1} (Table 2.2). Similarly, in 2016, applying N fertilizer increased GNR over the unfertilized control, but there were no differences between 90 and 134 kg N ha^{-1} (Table 2.2). Nitrogen application effects were more pronounced in 2017 and 2018 where the highest N rate of 134 kg N ha^{-1} had the greatest GNR compared with the other N rates. Across the four-year study, average GNR ranged from 40 kg ha^{-1} for the unfertilized control to 95 kg ha^{-1} for 134 kg N ha^{-1} (Table 2.2).

Nitrogen Use Efficiency

The main effects of tillage, N fertilizer application rate, and year on NAE and NAR are shown in Table 2.4. Averaged over the 4-year study period, NAE ranged from 17 kg kg^{-1} for CT to 26 kg kg^{-1} with NT. Nitrogen agronomic efficiency was significantly affected by year × tillage interaction (Table 2.4). The NAE with NT was greater than CT or RT in 2015 and 2016 growing seasons (Table 2.4). No significant differences in NAE were observed among tillage treatments in 2017 and 2018 (Table 2.4). Across tillage and N rates, NAE varied by year with greatest NAE in 2016 and 2018 but least in 2015 (Table 2.4). Similarly, the N rate × year interaction had significant effect on grain sorghum NAE (Table 2.4). In general, the increase in N rates decreased NAE irrespective of the growing season. Nitrogen fertilizer application had no significant effect on NAE in 2015. However, NAE associated with 45 kg N ha^{-1} was greatest compared to 90 or 134 kg N ha^{-1} in 2016, 2017, and 2018 (Table 2.4). Over four-year study period, applying 45 kg N ha^{-1} increased NAE over the higher N fertilizer treatments (Table 2.4). Across the 4-yr, average NAE ranged from 14 kg kg^{-1} for the 134 kg N ha^{-1} to 30 kg kg^{-1} for the 45 kg N ha^{-1}.

The ANR was significantly affected by the year × tillage interaction (Table 2.4). Applied N recovery was significantly greater with NT compared to CT or RT in 2016 (Table 2.4). There was no significant differences in ANR among tillage treatments in 2015, 2017 and 2018 (Table 2.4). Across tillage and N rates, ANR was greatest in 2016 and least in 2015 (Table 2.4). Across the four-year study, mean ANR was greater under NT (59%) compared to CT (47%) and RT (46%). Furthermore, the N rate × year interaction had significant effect on ANR (Table 2.4). Irrespective of year, the increased in N rates generally decreased ANR. Over the four-year study period and across tillage, ANR ranged from 41% for the 134 kg N ha^{-1} to 67% for for the 45 kg N ha^{-1}.

Discussion

The overall findings of this four-year study supported our hypothesis, suggesting NT tended to increase grain sorghum yields mostly through increased fallow and growing season precipitation storage efficiency in this semiard environment. Compared to NT, grain yield decreased significantly with increasing tillage intensity by approximately 8% and 11% for RT and CT, respectively. Although not directly measured in this study, greater yields under NT was possibly due to increased water storage (Bordovsky et al., 1998; Tarkalson et al, 2006). In the present study, grain sorghum yields under CT and RT were only affected by PG (Table 2.3). However, grain yield under NT was positively affected by both PF and PG. The soils under CT and RT were tilled ahead of sorghum planting and evaporative loss following the tillage operation could reduce soil water storage, a plausible reason why PF had no effect on grain yields with CT or RT. This finding agrees with previous studies which concluded that in semi-arid environments, growing season precipitation plus soil water at planting is the most limiting factor for dryland crop production (Stone and Schlegel, 2006; Schlegel et al., 2018). Furthermore, previous research from this long-term experiment reported significantly greater soil organic matter concentration in the soils under NT (Obour et al., 2017), which improved soil structure (Blanco-Canqui et al., 2011) and could potentially increase water storage under NT. Schlegel et al. (2018) reported greater residue cover and more fallow water capture in NT provided available water for in-season crop use and reduced moisture stress in sorghum grown under NT compared to CT or RT in southwest Kansas. Reducing tillage intensity benefits sorghum grain yields and water productivity in the following order NT > RT > CT (Schlegel et al., 2018). Others have shown that crop residue under NT mangement increased soil water capture compared to other tillage practices (Shaver et al., 2002; Baumhardt et al., 2012). This findings are consistent with our results that showed total PF had significant effect on grain yield under NT, but not so under CT or RT (Table 2.3) due to limited residue to increase precipitation storage with tillage. Similar to the present study, a long-term dryland maize study in Mexico reported more soil moisture under NT than CT, which resulted in greater crop yields under NT in drier years (Verhulst et al., 2011). Similarly, Pittelkow et al. (2015) concluded that in dry evironments, NT practice performed better with yields being equal to or greater than CT practices. In general, greater soil moisture storage and enhanced residue cover in arid and semiarid environments was demonstrated to increase grain sorghum yields under NT (Bordovsky et al., 1998; Tarkalson et al, 2006; Schlegel et al., 2018).

Nothwithstanding, results of the present study disagreed with findings by Fanzluebbers et al. (1995), which concluded no differences in grain sorghum yields under NT or CT after 11-yr in southcentral Texas. This disparity was possibly because of significantly greater precipitation (~1000 mm per anum) in southcentral Texas that limits advantage of NT over CT in environments that receive more rainfall (Pittelkow et al., 2015). Grain sorghum generally required 450 to 650 mm of water in the growing season to produce sufficient grain yields (Assefa et al., 2010). In the present study, the 2018 growing season had approximately 600 mm PG and resulted in a correspindingly greatest grain yield over the four-year study. Similary, PG in 2015 was 181 mm, which resulted in significantly less grain yield compared to the remaining years of the study (Table 2.2). However, less grain sorghum yield response to N fertilizer was observed in 2018 which was surprising and could be possibly due to relatively cooler temperatures in September of 2018 (Table 2.1). For example, the LTA temperature in September was 24.3 ^{O}C compared to average temperature of 20^{O}C in September of 2018. Lower temperatures which coincided with sorghum grain filling period in September could reduce grain yield. Grain sorghum yields are known to be limited by temperature and raditation even where water and N are adequatly supplied (Muchow et al., 1990; Muchow, 1998). On the other hand, high temperatures or low precipitation, such as that experienced in the 2015, could reduce nutrient uptake by roots through decreased diffusion rates of nutrients from soil to the roots (Alam, 1999; Assefa et al., 2010) which could create nutrient deficiency and subequently decreased grain yield.

In the present study, the tillage × N rate interaction had no signifcant effect on sorghum grain yield. This suggest that N fertilizer rates for grain sorghum under dryland conditions was not different among tillage practices. Sorghum grain yield generally responded positively to increased N application rates, similar to previous research reported by Varvel and Wilhelm (2003) and Wortmann et al. (2007). However, in 2015, grain yield did not respond to N fertilizer, which was not surprising because of drought conditions that made moisture the more limiting factor than N for grain sorghum production. Similar to our findings but for other cereals, Lollato et al (2019) suggested a greater response to N in higher yielding conditions as compared to dry years. Previously, Abunyewa et al., (2017) reported that relatively low grain sorghum response to N rate was because of low growing season precipitation, which also resulted in no significant differences in yield among tillage practices. In general, grain yield response to N fertilizer was significantly greater under NT compared with CT or RT (Table 2.3). This was possibly because of greater water storage under NT increasing efficiency of using PG and total PF for grain production.

Sorghum grain protein content expectedly increased with applying N fertilzer over the four-year study. however, irrespective of tillage or N fertilzer treatments, protein concentration was considerably more in drier years of the study (Figure 2.3). This was possibly because of a dilution effect (Greenwood et al., 1990), a phenomenon where increased grain yield tended to decrease grain protein concentration. Regardless of tillage and N fertilzer rates, grain protein content was greatest in 2015 and least in 2018 (Figure 2.3), which was inversely related to the corresponding grain yield obtained in the two years (Table 2.2). Across the four-year study period, protein content increased with increaseing N fertilizer rates compared to the control. However increasing the N rate to 134 kg ha^{-1} did not increase sorghum protein content more than that obtained applying 90 kg N ha^{-1} in two years out of the four-year study. Across the four-year study GNR was not significantly ($P < 0.05$) influenced by the tillage practices, but GNR increased with N fertilizer application (Table 2.2). Our results agreed with those from Sainju et al., (2007) who reported increasing rates of N fertilizer positivlty increased the GNR in cotton-sorghum rotation in Georgia, USA. In the present study, greater GNR, NAE, and ANR accompanied the high yields in 2016 and 2018 growing seasons. The least grain yield in 2015 resulted in the smallest GNR, NAE and ANR. This finding agreed with Muchow (1998) and Lollato et al. (2019), that observed NUE was positively associated with grain yield in cereal grains. Muchow (1990), reported higher NUE was associated with greater grain yield but lower grain N concentration, suggesting that increases in NUE at the same yield level comes at the expense of grain N concentration, similar to reports for other cereals (de Oliveira Silva et al., 2020).

The NAE is used as a short-term indicator of the impact of applied nutrients on productivity; as this parameter indicates how much grain yield improvement resulted from added

N fertilizer (Wortmann et al., 2007). Average NAE was 35 and 23% higher under NT compared to CT and RT across all four-year study periods. The average NAE range measured in the present study (~ 10 to 49 kg kg^{-1}) was greater than values reported for grain sorghum in Nebraska (Wortmann et al., , 2007) but similar to sorghum NAE values of 17 to 47 kg kg^{-1} reported in Uganda (Kaizzi et al., 2012). In the present study, averaged across N application rates, NAE under NT was 26 kg kg^{-1}, greater than 17 and 20 kg kg^{-1}, respectively, under CT or RT (Table 2.4). These findings showed that NT is best soil management option to improve NAE for grain sorghum production in dryland systems. Regardless of N fertilizer rates and tillage practices, the NAE ranged from 5 to 18 kg kg^{-1} for years with the least growing season precipitation (2015 and 2017), while the NAE ranged from 29 to 32 kg kg^{-1} for 2016 and 2018, respectively, years with greater precipitation during the growing season (Table 2.4). Similar to previous studies, increasing N rates resulted in decreased in NAE (Roberts, 2008, Mahama et al., 2016; Belete et al., 2018). This suggest the importance of balancing the N application with yield goal to improve NAE, which in dryland environments is dictated by growing season, and to some extent fallow precipitation as shown in the present study (Table 2.3).

Applied N recovery can be improved through timing of fertilizer application, placement, crop rotation, and applying the right amounts of N fertilizer to the crop (Yadav et al., 2017). In the present study, increasing N application rates beyond 45 kg N ha^{-1} decreased ANR by 36% and 39% where 90 and 134 kg N ha^{-1} was applied , respectively (Table 2.4). According to Fageria et al. (2005), fertilizer N recovey efficiency depends on the relationship between plant N requirement and the amount of N supplied. However, grain yield and ANR can be affacted by precipitation amounts over the growing season (Muchow, 1998; Belete et al., 2018). For example, ANR with NT in 2016 (with growing season precipitation of 320 mm) was significantly greater compared to CT or RT. However, when the growing season precipiation was less or greater than 300 mm, there was not signifigant differences among the tillage practices (Table 2.4). In general NAE and ANR was signicanlty greater with NT and decreased with increasing N rates averaged across the four-year study. The ANR values commonly reported in the literature ranged between 30 to 50%, while 50% to 80% indicated well managed systems (Fageria et al., 2005; Betele et al., 2018). In our study, ANR with NT averaged 59% and ranged from 43 to 67% with 90 and 45 kg N ha^{-1}, respectively. This suggested that NT management combined with N application from 45 to 90 kg N ha^{-1} can optimize sorghum grain yield and ANR, especially when the growing season precipitation was more than 300 mm.

Conclusion

Results from this study showed grain sorghum yield, protein content, GNR, and NUE indices were independly affected by tillage practices and N rates. Therefore, fertilzer rates for grain sorghum production will be similar regardless of tillage practice. Applying N fertilzer increased grain sorghum yields more under NT than CT or RT, resulting in significantly greater GNR, and NAE or ANR in soils under NT. The year-to-year variability in grain sorghum responses showed the significant impact of growing season precipitation on crop yield, a common occurance in semiarid regions of the central Great Plains. However, effect of precipitation varied with tillage, increasing grain yields by 8.1 kg ha^{-1} for every mm of precipitation received comapred with only 4 kg ha^{-1} yield increase with CT or RT. Applying N fertilizer generally increased grain yield but NAE and ANR decreased beyond 45 kg N ha^{-1}. We conclude NT increased grain sorghum yields and NUE's indices with optimum N rates of 45 to 90 kg ha^{-1} which depends on yield potential for the growing season.

Table 2.1 Average monthly precipitation and temperature over four grain sorghum growing seasons at Hays, KS

Yr/ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total / Average	§PF	§PG/TG
Summed Precipitation (mm)															
2015	17	4	1	21	153	16	102	10	10	43	38	29	445	197	138
2016	9	5	11	176	69	80	79	118	33	16	29	10	635	271	310
2017	29	2	33	135	100	40	39	82	47	51	2	0	559	299	207
2018	1	1	8	17	92	94	199	142	87	78	12	43	775	200	522
LTA‡	14	19	42	59	82	73	92	76	50	39	24	18	588	213	331
Average Temperature (ºC)															
2015	0	0	8	13	16	25	26	25	24	15	7	2	13	-	22.9
2016	0	4	9	12	16	25	27	24	21	16	9	-2	13	-	22.7
2017	0	5	8	13	16	24	27	23	22	13	7	-1	13	-	21.6
2018	-1	0	7	8	21	25	25	24	20	11	3	0	12	-	21.1

‡Long-term average (LTA) (43 years, 1975 to 2018).

§Total precipitation during fallow from January to May (PF); growing season (PG) from June to September; average growing season temperature (TG).

Table 2.2 Sorghum grain yield and grain N removal (GNR, kg ha^{-1}) influenced by tillage (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and N fertilizer rates over four growing seasons at Hays, KS

	2015	2016	2017	2018	mean	2015	2016	2017	2018	mean
Tillage		*Grain sorghum yield (Mg ha^{-1})*					*GNR (kg ha^{-1})*			
CT	3.00 $^{A\dagger c}$	3.25 ^{Bbc}	3.63 ^{Ab}	4.78 ^{Aa}	3.67 B	73 ^{Aa‡}	62 ^{Ba}	68 ^{ABa}	71 ^{Aa}	69 A
RT	3.11 ^{Ab}	3.65 ^{Bb}	3.58 ^{Ab}	4.85 ^{Aa}	3.80 B	77 ^{Ab}	68 ^{Bab}	60 ^{Bb}	72 ^{Aab}	69 A
NT	2.72 ^{Ac}	4.68 ^{Aa}	3.78 ^{Ab}	5.20 ^{Aa}	4.10 A	59 ^{Bb}	84 ^{Aa}	71 ^{Aab}	77 ^{Aa}	73 A
HSD[¶]	*0.41*	*0.67*	*0.31*	*0.67*	*0.27*	*11*	*15*	*9*	*13*	*7*
	----------	----------	----------	----------	---------- PR > F ----------	----------	----------	----------	----------	----------
	0.0718	*<.0001*	*0.2718*	*0.2754*	*0.0008*	*0.0007*	*0.0042*	*0.0074*	*0.4309*	*0.2830*
N Rate (kg ha^{-1})		*Grain sorghum yield (Mg ha^{-1})*					*GNR (kg ha^{-1})*			
0	2.73 ^{Aab}	2.16 ^{Bb}	2.56 ^{Cab}	3.09 ^{Ba}	2.63 C	46 $^{B\dagger a\ddagger}$	35 ^{Cb}	36 ^{Cb}	41 ^{Cab}	40 C
45	3.00 ^{Ac}	3.93 ^{Ab}	3.66 ^{Bb}	5.21 ^{Aa}	3.95 B	71 ^{Aa}	70 ^{Ba}	63 ^{Ba}	73 ^{Ba}	69 B
90	3.10 ^{Ac}	4.65 ^{Ab}	3.94 ^{Bb}	5.44 ^{Aa}	4.28 AB	82 ^{Aa}	82 ^{ABa}	68 ^{Ba}	79 ^{Ba}	78 B
134	2.94 ^{Ac}	4.71 ^{Ab}	4.51 ^{Ab}	6.04 ^{Aa}	4.55 A	80 ^{Aa}	98 ^{Aa}	99 ^{Aa}	101 ^{Aa}	95 A
HSD[¶]	*0.53*	*0.85*	*0.40*	*0.85*	*0.34*	*14*	*19*	*11*	*167*	*9*
	----------	----------	----------	----------	---------- PR > F ----------	----------	----------	----------	----------	----------
	0.3387	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*
Year	2.94 c	3.86 b	3.67 b	4.94 a	*3.85*	70 a	71 a	66 a	73 a	*70*

[†] Tillage or N rate means followed by same uppercase letter (s) within each year are not different using the Tukey's Honest Significant Difference for mean comparisons at P < 0.05

[‡] Lowercase letters represent tillage and N rate comparisons across years using Tukey's Honest Significant Difference Test at $P < 0.05$.

Table 2.3 Multiple linear regression analysis of grain sorghum yields as a function of N fertilizer rate (N rate, kg N ha^{-1}), total fallow precipitation (PF, mm, from January through May) and growing season precipitation (PG, mm, from June through September) for each tillage practices (CT, RT, and NT) over four growing seasons at Hays, KS

Tillage	**Variables**	**Regression coefficient**	***p*-value**	**Regression statistic**
CT	**Intercept**	1523	<.0001	
	N rate	12.7	<.0001	
	PG	4.4	<.0001	
	$R^{2\dagger}$			0.58
	$p^{\ddagger}$			<.0001
	$Cp^{\P}$			2.06
RT	**Intercept**	1676	<.0001	
	N rate	12.8	<.0001	
	PG	4.3	<.0001	
	$R^{2\dagger}$			0.56
	$p^{\ddagger}$			<.0001
	$Cp^{\P}$			2.05
NT	**Intercept**	-833	0.2583	
	N rate	15.8	<.0001	
	PF	6.7	0.0022	
	PG	8.1	<.0001	
	$R^{2\dagger}$			0.66
	$p^{\ddagger}$			<.0001
	$Cp^{\P}$			4.00

† The Coefficient of determination. ‡ The probability that the regression or regression coefficient was significant. ¶ The Cp is Mallows' Cp statistic.

Table 2.4 Means of sorghum grain nitrogen agronomic efficiency (NAE, kg grain /kg applied N) and applied N recovery (ANR,%) influenced by years of study (2015, 2016, 2017, and 2018), tillage (T) practices (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and N fertilizer rates (0, 45, 90, and 134 kg N/ha)

	2015	2016	2017	2018	Mean	2015	2016	2017	2018	Mean
Tillage			*NAE (kg kg^{-1})*					*ANR (%)*		
CT	0.3 $^{B\dagger c}$	21.6 ^{Bab}	19.6 ^{Ab}	29.7 ^{Aa}	17 B	41 ^{Aa‡}	50 ^{Ba}	51 ^{Aa}	48 ^{Aa}	47 B
RT	6.6 ^{ABc}	24.1 ^{Bab}	17.8 ^{Ab}	32.3 ^{Aa}	20 B	39 ^{Aa}	50 ^{Ba}	43 ^{Aa}	52 ^{Aa}	46 B
NT	11.2 ^{Ab}	40.5 ^{Aa}	16.8 ^{Ab}	34.8 ^{Aa}	26 A	50 ^{Ab}	77 ^{Aa}	51 ^{Ab}	57 ^{Aab}	59 A
HSD[¶]	*8.9*	*10.4*	*6.4*	*9.1*	*5*	*25*	*24*	*12*	*19*	*11*
---------- PR > F ----------										
	0.0241	*0.0002*	*0.5529*	*0.3320*	*<.0001*	*0.4789*	*0.0100*	*0.2357*	*0.4686*	*0.0086*
N Rate (kg ha^{-}1)			*NAE (kg kg^{-1})*					*ANR (%)*		
45	9.3 ^{Ac}	39.5 ^{Aa}	24.3 ^{Ab}	48.7 ^{Aa}	30 A	60 ^{Aa}	78 ^{Aa}	61 ^{Aa}	71 ^{Aa}	67 A
90	5.9 ^{Ac}	26.8 ^{Ba}	15.3 ^{Bb}	26.8 ^{Ba}	19 B	43 ^{ABa}	53 ^{Ba}	36 ^{Ba}	42 ^{Ba}	43 B
134	2.8 ^{Ab}	18.9 ^{Ba}	14.6 ^{Ba}	21.3 ^{Ba}	14 C	27 ^{Bb}	47 ^{Ba}	48 ^{Ba}	44 ^{Ba}	41 B
HSD[¶]	*8.7*	*10.4*	*6.4*	*9.0*	*5*	*25*	*24*	*12*	*19*	*22*
---------- PR > F ----------										
	0.1876	*0.0002*	*0.0011*	*<.0001*	*<.0001*	*0.0115*	*0.0081*	*<.0001*	*0.0011*	*<.0001*
Year	5 c	29 a	18 b	32 a	21	42 b	59 a	48 ab	52 ab	*50*

[†] Tillage or N rate means followed by same uppercase letter (s) within each year are not different using the Tukey's Honest Significant Difference for mean comparisons at P < 0.05

[‡] Lowercase letters represent tillage and N rate comparisons across years using Tukey's Honest Significant Difference Test at *P* < 0.05.

Figure 2.1 Grain sorghum yield variability as affected by tillage × N fertilizer rates (a); years of study (2015 through 2018) (b), tillage practice (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT) (c), and N fertilizer rate (d) in Hays, KS. Means followed by same letter (s) are not different using Tukey's Honest Significant Difference Test at P < 0.05

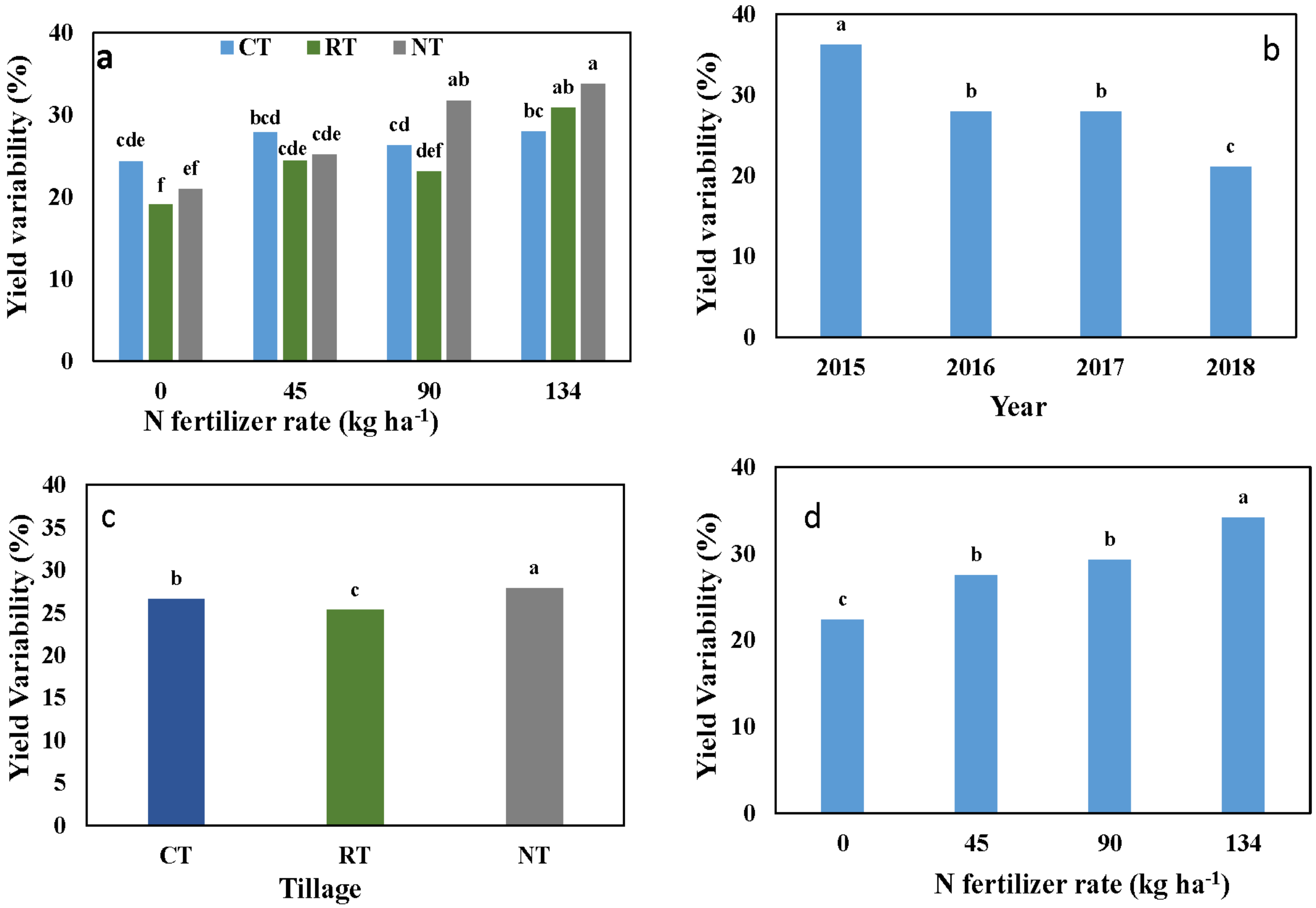
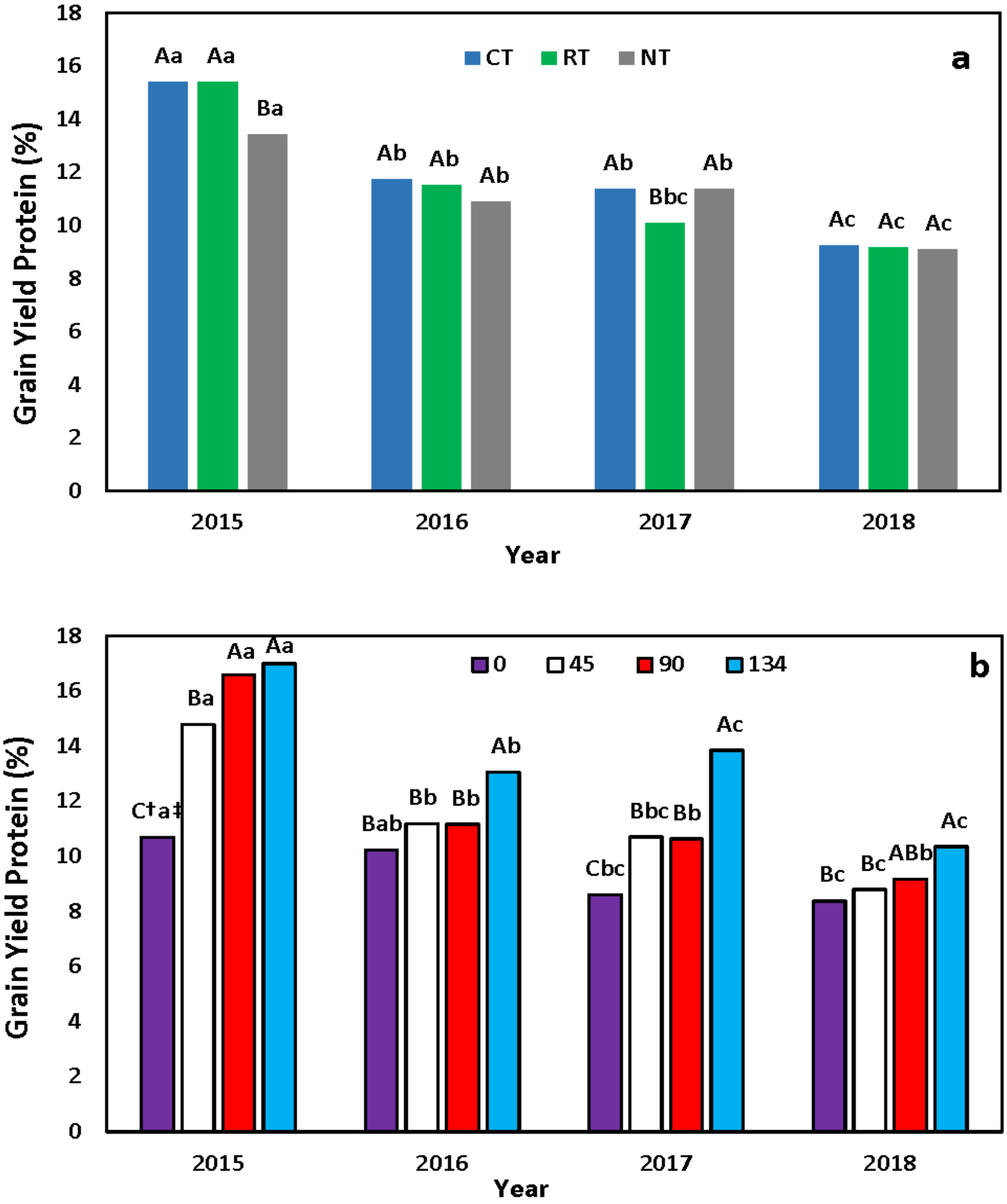


Figure 2.2 Sorghum grain protein concentration as affected by tillage (a) and N fertilization rates (b) over four study years in Hays, KS. Tillage and N rate means followed by same uppercase letter (s) within a given year are not different. Lowercase letters represent tillage and N rate comparisons across years. All mean comparisons done using Tukey's Honest Significant Difference Test at P < 0.05



References

Abunyewa, A. A., Ferguson, R. B., Wortmann, C. S., and Mason, S. C. 2017. Grain sorghum nitrogen use as affected by planting practice and nitrogen rate. Journal of soil science and plant nutrition, 17(1), 155-166.

Alam, S. M. 1999. Nutrient uptake by plants under stress conditions. Handbook of plant and crop stress, 2, 285-313.

Allison, P. D. 1999. Multiple Regression: A Primer. Thousand Oaks, CA: Pine Forge Press. p. 142.

Assefa, Y., Staggenborg, S. A., and Prasad, V. P. 2010. Grain sorghum water requirement and responses to drought stress: A review. Crop Management, *9*(1), 0-0.

Baumhardt, R. L., Johnson, G. L., and Schwartz, R. C. 2012. Residue and long-term tillage and crop rotation effects on simulated rain infiltration and sediment transport. Soil Science Society of America Journal, 76(4), 1370-1378.

Belete, F., Dechassa, N., Molla, A., and Tana, T. 2018. Effect of split application of different N rates on productivity and nitrogen use efficiency of bread wheat (Triticum aestivum L.). Agriculture & Food Security, 7(1), 92.

Bordovsky, D. G., Choudhary, M., and Gerard, C. J. 1998. Tillage effects on grain sorghum and wheat yields in the Texas Rolling Plains. Agronomy Journal, 90(5), 638-643.

Buah, S. S. J., Kombiok, J. M., and Abatania, L. N. 2012. Grain sorghum response to NPK fertilizer in the Guinea Savanna of Ghana. Journal of crop improvement, 26(1), 101-115.

Blanco-Canqui, H., A.J. Schlegel and W.F. Heer. 2011. Soil-profile distribution of carbon and associated properties in no-till along a precipitation gradient in the central Great Plains. Agriculture Ecosystems Environment, 144, 107-116.

Cassman, K. G., Dobermann, A., Walters, D. T., and Yang, H. 2003. Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environment and Resources, 28(1), 315-358.

Cui, Z., Zhang, F., Chen, X., Dou, Z., and Li, J. 2010. In-season nitrogen management strategy for winter wheat: Maximizing yields, minimizing environmental impact in an over-fertilization context. Field crops research, 116(1-2), 140-146.

de Oliveira Silva, A., Ciampitti, I. A., Slafer, G. A., and Lollato, R. P. 2020. Nitrogen utilization efficiency in wheat: A global perspective. European Journal of Agronomy, *114*, 126008.

Delgado, J. A., Gross, C. M., Lal, H., Cover, H., Gagliardi, P., McKinney, S. P., and Shaffer, M. J. 2010. A new GIS nitrogen trading tool concept for conservation and reduction of reactive nitrogen losses to the environment. Advances in agronomy, 105, 117-171.

Dickey, E. C., Jasa, P. J., and Grisso, R. D. 1994. Long-term tillage effects on grain yield and soil properties in a soybean/grain sorghum rotation. Journal of Production Agriculture, 7, 465-470.

Ding, L., Lu, Z., Gao, L., Guo, S., and Shen, Q. 2018. Is Nitrogen Key Determinant Of Water Transport And Photosynthesis In Higher Plants Upon Drought Stress? Frontiers in plant science, 9, 1143.

Fageria, N., Baligar, V., 2005. Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy 88, 97–185.

Franzluebbers, A. J., Hons, F. M., and Saladino, V. A. 1995. Sorghum, wheat and soybean production as affected by long-term tillage, crop sequence and N fertilization. Plant and Soil, 173(1), 55-65.

Greenwood, D.J., G. Lemaire, G. Gosse, P. Cruz, A. Draycott, and J.J. Neeteson. 1990. Decline in percentage N of C3 and C4 crops with increasing plant mass. Annals of Botany 66: 425-436.

Guarda, G., Padovan, S., and Delogu, G. 2004. Grain yield, nitrogen-use efficiency and baking quality of old and modern Italian bread-wheat cultivars grown at different nitrogen levels. European Journal of Agronomy, 21(2), 181-192.

Jug, D., Durdevic, B., Birkas, M., Brozovic, B., Lipiec, J., Vukadinovic, V., and Jug, I. 2019. Effect of conservation tillage on crop productivity and nitrogen use efficiency. Soil and Tillage Research, 194, 104327.

Kaizzi, K.C., Byalebeka, J., Semalulu, O., Alou, I., Zimwanguyizza, W., Nansamba, A., Musinguzi, P., Ebanyat, P., Ebanyat, P., Hyuha, T., and Wortmann, C. S. 2012. Sorghum response to fertilizer and nitrogen use efficiency in Uganda. Agronomy Journal 104, 83-90.

Lollato, R. P., Figueiredo, B. M., Dhillon, J. S., Arnall, D. B., and Raun, W. R. 2019. Wheat grain yield and grain-nitrogen relationships as affected by N, P, and K fertilization: a synthesis of long-term experiments. Field Crops Research, *236*, 42-57.

Lopez-Bellido, R.J., and L. Lopez-Bellido. 2001. Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. Field Crops Res. 71: 31-46.

Mahama, G.Y., P.V. Prasad, K.L. Roozeboom, J.B. Nippert, and C.W. Rice. 2016. Cover crops, fertilizer nitrogen rates, and economic return of grain sorghum. Agron. J. 108:1–16. doi:10.2134/ agronj15.0135.

Matson, P. A., Naylor, R., and Ortiz-Monasterio, I. 1998. Integration of environmental, agronomic, and economic aspects of fertilizer management. Science, 280(5360), 112-115.

Muchow, R. C. 1998. Nitrogen utilization efficiency in maize and grain sorghum. Field crops research, 56(1-2), 209-216.

Muchow, R. C., Sinclair, T. R., and Bennett, J. M. 1990. Temperature and solar radiation effects on potential maize yield across locations. Agronomy journal, 82(2), 338-343.

Obour, A. K., Mikha, M. M., Holman, J. D., and Stahlman, P. W. 2017. Changes in soil surface chemistry after fifty years of tillage and nitrogen fertilization. Geoderma, 308, 46-53.

Pittelkow, C. M., Linquist, B. A., Lundy, M. E., Liang, X., van Groenigen, K. J., Lee, J., and van Kessel, C. 2015. When does no-till yield more? A global meta-analysis. Field Crops Research, 183, 156-168.

Raun, W. R., and Johnson, G. V. 1999. Improving nitrogen use efficiency for cereal production. Agronomy journal, *91*(3), 357-363.

Reay, D. S., Davidson, E. A., Smith, K. A., Smith, P., Melillo, J. M., Dentener, F., and Crutzen, P. J. 2012. Global agriculture and nitrous oxide emissions. Nature climate change, 2(6), 410.

Roberts, T. L. 2008. Improving nutrient use efficiency. Turkish Journal of Agriculture and Forestry, 32(3), 177-182.

Sainju, U. M., Ghimire, R., Mishra, U., and Jagadamma, S. 2020. Reducing nitrous oxide emissions and optimizing nitrogen-use efficiency in dryland crop rotations with different nitrogen rates. Nutrient Cycling in Agroecosystems, 116, 381-395.

Sainju, U. M., Singh, B. P., Whitehead, W. F., & Wang, S. (2007). Accumulation and crop uptake of soil mineral nitrogen as influenced by tillage cover crops, and nitrogen fertilization. Agronomy Journal, *99*, 682-691.

SAS Institute. 2017. SAS user’s guide: Statistics. Version 9.4. SAS Inst., Cary, NC.

Schlegel, A. J., Assefa, Y., Haag, L. A., Thompson, C. R., and Stone, L. R. 2018. Long-term tillage on yield and water use of grain sorghum and winter wheat. Agronomy Journal, 110(1), 269-280.

Shaver, T. M., Peterson, G. A., Ahuja, L. R., Westfall, D. G., Sherrod, L. A., and Dunn, G. 2002. Surface soil physical properties after twelve years of dryland no-till management. Soil Science Society of America Journal, 66(4), 1296-1303.

Sherrod, L. A., Ahuja, L. R., Hansen, N. C., Ascough, J. C., Westfall, D. G., and Peterson, G. A. 2014. Soil and rainfall factors influencing yields of a dryland cropping system in Colorado. Agronomy Journal, *106*(4), 1179-1192.

Sinclair, T. R., and Rufty, T. W. 2012. Nitrogen and water resources commonly limit crop yield increases, not necessarily plant genetics. *Global Food Security*, *1*(2), 94-98.

Soil Survey Staff. 2010. Keys to Soil Taxonomy, 11th Ed. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC, USA.

Sommer, S. G., Schjoerring, J. K., and Denmead, O. T. 2004. Ammonia emission from mineral fertilizers and fertilized crops. Advances in agronomy, 82(557622), 82008-4.

Staggenborg, S. A., Dhuyvetter, K. C., and Gordon, W. B. 2008. Grain sorghum and corn comparisons: Yield, economic, and environmental responses. Agronomy journal, 100(6), 1600-1604.

Stone, L. R., and Schlegel, A. J. 2006. Yield–water supply relationships of grain sorghum and winter wheat. Agronomy Journal, 98(5), 1359-1366.

Tamang, P. L., Bronson, K. F., Malapati, A., Schwartz, R., Johnson, J., and Moore-Kucera, J. 2011. Nitrogen requirements for ethanol production from sweet and photoperiod sensitive sorghums in the Southern High Plains. Agronomy Journal, 103(2), 431-440.

Tarkalson, D. D., Hergert, G. W., and Cassman, K. G. 2006. Long-term effects of tillage on soil chemical properties and grain yields of a dryland winter wheat–sorghum/corn–fallow rotation in the Great Plains. Agronomy journal, 98(1), 26-33.

Thomas, G. A., Dalal, R. C., and Standley, J. 2007. No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. Soil and Tillage Research, 94(2), 295–304.

Thompson, C. A., and Whitney, D. A. 2000. Effects of 30 years of cropping and tillage systems on surface soil test changes. Communications in soil science and plant analysis, 31(1-2), 241-257.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., and Polasky, S. 2002. Agricultural sustainability and intensive production practices. Nature, 418(6898), 671-677.

Torres, G. M., Lollato, R. P., and Ochsner, T. E. 2013. Comparison of drought probability assessments based on atmospheric water deficit and soil water deficit. Agronomy Journal, *105*(2), 428-436.

Varvel, G. E., and Wilhelm, W. W. 2003. Soybean nitrogen contribution to corn and sorghum in western Corn Belt rotations. Agronomy Journal, 95(5), 1220-1225.

Verhulst, N., Nelissen, V., Jespers, N., Haven, H., Sayre, K. D., Raes, D., and Govaerts, B. 2011. Soil water content, maize yield and its stability as affected by tillage and crop residue management in rainfed semi-arid highlands. Plant and soil, *344*, 73-85.

Virupaksha, T. K., and Sastry, L. V. S. 1968. Protein content and amino acid composition of some varieties of grain sorghum. *Journal of Agricultural and Food Chemistry*, *16*(2), 199-203.

Wortmann, C. S., Mamo, M., and Dobermann, A. 2007. Nitrogen response of grain sorghum in rotation with soybean. Agronomy journal, 99(3), 808-813.

Yadav, M. R., Kumar, R., Parihar, C. M., Yadav, R. K., Jat, S. L., Ram, H., and Ghosh, A. 2017. Strategies for improving nitrogen use efficiency: A review. Agricultural Reviews, 38(1), 29-40.

Zhou, J., Gu, B., Schlesinger, W. H., and Ju, X. 2016. Significant accumulation of nitrate in Chinese semi-humid croplands. Scientific reports, 6, 25088.

Chapter 3 - Long-Term Tillage and Nitrogen Rates Influenced Winter Wheat Yield in Dryland Wheat-Sorghum Rotation

ABSTRACT

Winter wheat (*Triticum aestivum*) is the most widely grown base crop in dryland systems of the semiarid central Great Plains, but grain yields are limited by nitrogen (N) and soil water availability. We investigated the impacts of tillage intensity and N fertilization, on winter wheat grain yield, protein content, total N uptake, N utilization efficiency (NUtE), N agronomy efficiency (NAE), and applied N recovery (ANR) in a long-term wheat-sorghum-fallow rotation. The experimental design was a split-split-plot arrangement of rotation, tillage, and N application treatments in a randomized complete block design. The main plots were the crop phase (winter wheat, grain sorghum, or fallow), sub-plots were three tillage systems (conventional tillage (CT), reduced tillage (RT), and no-tillage (NT)). The sub-sub-plots included four N rates (0, 22, 45, and 67 kg/ha), which were later modified in fall 2014 for the winter wheat 2014-2015 growing season to 0, 45, 90, and 134 kgha^{-1}. Results showed winter wheat yield with CT was greater than RT or NT, but tillage had no significant effect on ANR, NAE or NUtE averaged across the four years. Grain yield, protein content, total N uptake, and NUtE of winter wheat increased with increasing N rates. However, NAE and ANR decreased at higher N rates. Our results indicated that tillage systems had little effect on the total N uptake and NUE's indices. The benefits of NT can be realized with appropriate N fertilization. However, the extent of that benefit and the appropriate N fertilization rate depends on the amount and timing of precipitation during the growing season.

Introduction

In a semiarid region of the United States central Great Plains, winter wheat (*Triticum aestivum* L.) is the most widely grown and valuable base crop (Nielsen and Vigil, 2018; Holman 2018), and the availability of water and N is usually the most limiting factor affecting dryland crop production (Lollato et al., 2017; 2019a). Whereas N fertilizer can be applied to supplement soil N, water availability depends on growing season precipitation and stored soil moisture (Halvorson et al., 2001; Torbert et al., 2001; Soon et al., 2008). In most production systems, 50% of the applied N inputs are recovered in harvested crops and their residues (Smil, 1999). The residual in the soil can potentially be lost through runoff, leaching or denitrification and volatilization (Cameron et al., 2013), which can have a detrimental impact on the environment (Erisman et al., 2013; Galloway et al., 2013). Efficient crop management practices are necessary to improve crop yield and fertilizer use efficiency to reduce nutrient loss. Practices that improve wheat grain yields, grain quality, and resource use efficiency is necessary for sustainable production. This further ensures food availability to the growing population (Lüder et al., 2020) as well as increase N use efficiency in wheat (Habbib et al., 2017).

In the absence of mineral fertilizer, differences in tillage intensity have been recognized to affect nutrient availability and yield of grain crops (Machado et al., 2007). Previous research have reported soils under NT or RT tend to increase short-term immobilization and decrease N mineralization because of slower plant decomposition process when tillage is limited (Gilliam and Hoyt, 1987; Grahmann, et al., 2013; Jug et al., 2019). It has been suggested soils under NT might require greater N inputs than under CT (Randall and Bandel, 1991; Torbert, et al., 2001; Grahmann, et al., 2013). Notwithstanding, as adoption of NT practices conserve soil water and have helped to intensify the frequency of cropping in the semi-arid region compared to the traditional crop–fallow system (Halvorson et al., 2001). With appropriate crop management, the long-term crop yields achieved from NT or RT can be comparable to those achieved from CT soils (Soane et al., 2012).

Commonly, in NT or RT systems, fertilizer N rates have been increased as much as 25% to compensate yield limitations from short-term immobilization (Randall and Bandel, 1991; Torbert, et al., 2001). This short immobilization could affect the N availability to the crop. This further helps to reduce losses and then increasing and improving NUE by reduced of different N losses (Goulding et al., 2008; Yadav et al., 2017); while N fertilizer management can be greatly affected by tillage practices (Torbert, et al., 2001). However, this short N immobilization is not an issue, but the increase N rates associated with NT might be an attributing factor to reduce this effect; but after 11 years of continual NT, the N fertilizer requirement became similar to that under CT as potential benefits of the reduced fertilizer requirements with long-term NT (Franzluebbers et al., 1995). It is therefore critical to develop soil management practices to provide for upper limit availability of nutrients for optimal plant nutrition during the during critical growth periods (eg. flowering and grain fill), to NUE and reduce N losses (Goulding et al., 2008; Yadav et al., 2017).

There are published reports on long-term tillage combined with N fertilizer rates, that showed significant increase of soil organic matter with less intensive tillage compared to more intensive (Obour et al., 2017). However, according to Rieger et al. (2008), no interaction occurred between N supply and tillage intensity. Also the authors reported a nominal overall reduction in winter wheat grain yield without N fertilization under NT compared to RT or CT. Environmental factors including temperature and rainfall, coupled with soil management determine crop response to applied N fertilizer consequently determining final grain yield (Halvorson et al., 2001; Omara et al., 2020).

Nutrient use efficiency can be affected by fertilizer administration as well as soil and plant-water relationships (Baligar, et al., 2001). However, the response of NUE to the tillage practices was not compared and uncleared in the Great Plains region. Comparisons of effects of tillage intensity on the yield and NUE indices of winter wheat as rotation with grain sorghum have not been quantified in the central Great Plain region. Therefore, there is an important need to assess optimum soil management for maximum availability of nutrients and water for plants for higher crop yield in combination with the application of less N fertilizer. Here, we wanted to investigate grain yield and NUE from 2015 to 2018 in a long-term tillage and N fertility experiment. The objectives of this study were to i) quantify grain yield, protein content, and total N uptake, and ii) determine N utilization efficiency (NUtE), applied N recovery (REN), and N agronomy efficiency (NAE) as influenced by tillage practices, and N fertilizer rates in a long-term winter wheat-grain sorghum-fallow rotation.

Materials and Methods

Site Description and Experimental Design

This research was conducted utilizing long-term experimental plots (established fall of 1965) at the Kansas State University Agricultural Research Center near Hays, Kansas (38°86′ N, 99°27′ W, 609.6 m elevation) to investigate tillage intensity (CT, RT, and NT) effects on crop yields in a winter wheat-grain sorghum-fallow crop production system. The soil at the study site is a Harney silt loam (fine, montmorillonite, mesic Typic Agriustoll) (Soil Survey Staff, 2010). The experiment was modified in 1975 by adding N fertilizer treatments in a split-split-plot arrangement of crop phase, tillage, and N application rates in a randomized complete block design with four replications. Each phase of the crop rotation and tillage treatment was present in each block in each year of the study. The main plots were the crop phase, which consisted of either winter wheat, grain sorghum, or fallow (sorghum stubble). Tillage practice was the subplot factor, and N rates were the sub-sub plot factor. Each block measuring (60.4 m × 30.5 m) contained the three tillage treatments (CT, RT, and NT plots). Each tillage practice (20.4 m × 30.5 m) was subdivided into six sub-plots (3.4 m × 30.5 m), that were assigned to four N fertilizer application rates (0, 22, 45, and 67 kg N ha^{-1}) with two unfertilized alleys between tillage treatments. Nitrogen rates were increased starting in fall 2014 (2014-2015 growing season) to 0, 45, 90, and 134 kg N ha^{-1} to reflect current producer N fertility practices. While the entire study site has not been amended with lime or phosphorus fertilizer since establishment in 1965. Specifics regarding field operations and crop management were presented previously in Thompson and Whitney (2000), Obour et al., (2015), and Obour et al., (2017). In Brief, the study was conducted in a WSF rotation with three tillage intensities, CT, RT, and NT plots. The CT system was tilled as needed to control weed growth during the fallow periods. On average, this resulted in four to five tillage operations prior to each crop, using a sweep plow for most tillage operations. The depth of tillage CT plot was plowed and disked to 15 cm soil depth to incorporate crop residue using a tandem disk, a one-way plow, and a mulch treader, which involves mixing soil and incorporating crop residue to approximately 15 cm depth. The RT system originally used tillage operations and were done with a V-blade or sweep plow to control weed growth during the fallow period before each crop. Whereas nearly three to four tillage operations were performed in the fallow phase prior to winter wheat planting in CT treatment plots while two operations occurred in the RT treatment plots. Only, one tillage operation was usually performed in both tillage treatments of CT and RT plots prior to sorghum planting. The

NT system relied solely on herbicides to control weed growth during the growing season and fallow periods. Herbicide selection varied year to year due to the weed type for each particular year.

Weather data including precipitation and temperature across years and growing seasons (Table 1) were recorded in a weather station pertaining to the Kansas Mesonet (Patrignani et al., 2021) located approximately 2.4 km from the plots.

Wheat crop yield and Biomass

The current study reports winter wheat grain yield from 2015 to 2018 of harvest seasons. However, the plots and treatments have been going and maintained throughout the 53-yr study period (1965 through 2018). Total aboveground biomass was measured from 58 to 69 growth stages (Zadoks et al., 1974) by hand sampling a c.a., 0.50 m^2 area from each experimental unit during the in 2015 to 2018 harvest seasons. The harvested samples were oven dried at 65 ^oC until constant weight to determined aboveground dry matter yield for each plot. Wheat grain yields were determined by harvesting an area of 1.7 m wide by 30.5 m long from the center of each plot using a Massey Ferguson 8XP small plot combine harvester (Massey Ferguson, Duluth, GA). Winter wheat grain moisture content was determined using a DICKEY-john grain moisture tester (DICKEY-john Inc., Auburn, IL), and then grain yield adjusted to 13.5% moisture content. Wheat grain samples and plant biomass samples were finely powder ground and analyzed for N concentration by dry combustion using a LECO CN analyzer (LECO Corporation, St. Joseph, MI). Then crude protein content of grain samples was determined by multiplying the grain N concentration by a crop factor of 5.7 (Wollmer et al., 2018). Winter wheat total N uptake (TNUp, kg ha^{-1}) was estimated by summed of grain N remove and N uptake by biomass for each plot.

Calculations of Nitrogen use efficiency indices

Nitrogen efficiency indices were computed annually for each tillage and N rate treatment similar to other studies (Zhang et al., 2016; Lüder et al., 2020) as follows:

$$\mathbf{NUtE} = (\mathbf{GY_{Nrate}}/\mathbf{TNUp_{Nrate}}) \quad \textbf{\textit{Eq. 3.1}}$$

$$\mathbf{NAE} = ((\mathbf{GY_{Nrate}} - \mathbf{GY_{CK}})/\mathbf{N\ rate}) \quad \textbf{\textit{Eq. 3.2}}$$

$$\mathbf{ANR} = \left(\left(\frac{\mathbf{GNR_{\ Nrate}} - \mathbf{GNR_{\ CK}}}{\mathbf{Nrate}}\right) * \mathbf{100}\right) \quad \textbf{\textit{Eq. 3.3}}$$

Where, NUtE is N utilization efficiency (kg grain/ kg total N uptake), NAE is N agronomic efficiency (NAE, kg grain /kg N applied), and ANR is applied N recovery in percentage (%). TNUp is total N uptake by grain and biomass, GY_{Nrate} and GY_{CK} is grain yield for the N fertilizer treatment and unfertilized control, respectively, (kg ha^{-1}), GNR_{Nrate} and GNR_{CK} (kg ha^{-1}) are N removal by the grain at a particular N fertilizer rate and unfertilized control, respectively.

Statistical Analysis

Statistical analysis was performed using PROC MIXED procedure in SAS (SAS version 9.4; SAS Institute., 2014) to assess differences in winter wheat responses to tillage and N fertilizer rates from 2015 to 2018. Tillage practices, N fertilizer rates and years were modeled and along with the interactions were considered as fixed effects, and blocks (replications) along with the interactions were considered as random effects in the mixed model to fit this split split-plot design. The final mixed model is selected based on Akaike Information Criterion (AIC) (Darlington 1968). The mean comparisons were done using Tukey's Honest Significant Difference **(**SAS Institute, 2014) with an alpha (α) of ≤ 0.05. With the significant result showing potential environmental (year) effect, we further investigated the association between grain yield and weather variables and N fertilizer rates for each tillage practice. The initial screening process was done based on selecting relevant explanatory variable and detecting multicollinearity among variables and to remove overlapping information associated with variables with high collinearity using the Variance Inflation Factor (Allison, 1999). A multiple linear regression model was developed using PROC REG procedure in SAS to assess detailed impact of the weather variables change on the winter wheat yield under each tillage practices. The Mallows' Cp statistic (<5 for a "good" model with an intercept) (Sherrod et al., 2014) was used to select the best model for each tillage practices.

Results

Winter Wheat Yield

Winter wheat yield was substantially affected by year × tillage interaction (Table 3.2). This interaction occurred because wheat yield was significantly lower with RT compared to CT in 2015. Overall wheat yield under CT averaged 2.47 Mg ha^{-1}, which was greater than RT (2.20 Mg ha^{-1}) or NT (2.26 Mg ha^{-1}). Wheat yield under NT was similar to CT in three-out of the four years study. However, winter wheat yield varied by year with greatest yields in 2017 and least in 2018. Wheat yield was not different among tillage treatments in 2016, but RT had significantly lower grain yield compared to CT and NT in 2015 and 2017. However, yields under NT were lower than RT or CT in 2018 (Table 3.2).

Nitrogen rate × year interaction had significant effect on wheat grain yield (Table 3.2). Nitrogen fertilizer application had effect on wheat yield over the unfertilized control in 2015, but there were no differences in yield beyond the 45 kg N ha^{-1}. In 2016, grain yields with the higher N rates were significantly greater than that achieved with 45 kg N ha^{-1}. Nitrogen application effects were more evident in 2017 and 2018, where the 134 kg N ha^{-1} exhibited the greatest grain yield compared with other N rate treatments. Over 4-yr study periods, increasing N fertilizer application rates linearly increased wheat yield over the unfertilized control. Averaged wheat yield ranged from 1.21 Mg ha^{-1} for the unfertilized control to 3.17 Mg ha^{-1} for 134 kg N ha^{-1}. Regression analysis of data across the four-year study showed differences in N fertilizer response under the different tillage practices (Table 3.3). Winter wheat yeild response to N fertilizer was slightly higher under NT (15.1 kg grain ha^{-1} for one kg N ha^{-1} added) compared to CT (14.8 kg grain ha^{-1} for one kg N ha^{-1} added) or RT (14.1 kg grain ha^{-1} for one kg N ha^{-1} added) (Table 3.3). Winter wheat yield under CT, RT, NT responded to growing season precipitation of Pfall and Pwinter (from October to Decebmer and from Jaruanry to March, respectively, (Table 3.3).

Winter Wheat Protein Content

Winter wheat protein content was significantly affected by year × tillage interaction (Table 3.2). Protein content was significantly lower with CT compared to RT, but there was no significant difference between NT and RT or CT in 2018. However, there was no differences in winter wheat protein content among tillage treatments in 2015, 2016, and 2017 and as well as across the 4-yr study periods. Regardless of tillage and N rates, protein content was the most in 2018 and least in 2017.

N rate × year interaction had significant effect on winter wheat protein content (Table 3.2). Nitrogen fertilizer application had significant effect on protein content in all the study years. In 2015 and 2016, protein content of winter wheat was least with the unfertilized control. While protein content of winter wheat was greatest with N-rate of 0 and 134 kg N ha^{-1} compared to 45 and 90 kg N ha^{-1} in 2017. In 2018, protein content was only significant from unfertilized control when 134 kg N ha^{-1} was applied. However, the 134 kg N ha^{-1} exhibited the greatest protein content compared with other N rate treatments among the study year periods but increasing N fertilizer application rates increased protein content. Averaged across the four-year study, winter wheat protein content ranged from 13.4% for the unfertilized control to 14.8% for 134 kg N ha^{-1} (Table 3.2).

Winter Wheat Total N Uptake

Winter wheat total N uptake (TNUp) was significantly affected by year × tillage interaction (Table 3.4). Total N uptake with RT were less than CT in 2015, but TNUp with NT was not different compared with CT or RT. The TNUp in 2016 and 2017 was different among the tillage practices. As shown in Table 3.4, the TNUp was lower with NT when compared to CT in the year 2018. Irrespective of N rates, TNUp was not different among tillage practices over the four years. Across tillage and N rates, TNUp was greatest in 2015 and least in 2018.

N rate × year interaction had significant effect on winter wheat TNUp (Table 3.4). Nitrogen fertilizer application had effect on TNUp compared to the unfertilized control in 2015, but there was no significant change on TNUp further than the 45 kg N ha^{-1}. Over the four study years, average TNUp ranged from 55 kg ha^{-1} for the unfertilized control and 140 kg ha^{-1} for 134 kg N ha^{-1} (Table 3.4).

N use efficiency indicators

Tillage x N rate interaction had no signficant effect on NAE, NAR, or NUtE. The main effects of tillage, N fertilizer application rate, and year on NAE, NAR, and NUtE are presented in Table 3.4 and 3.5. The NUtE of winter wheat was significantly affected by year × tillage interaction (Table 3.4). The NUtE was not different among the three tillage practices in all the study periods only in 2018. However, NUtE under NT was less than CT in 2018. Averaged across years, mean NUtE did not change significantly among tillage practices. Regredless of tillage and N rates, NUtE varied by year and was greatest in 2017 and least in 2015. Winter wheat NUtE across the four-year followed the order 2015 <2016 <2018 <2017. Across tillage and N rates, NUtE ranged from from kg ha^{-1} 17.5 kg kg^{-1} in 2015 to 30.9 kg kg^{-1} in 2017 (Table 3.4).

Nitrogen rate × year interaction had significant effect on NUtE (Table 3.4). Applying N fertilizer decreased NUtE significantly as N fertilizer rate increased. For example, in 2015, NUtE decreased signifianctly with the highest N rate (134 kg N ha^{-1}) as well as 90 kg N ha^{-1} compared to unfertilizered control. However, no significant differences was observed between N rates of 45 and 90 kg N ha^{-1}. But in 2016, NUtE decreased signifianctly with the highest N rate (134 kg N ha^{-1}) compared to 45 kg N ha^{-1} and unfertilizered control N rate; whereas no significant differences was observed between N rates of 90 and 134 kg N ha^{-1}. Nitrogen fertilizer rate had significant effect on NUtE in 2017 and 2018, whereas the unfertilizered control N rate was showed lowest values of NUtE compared to 45 to 134 kg N ha^{-1}. No significant differences in NUtE was observed among the 45 to 134 kg N ha^{-1} rates. While, unfertilized control N rate was significantly higher on NUtE compared to 134 kg N ha^{-1}, but there was not significant difference among the rate of 0, 45, and 90 kg N ha^{-1} in 2015 and 2016. Over the 4-yr study periods, increasing N fertilizer application rates beyond 45 kg N ha^{-1} decreased NUtE. Averaged NUtE ranged from 22.7 kg kg^{-1} for the unfertilized control to 38.4 kg kg^{-1} for the 134 kg N ha^{-1} (Table 3.4).

Nitrogen agronomic efficiceny (NAE) was significantly affected by year × tillage interaction (Table 3.5). The NAE with NT was greater than CT and RT in 2015 growing season. But no significant differences in NAE was observed between CT tillage treatments compared to

RT or NT and CT in 2016. However, the NAE under RT was significantly less compared to CT, whereas NAE with NT was not significiantly different compared to RT or CT in 2017. The NAE with CT was greater than RT and NT in 2018 growing season. Average over the 4-yr study periods, NAE was not significant different among tillage practices. The NAE was significant among years, ranging from 15.9 kg kg^{-1} in 2016 to 27.1 kg kg^{-1} in 2017 (Table 3.5).

N rate × year interaction had significant effect on NAE. In general, increasing N fertilizer rates decreased NAE irrespective of growing season. Nitrogen fertilizer application had no significant effect on NAE in 2015 and 2016. But NAE with 45 kg N ha^{-1} was greatest compared to 134 kg N ha^{-1} in 2017. Similarly, NAE with 45 kg N ha^{-1} was greatest compared to 90 and 134 kg N ha^{-1} in 2018. Over 4-study years, decreasing N fertilizer application rates increased NAE over the highest N rate fertilized treatment (Table 3.5).

Similarly, year × tillage interaction had an effect on ANR (Table 3.5). Applied N recovery was significant greater with NT compared to CT or RT in 2015. In 2016, there was no significant differences in ANR among tillage treatments. While, the ANR with RT was lowest than CT and NT, no differences in ANR was observedbetween CT or NT in 2017 growing season. In 2018, ANR with NT was lowest compared to CT and RT. While there was no significant differences in ANR among tillage practices across the 4-yr study period. Across tillage and N rates, ANR was greatest in 2017 and 2018 but least in 2015. The ANR averaged 27% in 2015 to 55% kg kg^{-1} in 2018.

Nitrogen rate × year interaction had significant effect on ANR (Table 3.5). Irrespective of year, increasing N fertilizer rates generally decreased ANR. Applied N recovery was greatest with 45 kg N ha^{-1} compared to 90 and 134 kg N ha^{-1} in 2015. But there was no effect of N fertilizer rate on ANR in 2016. The ANR with 90 kg N ha^{-1} was greater than 45 kg N ha^{-1}, but ANE under 134 kg N ha^{-1} was not different compared to 45 or 90 kg N ha^{-1} in 2017 growing season. But in 2018, ANR with 134 kg N ha^{-1} was lower compared to 45 kg N ha^{-1}. Over the 4-study year periods, average ANR ranged from 40 % for the 134 kg N ha^{-1} to 47% for for the 45 kg N ha^{-1}, but no significant differences among the N rate (Table 3.5).

Discussion

The individual effect of year, tillage practices, N fertilizer application rates, and their interactions with year on winter wheat grain yield were significant in majority of cases. In general, grain yield of winter wheat with NT was less than that under CT in one out of the four years while yields with RT were less than CT in two out of the four years. Averaged across the four years, winter wheat yield decreased with RT and NT was approximately 11% and 9%, respectively, compared to CT (Table 3.2). The decrease in wheat yield under NT and RT may be increased competition of grass weeds and poor plant stands in the less intensive tillage treatments due to drier soils at the time of planting. This is consistent with previous results from this experiment field that reported poor control of herbicide tolerant tumblegrass [Schedonnardus paniculltus (Nutt.) Trel] and windmillgrass (Chloris verticillata Nutt.) in the NT plots compared to CT caused significant yield reductions in the NT system (Thompson and Whitney, 1998; Obour et al., 2015). Additionally, the increase in incidence and severity of root diseases are among the major constraints to adoption of NT in semi-arid regions where cereals predominate (Paulitz et al., 2002). Although we did not quantify disease incidence in this research, it could have potentially contributed to poorer plant stands in the NT treatment.

The findings of the present study are in agreement with others that concluded winter wheat yields with NT are less than those reported from CT systems (Sharpley and Smith, 1994;

López-Bellido and López-Bellido, 2001; Halvorson et al., 2001; Camara et al., 2003). Sharpley and Smith, (1994), reported that even with more than 25% increase available soil water in the NT, there was average reduction of winter wheat yield by 33% compared to CT, because of lower availability of surface-applied fertilizer and weed problems in NT. Similarly, the lack of downy brome (*Bromus tectorum*) weed control in NT systems caused a significant wheat yield reduction compared to NT (Camara et al., 2003).

Nevertheless, our results are in contrast with the finding reported by Schlegel et al. (2018), who concluded that reduced tillage intensity benefits wheat yields and water productivity in the following order NT > RT > CT. However, that was performed in a more semi-arid region than the current study (annual precipitation of c.a. 380 mm versus c.a. 600 mm; Lollato et al., 2020), case in which there is evidence for improved performance of wheat under no-till (Pittelkow et al., 2015). This is an agreement with Soon et al, (2008), who reported that higher yield was with NT than CT, that is likely due to improved soil moisture conservation under NT. However, there are many other possibilities why winter wheat grain yield with CT was greater than NT. For example, CT can cause an increase in soil aeration, residue decomposition, organic N mineralization, and the availability of N for plant use (Halvorson et al., 2001; Dinnes et al., 2002). Likewise, NT can increase surface soil compaction, restricting root growth and preventing adequate drainage (Howeler et al., 1993). Our results are in agreement with Guan et al. (2015), that CT can be feasible tillage practice for winter wheat production under the rainfall condition in the North China Plain. This could be mainly due to reduced soil bulk density and penetration resistance, which in turn leads to greater root weight density, root length density, and root surface density as reported elsewhere (Guan et al., 2015). The CT is known to reduce NO_3^- losses to the groundwater due to greater water use efficiency, which results in greater N uptake and higher yield. This phenomenon is more common in drier or non-irrigated conditions of the Great Plains (Randall and Bandel, 1991). In our study, grain yield of winter wheat was affected by seasonal weather conditions. Accordingly, there was not clear pattern of tillage effects in each study year period on winter wheat yield; which was mostly due to varied precicpation timing and distribution (Table 3.1). While winter wheat yield under NT responded more by summed of growing season precipitation PWinter and PFall compared to yield under CT or RT (Table 3.1). Then these period precipitations were the most and significant factor of determining winter wheat yield for all the tillage practices (Table 3.3).

In general, increasing N fertilizer rate is directly proportional to wheat TNUp. The N fertilizer rates effect on wheat TNUp differed across years and the responses to fertilizer application also different among years. That matched the results found by Lollato et al. (2019), who reported an increase in N uptake with an increase in N application rate.

The N efficiency component analysis is valuable for evaluating improvements in N efficiency could lead to greater grain N (Huggins and Pan, 1993). The protein content quality of wheat is influenced by the N fertilizer rate, which is dominated by the yearly weather conditions and by the remaining mineral N appear in the soil (López-Bellido and López-Bellido, 2001) whereas they reported that soil NO_3^- was significantly higher with CT than NT at sowing and harvesting time. Both water stress and residual soil NO_3^- would contribute to high protein content level (Long et. al., 2017). Our results showed that are no significant differences in grain protein content of winter wheat among tillage practices regardless of N fertilizer rates and years. This agrees with the results reported by Lüder et al., (2020), that wheat grain protein was not different with tillage practices when N fertilizer was adequate; but there was higher grain protein content in NT than in CT at the unfertilized control plots and at the rate of 50 kg N ha^{-1}. The decrease in grain protein content at lower N fertilizer rate is due to a dilution effect (Wikström, 1994; Triboi et al., 2006). In the present study across the N rates and years, the term of NUE indices under CT, RT, and NT, were not different, which agrees with Montemurro, (2009) who reported NUE was not different between conventional and minimum tillage. In contrast, greater NUE was recorded with CT than NT system, which indicated that increasing intensity of the tillage was an efficiency pathway to improve the NUE (López-Bellido, and López-Bellido, 2001), possibly due to greater N mineralization or supply and available in soil under CT compared to NT (Huggins and Pan, 1993; Silgram and Shephred, 1999). The process of decomposition and mineralization are greater in CT than NT (Marahatta et al., 2014). This is due to the fact that greater immobilization is always impacted by the leftover residues of conservation practices such as RT and or NT (Rice and Smith, 1984; Gramman et al., 2013). Late moisture stress during grain filling plays a major role in limiting N translocation leading to reduction in starch accumulation and grain protein content (Campbell et al., 1981; Altenbach et al., 2003). Also, limitation of NUtE (N mobilization and redistribution) would in turn lead to high N concentration in residual plant parts and then that leads to low NUE (Masclaux-Daubresse et al., 2010). The measured NUtE values in our study reflected well the range in wheat NUtE recently reported in a global synthesis (de Oliveira Silva et al., 2020). Our results of NUtE in 2018 was higher under CT than NT, which is in agreement with previously reported study by Huggins and Pan (1993), that spring wheat with CT generally having higher efficiency values than NT because of higher yields. This is possibly due to low N uptake associated with low dry weight biomass (data not shown) by drought affected wheat. This observation is in agreement with earlier research conducted by Soon et al., (2008). The results from tillage practices of our research had little effect on wheat N accumulation and remobilization as per

Soon et al., 2008. This is attributed to improving N supply by N fertilizer along with reduced N utilization efficiency relative to unfertilized control. However, in contrast to Soon et al. (2008), the CT resulted in higher NUtE than NT in 2018 from our research, which is because of the grain yield of winter wheat was higher under CT than NT practices.

Applied N recovery (ANR, %) varied significantly according to year and it's interaction with tillage and N rate. Instead, in 2015, ANR under NT was significantly higher (43%) than ANA under CT either RT (23 or 15%, respectively); which was possibly due to lower grain yield of winter wheat under NT with unfertilized control plot. Meanwhile, in 2018 showed opposite response of NAR under tillage practices compared 2015. Whereas intensive tillage (CT and RT) had a higher value of ANR (64 and 59 %, respectively) than NT (42%). Our results supported by other findings that showed a reduction in NUE with increasing N supply. That could be due to a decline in N utilization and N availability efficiencies (Huggins and Pan, 1993; Sowers et al., 1994). They also reported that N uptake efficiency was not related to a decreased NUE. Nitrogen use efficiency would be more reasonably evaluated if loss of N during crop senescence is considered. In general, our results of NAE decreased as N fertilizer rates increase agrees with findings (Roberts, 2008). According to Craswell and Godwin, (1984), reported that a greater value of NAE could be achieved when the yield increment per unit N applied was higher due to the increasing N uptake as well as reduced losses.

Conclusion

Winter wheat grain yield, protein content and N uptake, and NUE indices were affected by years, tillage practices and N rates, however, these responses were not consistent during the four-year study. In the Central Great Plains (Hays, KS), precipitation is limited and more variable across the season, which affected winter wheat yield. Notwithstanding, averaged winter wheat yields across the four years under CT was more than RT and or NT practices. However, winter wheat yields with responses were impacted by growing season timing and distribution of precipitation. Results showed averaged NUtE, NAE, and RAN with CT was not greater than RT or NT, but they were varied year-to-year, especially in 2018. Grain yield, protein content, total N uptake, and NUtE of winter wheat increased with increasing N rates. However, the NAE and ANR decreased at higher N rates. Our results indicated that tillage systems had little effect on the total N uptake then NUE's indices. The benefits of NT can be realized with appropriate N fertilization. However, the extent of that benefit and the appropriate N fertilization rate depends on the amount and timing of precipitation during the growing season.

Table 3.1 Total and average monthly and growing season periods of precipitation and temperature of winter wheat growing season for 2015, 2016, 2017, and 2018 at Hays, KS

Yr/ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total / Average	[§]PF/TF	[§]PG/TG	[§]PFall/ PWinter
								Summed Precipitation (mm)								mm
2015	17	4	1	21	153	16	102	10	10	43	38	29	455	462	318	105
2016	9	5	11	176	69	80	79	118	33	16	29	10	635	395	445	110
2017	29	2	33	135	100	40	39	82	47	51	2	0	559	648	393	55
2018	1	1	8	17	92	94	199	142	87	78	12	43	775	545	267	53
LTA[‡]	14	19	42	59	82	73	92	76	50	39	24	18	588	578	367	80
								Average Temperature (ºC)								mm
2015	0	0	8	13	16	25	26	25	24	15	7	2	13	13.0	13.0	22
2016	0	4	9	12	16	25	27	24	21	16	9	-2	13	13.0	13.7	25
2017	0	5	8	13	16	24	27	23	22	13	7	-1	13	13.7	13.0	64
2018	-1	0	7	8	21	25	25	24	20	11	3	0	12	13.0	12.2	11

[‡] Long-term average (LTA) (43 years, 1975 to 2018).

[§] Total precipitation during fallow (PF, Nov. to Sept.); growing season (PG, from Oct to June); average growing season and during fallow temperature (TG and TF); total precipitation of PFall (Oct. through Dec.) and PWinter (Jan. through March).

Table 3.2 Means of winter wheat yield and grain protein concentration influenced by years of study (2015, 2016, 2017, and 2018), tillage (T) practices (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and N fertilizer rates (0, 45, 90, 134, kg N/ha), and their interaction

	2015	2016	2017	2018	mean	2015	2016	2017	2018	mean
Tillage	*Winter wheat yield (Mg ha^{-1})*					*Protein (%)*				
CT	2.58 $^{A\dagger a\ddagger}$	2.53 ^{Aa}	2.78 ^{Aa}	1.97 ^{Ab}	2.47 A	14.70 $^{A\dagger b\ddagger}$	13.41 ^{Ac}	11.37 ^{Ad}	15.90 ^{Ba}	13.83 A
RT	2.24 ^{Ba}	2.41^{Aa}	2.39 ^{Ba}	1.75 ^{Ab}	2.20 B	14.68 ^{Ab}	13.10 ^{Ac}	11.35 ^{Ad}	16.67 ^{Aa}	13.95 A
NT	2.33 ^{ABb}	2.49 ^{Aab}	2.74 ^{Aa}	1.46 ^{Bc}	2.26 B	14.27 ^{Ab}	13.48 ^{Ac}	11.56 ^{Ad}	15.99 ^{ABa}	13.83 A
HSD[¶]	*0.27*	*0.38*	*0.29*	*0.25*	*0.16*	*0.45*	*0.57*	*0.53*	*0.73*	*0.30*
	--	PR > F	--							
	0.0120	*0.7170*	*0.0029*	*<.0001*		*0.0368*	*0.2402*	*0.6035*	*0.0263*	
N Rate	*Winter wheat yield (Mg ha^{-1})*					*Protein (%)*				
0	1.98 $^{B\dagger a\ddagger}$	1.48 ^{Cb}	0.87 ^{Dc}	0.53 ^{Dd}	1.21 D	13.02 $^{C\dagger b\ddagger}$	12.53 ^{Cbc}	12.09 ^{Ac}	16.05 ^{Ba}	13.43 C
45	2.41 ^{Aa}	2.18 ^{Ba}	2.19 ^{Ca}	1.57 ^{Cb}	2.09 C	14.78 ^{Bb}	12.58 ^{Cc}	10.26 ^{Cd}	15.83 ^{Ba}	13.36 C
90	2.43 ^{Ab}	3.05 ^{Aa}	3.39 ^{Ba}	2.16 ^{Bb}	2.76 B	14.93 ^{ABb}	13.51 ^{Bc}	11.20 ^{Bd}	15.88 ^{Ba}	13.88 B
134	2.72 ^{Ac}	3.21 ^{Ab}	4.10 ^{Aa}	2.65 ^{Ac}	3.17 A	15.46 ^{Ab}	14.71 ^{Ac}	12.15 ^{Ad}	16.99 ^{Aa}	14.81 A
HSD[¶]	*0.34*	*0.48*	*0.36*	*0.32*	*0.20*	*0.57*	*0.72*	*0.68*	*0.93*	*0.38*
	--	PR > F	--							
	<.0001	*<.0001*	*<.0001*	*<.0001*		*<.0001*	*<.0001*	*<.0001*	*0.0078*	
Year	2.39 b	2.48 ab	3.64 a	1.73 c		14.55 b	13.33 c	11.43 d	16.17 a	

[†] The different uppercase letters within each year represent significant differences ($P < 0.05$) among tillage or N rate treatments

[‡] The different lowercase letters within each Tillage and N-rate represent significant differences ($P < 0.05$) among the years

[¶] Tukey's Honest Significant Difference for mean comparisons with an alpha (α) of 0.05.

Table 3.3 Linear regression analysis over 4-yr study periods (2015 through 2018) of winter wheat yields as a function of N fertilizer rate (N rate, Kg N ha^{-1}), PFall (Oct. through Dec.), PWinter (Jan. through March) by each tillage practices (CT, RT, and NT)

Tillage	**Variables**	**Regression coefficient**	***p*-value**	**Regression statistic**
CT	**Intercept**	450	0.1581	
	N rate	14.8	<.0001	
	PFall	7.1	0.0158	
	PWinter	14.7	0.0003	
	R^2†			0.67
	p‡			<.0001
	Cp¶			3.3774
RT	**Intercept**	246	0.4051	
	N rate	14.1	<.0001	
	PFall	8.0	0.0040	
	PWinter	11.8	0.0016	
	R^2†			0.67
	p‡			<.0001
	Cp¶			3.2286
NT	**Intercept**	-464	0.1246	
	N rate	15.1	<.0001	
	PFall	12.1	<.0001	
	PWinter	24.0	<.0001	
	R^2†			0.74
	p‡			<.0001
	Cp¶			3.0199

† The Coefficient of determination

‡ The probability that the regression or regression coefficient was significant

¶ The Cp is Mallows' Cp statistic.

Table 3.4 Means of winter wheat total N uptake (TNUp, kg ha^{-1}) and N utilization efficiency (NUtE, kg grain/ kg N applied) influenced by years of study (2015, 2016, 2017, and 2018), tillage (T) practices (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and N fertilizer rates (0, 45, 90, 134, kg N/ha) and their interaction

	2015	2016	2017	2018	Mean	2015	2016	2017	2018	Mean
Tillage	*TNUp (kg ha^{-1})*					*NUtE (kg kg^{-1})*				
CT	150 $^{A\dagger a\ddagger}$	116 ^{Ab}	85 ^{Ac}	66 ^{Ad}	104 A	17.5 $^{A\dagger d\ddagger}$	23.2 ^{Ac}	31.7 ^{Aa}	28.2 ^{Ab}	25.1 A
RT	132 ^{Ba}	116 ^{Ab}	81 ^{Ac}	61 ^{ABd}	98 A	17.5 ^{Ac}	22.0 ^{Ab}	29.2 ^{Aa}	26.3 ^{ABa}	23.8 A
NT	139 ^{Abba}	111 ^{Ab}	84 ^{Ac}	55 ^{Bd}	97 A	17.5 ^{Ac}	23.7 ^{Ab}	31.7 ^{Aa}	25.6 ^{Bb}	24.6 A
HSD[¶]	*16*	*18*	*11*	*6*	*7*	*2.4*	*3.9*	*3.6*	*2.2*	*0.9*
	----------	----------	----------	----------	---------- PR > F ----------	----------	----------	----------	----------	----------
	0.0310	*0.6799*	*0.5461*	*0.0009*		*0.9993*	*0.5727*	*0.1595*	*0.0170*	
N Rate	*TNUp (kg ha^{-1})*					*NUtE (kg kg^{-1})*				
0	98 $^{C\dagger a\ddagger}$	59 ^{Db}	38 ^{Dbc}	26 ^{Dc}	55 D	20.5 $^{A\dagger b\ddagger}$	26.2 ^{Aa}	23.6 ^{Bab}	20.6 ^{Bb}	22.7 C
45	135 ^{Ba}	88 ^{Cb}	63 ^{Cc}	55 ^{Cc}	85 C	17.9 ^{ABc}	24.9 ^{Ab}	35.1 ^{Aa}	28.0 ^{Ab}	26.5 A
90	157 ^{Aa}	144 ^{Bb}	103 ^{Bc}	71 ^{Bd}	119 B	15.5 ^{Bc}	21.5 ^{ABb}	33.1 ^{Aa}	30.3 ^{Aa}	25.1 AB
134	171 ^{Aa}	167 ^{Aa}	130 ^{Ab}	91 ^{Ac}	140 A	16.1 ^{Bd}	19.3 ^{Bc}	31.7 ^{Aa}	27.9 ^{Ab}	23.8 BC
HSD[¶]	*20*	*22*	*13*	*8*	*9*	*3.1*	*5.0*	*4.5*	*2.7*	*1.1*
	----------	----------	----------	----------	---------- PR > F ----------	----------	----------	----------	----------	----------
	<.0001	*<.0001*	*<.0001*	*0.0187*		*0.0004*	*0.0023*	*<.0001*	*0.0062*	
Year	140 a	114 b	83 c	61 d		17.5 d	23.0 c	30.9 a	26.8 b	

[†] The different uppercase letters within each year represent significant differences ($P < 0.05$) among tillage or N rate treatments

[‡] The different lowercase letters within each Tillage and N-rate represent significant differences ($P < 0.05$) among the years

[¶] Tukey's Honest Significant Difference for mean comparisons with an alpha (α) of 0.05.

Table 3.5 Means of winter wheat nitrogen agronomic efficiency (NAE, kg grain /kg applied N) and applied N recovery (ANR,%) influenced by years of study (2015, 2016, 2017, and 2018), tillage (T) practices (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and N fertilizer rates (0, 45, 90, and 134 kg N/ha) and their interaction

	2015	2016	2017	2018	Mean	2015	2016	2017	2018	Mean
Tillage			*NAE (kg kg^{-1})*					*ANR (%)*		
CT	4.6 $^{B\dagger c\ddagger}$	16.3 ^{ABb}	28.9 ^{Aa}	23.6 ^{Aa}	18.4 A	23 $^{B\dagger c\ddagger}$	43 ^{Ab}	55 ^{Aab}	64 ^{Aa}	46 A
RT	2.3 ^{Bc}	17.8 ^{Ab}	24.0 ^{Ba}	19.6 ^{Aab}	15.9 A	15 ^{Bc}	42 ^{Ab}	45 ^{Bab}	59 ^{Aa}	40 A
NT	13.3 ^{Ab}	11.9 ^{Bb}	28.5 ^{ABa}	14.3 ^{Bb}	17.0 A	43 ^{Aab}	32 ^{Ab}	57 ^{Aa}	42 ^{Bab}	44 A
HSD[¶]	*5.5*	*5.4*	*4.7*	*4.7*	*2.7*	*14*	*12*	*8*	*15*	*7*
					PR > F					
	0.0001	*0.0308*	*0.0288*	*0.0002*		*0.0002*	*0.0481*	*0.0024*	*0.0034*	
N Rate			*NAE (kg kg^{-1})*					*ANR (%)*		
45	9.7 $^{A\dagger c\ddagger}$	15.5 ^{Abc}	29.3 ^{Aa}	23.3 ^{Aab}	19.4 A	39 $^{A\dagger b\ddagger}$	35 ^{Ab}	47 ^{Bab}	65 ^{Aa}	47 A
90	4.9 ^{Ac}	17.6 ^{Ab}	28.1 ^{ABa}	18.3 ^{Bb}	17.2 AB	21 ^{Bb}	45 ^{Aa}	58 ^{Aa}	52 ^{ABa}	44 A
134	5.6 ^{Ac}	13.0 ^{Ab}	24.1 ^{Ba}	15.9 ^{Bb}	14.7 B	22 ^{Bc}	38 ^{Ab}	53 ^{ABa}	49 ^{Bab}	40 A
HSD[¶]	*5.5*	*5.4*	*4.7*	*4.7*	*2.7*	*14*	*12*	*8*	*15*	*7*
					PR > F					
	0.0859	*0.1273*	*0.0299*	*0.0021*		*0.0056*	*0.1158*	*0.0189*	*0.0229*	
Year	6.7 d	15.4 c	27.1 a	19.2 b		27 c	39 b	52 a	55 a	

[†] The different uppercase letters within each year represent significant differences ($P < 0.05$) among tillage or N rate treatments

[‡] The different lowercase letters within each Tillage and N-rate represent significant differences ($P < 0.05$) among the years

[¶] Tukey's Honest Significant Difference for mean comparisons with an alpha (α) of 0.05.

References

Allison, P. D. 1999. Multiple Regression: A Primer. Thousand Oaks, CA: Pine Forge Press. p. 142.

Altenbach, S. B., DuPont, F. M., Kothari, K. M., Chan, R., Johnson, E. L., and Lieu, D. 2003. Temperature, water and fertilizer influence the timing of key events during grain development in a US spring wheat. *Journal of Cereal Science*, *37*(1), 9-20.

Baligar, V. C., Fageria, N. K., and He, Z. L. 2001. Nutrient use efficiency in plants. Communications in soil science and plant analysis, 32(7-8), 921-950.

Camara, K. M., Payne, W. A., and Rasmussen, P. E. 2003. Long-term effects of tillage, nitrogen, and rainfall on winter wheat yields in the Pacific Northwest. Agronomy journal, 95(4), 828-835.

Cameron, K. C., Di, H. J., and Moir, J. L. 2013. Nitrogen losses from the soil/plant system: a review. Annals of applied biology, 162(2), 145-173.

Campbell, C. A., Davidson, H. R., and Winkleman, G. E. 1981. Effect of nitrogen, temperature, growth stage and duration of moisture stress on yield components and protein content of Manitou spring wheat. *Canadian Journal of Plant Science*, *61*(3), 549-563.

Craswell, E. T., and Godwin, D. C. 1984. The efficiency of nitrogen fertilizers applied to cereals grown in different climates (No. REP-3326. CIMMYT.).

Darlington, R. B. 1968. Multiple regression in psychological research andpractice. *Psychological bulletin*, *69*(3), 161.

Dinnes, D. L., Karlen, D. L., Jaynes, D. B., Kaspar, T. C., Hatfield, J. L., Colvin, T. S., and Cambardella, C. A. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. *Agronomy journal*, *94*(1), 153-171.

Erisman, J. W., Galloway, J. N., Seitzinger, S., Bleeker, A., Dise, N. B., Petrescu, A. R., and de Vries, W. 2013. Consequences of human modification of the global nitrogen cycle. Philosophical Transactions of the Royal Society B: Biological Sciences, 368(1621), 20130116.

Franzluebbers, A. J., Hons, F. M., and Saladino, V. A. 1995. Sorghum, wheat and soybean production as affected by long-term tillage, crop sequence and N fertilization. *Plant and Soil*, *173*(1), 55-65.

Galloway, J. N., Leach, A. M., Bleeker, A., and Erisman, J. W. 2013. A chronology of human understanding of the nitrogen cycle. Philosophical Transactions of the Royal Society B: Biological Sciences, 368(1621), 20130120.

Gilliam, J.W., and Hoyt. G.D. 1987. Effect of conservation tillage on fate and transport of nitrogen. p. 217–240. In T.J. Logan et al. (ed.) Effects of conservation tillage on groundwater quality: Nitrates and pesticides. Lewis Publ., Chelsea, MI.

Goulding, K., Jarvis, S., & Whitmore, A. (2008). Optimizing nutrient management for farm systems. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1491), 667-680.

Grahmann, K., Verhulst, N., Buerkert, A., Ortiz-Monasterio, I., and Govaerts, B. 2013. Nitrogen use efficiency and optimization of nitrogen fertilization in conservation agriculture. CAB Reviews, 8(053), 1-19.

Guan, D., Zhang, Y., Al-Kaisi, M. M., Wang, Q., Zhang, M., and Li, Z. 2015. Tillage practices effect on root distribution and water use efficiency of winter wheat under rain-fed condition in the North China Plain. Soil and Tillage Research, 146, 286-295.

Habbib, H., Hirel, B., Verzeaux, J., Roger, D., Lacoux, J., Lea, P., and Tétu, T. 2017. Investigating the combined effect of tillage, nitrogen fertilization and cover crops on nitrogen use efficiency in winter wheat. Agronomy, 7(4), 66.

Halvorson, A. D., Wienhold, B. J., and Black, A. L. 2001. Tillage and nitrogen fertilization influence grain and soil nitrogen in an annual cropping system. Agronomy Journal, 93(4), 836–841.

Holman, J. D., Arnet, K., Dille, J., Maxwell, S., Obour, A., Roberts, T., and Schlegel, A. 2018. Can cover or forage crops replace fallow in the semiarid Central Great Plains?. Crop Science, 58(2), 932-944.

Howeler, R.H., Ezumah, H.C. and Midmore, D.J. 1993. Tillage systems for root and tuber crops in the tropics. *Soil and Tillage Research*, *27*(1-4), pp.211-240.

Huggins, D. R., and Pan, W. L. (1993). Nitrogen efficiency component analysis: an evaluation of cropping system differences in productivity. *Agronomy Journal*, *85*(4), 898-905.

Jug, D., Đurđević, B., Birkás, M., Brozović, B., Lipiec, J., Vukadinović, V., and Jug, I. 2019. Effect of conservation tillage on crop productivity and nitrogen use efficiency. *Soil and Tillage research*, *194*, 104327.

Lollato, R. P., Figueiredo, B. M., Dhillon, J. S., Arnall, D. B., and Raun, W. R. 2019. Wheat grain yield and grain-nitrogen relationships as affected by N, P, and K fertilization: a synthesis of long-term experiments. Field Crops Research, 236, 42-57.

Lollato, R.P., Bavia, G.P., Perin, V., Knapp, M., Santos, E.A., Patrignani, A. and DeWolf, E.D., 2020. Climate-risk assessment for winter wheat using long-term weather data. *Agronomy Journal*.

Lollato, R.P., Edwards, J.T. and Ochsner, T.E., 2017. Meteorological limits to winter wheat productivity in the US southern Great Plains. *Field Crops Research*, *203*, pp.212-226.

Lollato, R.P., Ruiz Diaz, D.A., DeWolf, E., Knapp, M., Peterson, D.E. and Fritz, A.K., 2019. Agronomic practices for reducing wheat yield gaps: a quantitative appraisal of progressive producers. *Crop Science*, *59*(1), pp.333-350.

Long, D. S., McCallum, J. D., Reardon, C. L., and Engel, R. E. 2017. Nitrogen requirement to change protein concentration of spring wheat in semiarid Pacific Northwest. Agronomy Journal, 109(2), 675-683.

López-Bellido, R. J., and López-Bellido, L. 2001. Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. Field Crops Research, 71(1), 31-46.

Lüder, R. M. H., Qin, R., Richner, W., Stamp, P., Streit, B., Herrera, J. M., and Noulas, C. 2020. Small-Scale Variation in Nitrogen Use Efficiency Parameters in Winter Wheat as Affected by N Fertilization and Tillage Intensity. Sustainability, 12(9), 3621.

Machado, S., Petrie, S., Rhinhart, K., and Qu, A. 2007. Long-term continuous cropping in the Pacific Northwest: Tillage and fertilizer effects on winter wheat, spring wheat, and spring barley production. Soil and Tillage Research, 94(2), 473-481.

Marahatta, S., Sah, S. K., MacDonald, A., Timilnisa, J., and Devkota, K. P. 2014. Influence of conservation agriculture practices on physical and chemical properties of soil. *International Journal*, *2*(12), 43-52.

Masclaux-Daubresse, C., Daniel-Vedele, F., Dechorgnat, J., Chardon, F., Gaufichon, L., and Suzuki, A. 2010. Nitrogen uptake, assimilation and remobilization in plants: challenges for sustainable and productive agriculture. Annals of botany, 105(7), 1141-1157.

Montemurro, F. 2009. Different nitrogen fertilization sources, soil tillage, and crop rotations in winter wheat: effect on yield, quality, and nitrogen utilization. Journal of plant nutrition, 32(1), 1-18.

Nielsen, D. C., and Vigil, M. F. 2018. Wheat yield and yield stability of eight dryland crop rotations. *Agronomy Journal*, *110*(2), 594-601.

Obour, A. K., Mikha, M. M., Holman, J. D., and Stahlman, P. W. 2017. Changes in soil surface chemistry after fifty years of tillage and nitrogen fertilization. *Geoderma, 308*, 46-53.

Obour, A. K., Stahlman, P. W., and Thompson, C. A. 2015. Wheat and grain sorghum yields as influenced by long-term tillage and nitrogen fertilizer application. *Int. J. Soil Plant Sci, 7*, 19-28.

Omara, P., Aula, L., Dhillon, J. S., Oyebiyi, F., Eickhoff, E. M., Nambi, E., and Raun, W. 2020. Variability in Winter Wheat (Triticum aestivum L.) Grain Yield Response to Nitrogen Fertilization in Long-Term Experiments. Communications in Soil Science and Plant Analysis, 51(3), 403-412.

Patrignani, A., Knapp, M., Redmond, C. and Santos, E. 2020. Technical overview of the Kansas Mesonet. *Journal of Atmospheric and Oceanic Technology*, pp.1-49.

Paulitz, T.C., Smiley, R.W. and Cook, R.J. 2002. Insights into the prevalence and management of soilborne cereal pathogens under direct seeding in the Pacific Northwest, USA. Canadian Journal of Plant Pathology, 24(4), pp.416-428.

Pittelkow, C.M., Linquist, B.A., Lundy, M.E., Liang, X., van Groenigen, K.J., Lee, J., van Gestel, N., Six, J., Venterea, R.T. and van Kessel, C., 2015. When does no-till yield more? A global meta-analysis. *Field Crops Research*, *183*, pp.156-168.

Randall, G.W., and Bandel. V.A. 1991. Overview of Nitrogen management for conservation tillage systems: An overview. p. 39–63 In T.J. Logan et al. (ed.) Effects of conservation tillage on groundwater quality, nitrogen and pesticides. Lewis Publ., Chelsea, MI.

Rice, C. W., and Smith, M. S. 1984. Short-term immobilization of fertilizer nitrogen at the surface of no-till and plowed soils. Soil Science Society of America Journal, 48(2), 295-297.

Rieger, S., Richner, W., Streit, B., Frossard, E., and Liedgens, M. 2008. Growth, yield, and yield components of winter wheat and the effects of tillage intensity, preceding crops, and N fertilisation. European Journal of Agronomy, 28(3), 405-411.

Roberts, T. L. 2008. Improving nutrient use efficiency. Turkish Journal of Agriculture and Forestry, 32(3), 177-182.

SAS Institute. 2014. SAS user’s guide: Statistics. Version 9.4. SAS Inst., Cary, NC.

Schlegel, A. J., Assefa, Y., Haag, L. A., Thompson, C. R., and Stone, L. R. 2018. Long-term tillage on yield and water use of grain sorghum and winter wheat. Agronomy Journal, 110(1), 269-280.

Sharpley, A. N., and Smith, S. J. 1994. Wheat tillage and water quality in the Southern Plains. Soil and Tillage Research, 30(1), 33-48.

Sherrod, L. A., Ahuja, L. R., Hansen, N. C., Ascough, J. C., Westfall, D. G., and Peterson, G. A. 2014. Soil and rainfall factors influencing yields of a dryland cropping system in Colorado. Agronomy Journal, 106(4), 1179-1192.

Silgram, M., and Shepherd, M. A. 1999. The effects of cultivation on soil nitrogen mineralization. In *Advances in agronomy* (Vol. 65, pp. 267-311). Academic Press.

Smil, V. 1999. Nitrogen in crop production: An account of global flows. *Global biogeochemical cycles*, *13*(2), 647-662.

Soane, B. D., Ball, B. C., Arvidsson, J., Basch, G., Moreno, F., and Roger-Estrade, J. 2012. No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. Soil and Tillage Research, 118, 66-87.

Soil Survey Staff. 2010. Keys to Soil Taxonomy, 11th Ed. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC, USA.

Soon, Y. K., Malhi, S. S., Wang, Z. H., Brandt, S., and Schoenau, J. J. 2008. Effect of seasonal rainfall, N fertilizer and tillage on N utilization by dryland wheat in a semi-arid environment. Nutrient cycling in agroecosystems, 82(2), 149-160.

Sowers, K. E., Pan, W. L., Miller, B. C., and Smith, J. L. 1994. Nitrogen use efficiency of split nitrogen applications in soft white winter wheat. *Agronomy Journal*, *86*(6), 942-948.

Thompson, C. A., and Whitney, D. A. 1998. Long-term tillage and nitrogen fertilization in a west central Great Plains wheat-sorghum-fallow rotation. *Journal of production agriculture*, *11*(3), 353-359.

Thompson, C. A., and Whitney, D. A. 2000. Effects of 30 years of cropping and tillage systems on surface soil test changes. *Communications in soil science and plant analysis*, *31*(1-2), 241-257.

Torbert, H. A., Potter, K. N., and Morrison, J. E. 2001. Tillage system, fertilizer nitrogen rate, and timing effect on corn yields in the Texas Blackland Prairie. Agronomy Journal, 93(5), 1119-1124.

Triboi, E., Martre, P., Girousse, C., Ravel, C. and Triboi-Blondel, A.M. 2006. Unravelling environmental and genetic relationships between grain yield and nitrogen concentration for wheat. *European Journal of Agronomy*, *25*(2), pp.108-118.

Wikström, F. 1994. A theoretical explanation of the Piper-Steenbjerg effect. *Plant, Cell & Environment*, *17*(9), 1053-1060.

Wollmer, A. C., Pitann, B., and Mühling, K. H. 2018. Grain storage protein concentration and composition of winter wheat (Triticum aestivum L.) as affected by waterlogging events during stem elongation or ear emergence. Journal of Cereal Science, 83, 9-15.

Yadav, M. R., Kumar, R., Parihar, C. M., Yadav, R. K., Jat, S. L., Ram, H., and Ghosh, A. 2017. Strategies for improving nitrogen use efficiency: A review. Agricultural Reviews, 38(1), 29-40.

Zadoks, J. C., Chang, T. T., and Konzak, C. F. 1974. A decimal code for the growth stages of cereals. *Weed research*, *14*(6), 415-421.

Zhang, J., Dong, S., Dai, X., Wu, T., Wang, X., Bai, H., and He, M. 2016. Combined effect of plant density and nitrogen input on grain yield, nitrogen uptake and utilization of winter wheat. Vegetos-An international Journal of Plant Research, 29(2), 63-73.

Chapter 4 - Crop Yield Stability as Affected by Long-Term Tillage and Nitrogen Fertilizer Rates in Dryland Wheat and Sorghum Production Systems

Abstract

A major challenge for agronomists is developing cropping systems that exhibit superior performance across variable environmental conditions, especially precipitation. Long-term field research trials provide a direct measure of the effect of environmental conditions within the context of treatment effects. Here we investigated the impact of tillage practices and nitrogen (N) fertilization rates on yields for dryland winter wheat (*Triticum aestivum* L.) and grain sorghum (*Sorghum bicolor* L. Moench ssp. *Bicolor*) as influenced by weather and precipitation. This study reviewed the yields of a 40-year experiment encompassing varying tillage intensity and nitrogen fertilizer application rates starting in 1975. A split-split-plot arrangement of rotation (winter wheat, grain sorghum, fallow) with three tillage systems (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), and four N application rates (0, 22, 45, and 67 kg N ha^{-1}) were applied in a randomized complete block design. An analysis of variances was shown that practices were a significant factor for predicting yield in 24 out of 31 years (77% of years) for winter wheat and in 17 out 30 years (57% of years) for grain sorghum. N fertilizer rate was a significant factor for predicting yield in 31 out of 31 years (100% of years) for winter wheat and in 27 out 30 years (90% of years) for grain sorghum during the study periods at significant level of 0.05. Yield stability analysis indicated yields under NT responded poorly in winter wheat or equally in grain sorghum in low-yielding environments compared to the more intensive tillage practices of CT or RT. In high-yielding environments CT and RT produced greater yields than

NT. In general, N fertilizer application resulted in more stable yields compared to unfertilized controls. This effect was more pronounced in low yielding environments for both crops. When fertilized, NT production in low yielding environments generated yields comparable to CT or RT treatments. The amount and distribution of precipitation throughout the growing season or during the fallow period preceding crop planting were the most important factors influencing yields of both crops, though that impact was influenced by N fertilization rate. Overall, yield stability analysis indicated that the use of RT or CT along with adequate N fertilization produced higher wheat yields across all yield environments compared to NT.

Introduction

Crop production systems are very sensitive to the weather experienced during the growing season, with quantity and distribution of rainfall accounting for a large proportion of the year-to-year variability in crop yield (Boyer, 1982). This is especially important in semi-arid regions, where the year effect might account for up to 40% of crop yield variability even in relatively small homogenous regions owing to the erratic nature of precipitation (Munaro et al., 2020), as compared to c.a., 4% in more stable sub-humid cropping systems (Rattalino Edreira et al., 2017). The Great Plains region in the United States (US) is an example of a semi-arid region with significant winter wheat (*Triticum aestivum* L.) and grain sorghum (*Sorghum bicolor* (L.) Moench ssp. *Bicolor*) production usually in a wheat-sorghum-fallow rotation, and with high year-to-year yield variability (Schlegel et al., 1999). West-central Kansas, like the rest of the US Great Plains, is primarily limited by water availability and distribution (Obour et al., 2015; Lollato et al., 2017; Schlegel et al 2018). Thus, developing crop production systems that can increase water storage in dryland is of utmost importance, as soil water storage plays a crucial role in stabilizing and increasing crop yields (Unger et al., 1997; Nielsen and Vigil, 2010).

Conservation tillage, defined as not inverts, the soil with a no or less moldboard plow and also calls the soil with less disruptive, leaving at least 30% of the previous crop residue (Troeh et al., 1980; Hobbs et al., 2008); that is a highly effective mechanism to conserve soil water because of the surface residue cover and improved soil structure (Unger et al., 1997). No-tillage or RT has led to reduced erosion, increased soil organic matter, and increased precipitation storage in the US Great Plains (Logan et al., 1991; Thomas et al., 2007; Triplett and Dick, 2008; Obour et al., 2017).

Nitrogen (N) is the most limiting nutrient for crops and is a key component to increasing crop yield (Nielsen and Halvorson, 1991; Halvorson and Reule, 1994; Halvorson et al., 2001). Because plants acquire N through mass flow, water availability and nitrogen availability are intrinsically linked (Plett et al., 2020) and can co-limit crop production (Cossani and Sadras, 2018). Soil N availability is further regulated by the N cycle and microbial-mediated mineralization of organic N into plant-available mineral nitrogen such as nitrate and ammonium (Montemurro, 2009; Plett et al., 2020). The mineralization process is influenced by the crop production system, tillage, and N fertilizer application method (Wienhold and Halvorson, 1999; McConkey et al., 2002). Improved management practices that promote efficient N cycling, such as crop rotation, no-tillage (NT), and adequate N fertilizer application can increase cropping system nitrogen use efficiency, reduce N loss, and enhance agronomic performance and environmental sustainability (Pieri et al., 2011; Sainju et al., 2012; 2014; 2019). Different N fertilization strategies have also shown to affect crop yield stability (Raun et al., 1993).

While yield stability analysis has primarily been developed and used in plant breeding for evaluating crop cultivars or genotypes across environments (Yate and Cochran, 1938; Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Crossa, 1988), it has also been used to explore agronomic practices and concepts, including the effects of NT and permanent bed planting on yield stability of corn (*Zea mays L.*) and wheat (Piepho, 1998; Govaerts et al. 2005); the impact of soil organic matter on yield stability of cereals (Pan et al. 2009); the impact of different crop intensification management practices on wheat grain yield (Jaenisch et al., 2019); the impact of fertility management on corn yield stability (Grover et al. 2008); as well as effects of cropping sequence diversification on yield stability of corn and soybean (*Glycine max*) (Gaudin et al. 2015). Raun et al., (1993) used yield stability analyses in two long-term fertility experiments on wheat and corn to determine that beef manure as a N source resulted in a poor wheat response compared to a chemical fertilizer treatment particularly when environment means were less than 2 Mg ha^{-1}. They also used yield stability analysis in an irrigated corn experiment and determined that sidedressing with anhydrous ammonia resulted in higher yield more stable as well compared to sidedressing or preplanting with urea-ammonium nitrate (Raun et al., 1993).

Few research studies have focused on the yield stability to explore the effects of long-term tillage management, crop rotations, and their interaction with fertilization rates. Daigh et al. (2018) used stability analysis to conclude that there was no significant difference in yield between chisel-plow (CP) and NT managed corn and soybean. Further, yield stability analysis of environmental conditions did not show differences between NT and CP among years (Daigh et al., 2018). In a 24-year study, Nielson and Vigil (2018) reported that wheat yield was more stable for NT wheat-fallow compared to CT wheat-fallow, and that both NT wheat-fallow and CT wheat-fallow were more stable than more intensive crop rotations. However, to our knowledge, there has been no explicit attempt to quantify yield stability in wheat-sorghum-fallow rotations as affected by tillage system and its interaction with N rate in the semi-arid US Great Plains.

A stable agronomic system is one in which changes in response to environmental conditions are minimized (Lightfoot et al., 1987). Long-term field experiments can help clarify the complex plant-soil-climate interactions and their effect on crop yield as well as define the most common crop response to different management practices (Lollato et al., 2019). Thus, yield stability analysis of long-term studies thus serve an important role for better understanding the effects of agronomic practices in different cropping systems that might result from improvements to soil quality and storage of C and N (Karlen et al. 2013; van Eerd et al. 2014), as well as the year-to-year effects within treatments due to different weather conditions. However, interpretation of interaction effects using conventional analysis methods (e.g. analysis of variance) is difficult because of the complexity of environmental factors. Particularly, long-term field experiments have led to the assumption that agronomic treatments, such as crop rotation and fertilization affect the yield stability of wheat, and that higher N fertilization rates result in more stable grain yields of winter wheat (Macholdt and Honermeier, 2019). Stability analysis thus allows performance of management practices to be evaluated for environmental factors that change over time within a given location.

The agronomic focus is shifting from targeting only high grain yields to more ecologically stable wheat cropping systems (Macholdt and Honermeier 2019). Thus, a reliable and stable yield under various environmental and agronomic conditions will become increasingly relevant. This is particularly the case for the US Great Plains region and its semiarid climate and high year-to-year yield variability (Lollato et al., 2017). The study presented here evaluated data from a long-term field experiment initiated in 1965 in Western Kansas to evaluate the effects of tillage intensity and N fertilizer application rates on wheat and grain sorghum yield and yield stability. We hypothesized that increasing N application rates and reducing tillage intensity would increase grain yield and yield stability. The objective of this study was to investigate the impact of tillage systems (CT, RT, and NT) combined with different nitrogen fertilization rates over 45 years to i) determine the main sources contributing toward yield variability and grain yield variation of winter wheat and grain sorghum, ii) explore effects of CT, RT, and NT and N fertilization rates on yield stability of winter wheat and grain sorghum.

Materials and Methods

Site Description and Experimental Design

This research was conducted using long-term experimental plots initiated in the fall of 1965 at the Kansas State University Agricultural Research Center near Hays, Kansas (38°86′ N, 99°27′ W, 610 m elevation) to investigate tillage intensity (CT, RT, and NT) effects on crop yields in a winter wheat- grain sorghum-fallow crop rotation system. The soil at the study site was a Harney silt loam (fine, montmorillonite, mesic Typic Agriustoll) (Soil Survey Staff, 2010). The experiment was modified in 1975 by adding N fertilizer treatments in a split-split-plot arrangement of crop phase, tillage, and N application rates with four replications in a randomized complete block design. Each phase of the crop rotation and tillage treatment was present in each block in each year of the study. The main plots were the crop phase, which consisted of either winter wheat, grain sorghum, or fallow (sorghum stubble). Tillage practice was the subplot factor, and N rate was the sub-sub plot factor. Whole plot measuring (60.4 m × 30.5 m) contained the three tillage treatments (CT, RT, and NT plots). Each tillage practice (20.4 m × 30.5 m) was subdivided into six sub-plots (3.4 m × 30.5 m), that were assigned to four N fertilizer application rates (0, 22, 45, and 67 kg N ha^{-1}) with two unfertilized alleys between tillage treatments. The entire study site has not been amended with lime or phosphorus fertilizer since its establishment in 1965. Specifics regarding field operations and crop management were presented previously in Thompson and Whitney (2000); and Obour et al., (2015 and 2017). In brief, the study was conducted in a WSF rotation with three tillage intensities, CT, RT, and NT plots. The CT system was tilled as needed to control weed growth during the fallow periods. On average, this resulted in four to five tillage operations prior to each crop, using a sweep plow for most tillage operations. The depth of tillage CT plot was plowed and disked to 15 cm soil depth to incorporate crop residue using a tandem disk, a one-way plow, and a mulch treader, which involves mixing soil and incorporating crop residue to approximately 15 cm depth. The RT system originally used tillage operations and were done with a V-blade or sweep plow to control weed growth during the fallow period before each crop. Whereas nearly three to four tillage operations were performed in the fallow phase prior to winter wheat planting in CT treatment plots while two operations occurred in the RT treatment plots. Only, one tillage operation was usually performed in both tillage treatments of CT and RT plots prior to sorghum planting. The NT system relied solely on herbicides to control weed growth during the growing season and fallow periods. Herbicide selection varied year to year due to the weed type for each particular year.

Weather Influence on Crop Yields

Weather data including precipitation across years and growing seasons of winter wheat and grain sorghum (Figure 4.1 a and b, respectively) were recorded in a weather station pertaining to the Kansas Mesonet weather monitoring network (Patrignani et al., 2020). For grain sorghum, the precipitation information was grouped into growing season precipitation (PG, precipitation from June through October) and total precipitation of the fallow period (PF, precipitation in a given year, through March to May). For winter wheat, precipitation information was grouped into growing season precipitation (PG, precipitation from October through June), total precipitation during the fallow period (PF, precipitation after grain sorghum harvest (October) through October of the following year when winter wheat was sowed), cumulative precipitation into fall period (PFall, from Oct. to Dec), into winter period which that affects winter survival (Pwinter, from January to March), April which that represents a critical period which that affects kernel number determination (PApril), May to June as a grain filling period which that affects grain weight (PGFP).

Wheat and grain sorghum crop yield

The data on grain yield for winter wheat and sorghum have been recorded from 1975 to 2003 for wheat and 1975 to 2002 for sorghum, and from 2013 to 2014 for both crops. There were no yield data for wheat or sorghum from 2003 to 2012 or 2002 to 2012, respectively, due to changes in research personnel; however, the plots and treatment were maintained throughout the study period. Grain yield of both crops was determined by harvesting of 1.7 m wide by 30.5 m long from the center of each plot using a Massey Ferguson 8XP small plot combine harvester (Massey Ferguson, Duluth, GA). Grain moisture content at harvest was determined using a DICKEY-john grain moisture tester (DICKEY-john Inc., Auburn, IL) and then grain yield adjusted to 135 g kg^{-1} water basis.

Statistical Analysis Methods

Analyses of Variance (ANOVA)

Data for winter wheat and grain sorghum yield in all years throughout 1975 to 2014 (data was missing from 2004 for wheat and 2003–2012 for sorghum) were analyzed for variance (ANOVA) using the PROC MIXED procedure in SAS (v. 9.4, SAS Inst., Cary, NC). The Tukey's Honest Significant Difference was used for mean comparisons with an alpha (α) of 0.05. A repeated measure analysis was conducted to test the effects of tillage and N fertilizer rates on yield of winter wheat or grain sorghum in the PROC MIXED procedure in. The model included yield of winter wheat or grain sorghum as a response variable; tillage practices, N fertilizer rates and years as variables; and the interaction of tillage x N fertilizer rate as a fixed effect. The replications and replication x tillage and replication x tillage x N fertilizer rates were considered as random effects in the mixed model to fit this split-plot design. The final mixed model was selected based on Akaike Information Criterion (AIC) (Darlington 1968). Mean separation tests were conducted using Tukey’s Honest Significant Difference (HSD) test when there were significant treatment effects ($P < 0.05$).

Variability of yields

We also compared the variability of the grain yields of both crops by calculating the coefficient of variation (CV) over time for the three tillage practices and N fertilizer rate treatments. Analysis of variance was conducted on CV using the output of PROC CAPABILITY procedure of SAS (SAS Institute, 2014). Mean CV ‘s of wheat and grain sorghum yields among the three tillage practices and four N fertilizer rates, and their interaction were reported along with standard error, mean, maximum, and minimum.

With the significant result showing the potential environmental effect, we further investigated the association between grain yield with the weather variables and N fertilizer rates that affected yield under each tillage for both crops. The initial screening process was done based on Variance Inflation Factors (VIF, Allison, (1999)) for detecting multicollinearity among weather variables to remove some overlapping information in the regressors. Then PROC GLMSelected in SAS was applied for model selection by including both treatment variables and weather variable in the general linear models. The stepwise variable selection procedure (Mantel, 1970) was used, and the terminating criteria is based on minimizing the predicted residual sum of squares in leave-one-out cross validation (Stone, 1974). The selected influential variables are interaction of winter wheat yield under tillage practice with total precipitation of PF, PG, PFall, PWinter, PApril, and PGFP. The selected influential variables are interaction of grain sorghum under tillage practice with total precipitation of PG and PF. This a multiple linear regression model fitting showed the a different period of total precipitation periods and N fertilizer effect varies over different tillage practices, by fixing tillage practices, a multiple linear regression analysis is conducted to specify the detailed impact of the weather variables change on the winter wheat and grain sorghum yields under each tillage practices.

Stability Analysis of both Crop Yields

The stability analysis used in this study is based on a similar analysis described by Raun et al., (1993) and adapted from Eberhart and Russell (1966). Stability analysis was used to compare yield stability of winter wheat and grain sorghum under three tillage practices, CT, RT, and NT, within four N application rates of 0, 22, 45, and 67 kg N ha^{-1} for 30 years. The models regressed yield from each treatment (individual and combination of tillage practices and N fertilizer rates) linearly over an environmental index to determine stability within tillage practices, N fertilizer rates, and their interaction. The environmental index (I_j) was calculated as the mean of all treatments in each year minus the grand mean of all treatments across years. The grand mean was calculated as a mean yield average across all the ith treatments and jth years. The grand mean could be lower or higher than the mean yield of the specific treatments in a given year. Therefore, the environmental index (I_j) value could be negative or positive depending on the mean yield of a given year.

The year or environmental index (I_j) was calculated as follows:

$$\boldsymbol{I_j = \frac{\sum_i Y_{ij}}{t} - \frac{\sum_i \sum_j Y_{ij}}{ty}} \quad \textbf{\textit{Eq. 4}}$$

Where *Y* represents yield of crops, *t* represents number of treatments, and *y* represents the study period (years). Steps to determine differences in slope and intercept components for linear equations from the stability analysis were derived from Student's *t*-test (Zhuang et al., 2008).

Results and Discussion

Yield Response

The combined analysis of variance indicated significant effects of year, tillage practice, and N fertilizer rate in winter wheat grain yield (Table 4.1). The interactions between year x tillage x N fertilizer as well as tillage x N fertilizer were also statistically significant. The combined analysis of variance indicated significant differences in grain sorghum yields for the year and N fertilizer rates (Table 4.1). There was not significant overall effect of tillage practices. The interactions between year x tillage x N fertilizer and tillage x N fertilizer were also significant.

During the study period, winter wheat yield was not significantly ($P > 0.05$) influenced by tillage practices in only seven out of the 31 years (Table 4.2). Yield with CT was superior to yield with NT for 21 of the 24 years. Yield under NT was superior to yield under CT in only one year of the 24 years. Potential explanations for the increased yield with year of the study may include the different varieties adopted in different years of the study and a greater yield potential of modern genotypes (Maeoka et al., 2020), improved management practices, and favorable weather. Other researchers have indicated that temporal variability in yields may simply be caused by environmental factors, such as precipitation and temperature (Hu and Buyanovsky, 2003; Tannura et al., 2008).

Throughout the study period, sorghum yield was not significantly ($P>0.05$) influenced by tillage practices in 13 out of 30 years (Figure 4.3). Grain sorghum yield with CT was superior to yield with NT for 11 out 17 years. Yield under NT was superior to yield under CT for only three years out 17. CT and NT yield were similar for two years. That could be possible due to soil conditions with differing soil water content, NT had greater connecting pores in the soil profile and greater infiltration, resulting in higher water retention in the soil; which would indicate that higher N fertilization would have more of an impact on yield and its stability then than might be different (Smith and Kucera, 2018).

The decrease in wheat yield under NT and RT may be related to increased competition from grass weeds and poor plant stands in the less intensive tillage treatments, due to drier soils and heavier residue levels at the time of planting, which warrant greater seeding rates and N rates (Staggenborg et al., 2003; Hofmeijer et al., 2019). The findings of this study agree with others that concluded that winter wheat yields with NT are less than those reported from CT systems (Sharpley and Smith, 1994; López-Bellido and López-Bellido, 2001; Halvorson et al., 2001; Camara et al., 2003). These results are also consistent with previous results from this experiment field that reported poor control of herbicide tolerant tumble grass [*Schedonnardus paniculltus* (Nutt.) *Trel*] and windmill grass (*Chloris verticillata* Nutt.) in the NT plots compared to CT. The tumble grass and windmill grass caused significant yield reductions in the NT system (Thompson and Whitney, 1998; Obour et al., 2015). At this study, that showed positive influence that associated with the summed of April precipitation; with an average 5 kg ha^{-1} per one mm observed for the winter wheat for all CT, RT, and NT (Table 4.7). Winter wheat under CT and RT responded to the total precipitation during the fallow period (1.4 and 1.2 kg ha^{-1} per one mm^{-1}, respectively) compared to NT, which was less than one kg ha^{-1} per one mm. Although our treatment of tillage practices was responded very differently to the sum of PWinter precipitation. Yield of winter wheat under RT was showed highest by one kg ha^{-1} for each mm compared to CT and two kg ha^{-1} for each mm compared to NT (Table 4.7). For grain sorghum, yield responded to total precipitation during the growing season PG and PF (Table 4.8). At this study, that showed positive influence that associated with the summed of PG; with an average 5 kg ha^{-1} per one mm observed for the grain sorghum for all CT, RT, and NT. Whereas, the yield of grain sorghum with CT and RT were responded to PF (of March to May; with an average 3 kg ha^{-1} per one mm observed (Table 4.8). Likewise, NT can increase surface soil compaction, restricting root growth and preventing adequate drainage (Howeler et al., 1993).

Several factors may have contributed to the advantage of CT as compared to NT. For instance, either improved N mineralization rate and its availability with CT compared to NT, or a slower rate of net N mineralization from organic matter under NT, may have increased yields in CT in this study which likely were N limited (McConkey et al., 2002). Another factor may have been increased temporal losses of N by immobilization (Rice and Smith, 1984). Also, lower herbicide efficacy because of crop residues may also have led to CT being favorably compared to NT (Teasdale and Rosecrance, 2003; Chauhan et al., 2012). These differences in yield of winter under treatment of tillage practices were mostly due to differences in growing season precipitation distribution of timing and quantity over the long-year study as well as its responded. While winter wheat yield under NT responded less by summed of growing season precipitation PF, PWinter, and PApril compared to yield under CT or RT (Table 4.7). Then these period precipitations were the most and significant factor of determining winter wheat yield for all the tillage practices.

During the study period, winter wheat and grain sorghum yields were significantly influenced by N fertilizer rates in 31 out of 31 years and 27 out of 30 years, respectively (Table 4.2 and 4.3). Also evident in this study was that increasing N fertilizer rates led to increased winter wheat and grain sorghum yields. The highest yield was obtained with 67 kg N ha^{-1} and the lowest yield was with the unfertilized control for both crops (Table 4.4 and 4.5). The fact that the highest N rate was the one usually resulting in greatest grain yield suggests that the N rates evaluated in this study were likely still limiting yields. These results align with previous research summarizing 155 site-years of field experiments in a neighboring state in which the optimum N rate for wheat yield was c.a., 90 kg N ha^{-1} (Lollato et al., 2020). Additionally, winter wheat responded more to N fertilizer rate under NT (16 kg ha^{-1} for each kg N ha^{-1}) compared to CT or RT (13 kg ha^{-1} for each kg N ha^{-1}) (Table 4.7). Grain sorghum yield response to N rate was 18 kg ha^{-1} for each kg N ha^{-1} with RT or NT compared to CT 15 kg ha^{-1} for each kg N ha^{-1} (Table 4.8).

Several factors may have contributed to the advantage of CT as compared to NT. For instance, either improved N mineralization rate and its availability with CT compared to NT, or a slower rate of net N mineralization from organic matter under NT, may have increased yields in CT in this study which likely were N limited (McConkey et al., 2002). Another factor may have been increased temporal losses of N by immobilization (Rice and Smith, 1984). As well as lower herbicide efficacy because of crop residues may also have led to CT being favorably compared to NT (Teasdale and Rosecrance, 2003; Chauhan et al., 2012).

Stability Analysis

This study demonstrated that tillage practices and N fertilizer rates can influence the temporal variability and stability of wheat and sorghum grain yields. It is difficult to determine the exact cause of these differentials.

When averaged across the four N fertilizer rates treatments, CV of winter wheat yields under NT was 34% higher than CT and similar to RT at 33% (Table 4.4). The CV of grain sorghum yields with NT was 41% higher than CT and RT, whereas the CT and RT were 37% (Table 4.5). NT yields had the most variable yields across three tillage practices in both crops. That was agreed with Pittelkow et al. (2015), who found significant annual variability of yield was shown with NT or retention crop residues.

This study demonstrated that N fertilizer can influence the temporal variability of crop yields. In the CV analysis, applying N rates of 22 to 67 kg N ha^{-1} produced the least variable winter wheat yields. The control unfertilized treatment variability was the highest at 32%; the variability of the rest of the N application rates was 29%. For grain sorghum, the CV of the unfertilized control and 45 kg N ha^{-1} were 37%. The CVs of 22 kg N ha^{-1} and 67 kg N ha^{-1} were 36% for grain sorghum yields (Table 4.5).

A comparison of the yield CVs of tillage practices into each N rate showed that NT in 22 kg N ha^{-1} to 67 kg N ha^{-1} had lower CVs (c.a., 26 to 28%) than CT or RT for winter wheat yield (c.a., 28 to 30%) (Table 4.4). The opposite was true for grain sorghum yields, in which NT in 22 kg N ha^{-1} to 67 kg N ha^{-1} have highest variation (CV = 39%) when compared to CT or RT (Table 4.5). This study showed less variability of winter wheat yield with an increasing N fertilizer rate, which agrees with Macholdt et al. (2020), who reported that mineral N fertilization led to lower yield variability of winter wheat.

The stability analysis provided a valid means of assessing this dataset and visualizing treatment interactions with the environment index (Figure 4.2 and 4.3 and Table 4.6). Yield was significantly correlated with the environmental index at all cases, and the variability about the intercept and slope components increased as N rate increased for both winter wheat (Table 4.4

and 4.6) and grain sorghum (Table 4.5 and 4.6). This indicates that increases in N rate increased mean yield (intercept) and yield increases were greater at higher yielding environments (slope). Likewise, intensity of tillage practices increased the variability in the intercept and slope components. For example, CT and RT's had similar intercepts and slopes as compared to NT for winter wheat (Figure 4.2A and Table 4.6A). For grain sorghum, there were no significant differences among tillage practices for intercepts and slopes (Figure 4.2B and Table 4.6B). In general, the yield stability was lowest in NT and highest in CT for winter wheat, as evidenced by lower R^2 (Figure 4.2A and Table 4.6A). A potential explanation for less yield and stability under NT is that there was evidence of vertical nutrient stratification, especially phosphorus (P), with NT system near the soil surface in these plots (Obour et al., 2017). This likely corresponded with poor root growth in the soil surface and might have reduced dry matter and P uptake by wheat (Cornish, 1987). Additionally, NT can affect the availability of N as well as the response to application of N fertilizers (Armstrong et al., 2015) due to greater of N immobilization in this system (Rice and Smith, 1984; Rasmussen and Rohde, 1991).

N fertilizer rates affected yield stability for both winter wheat and grain sorghum. The yield stability was impacted by tillage practices within each N rate. This result could be because wheat plants can exploit the prevailing growing conditions better and be more resilient to environmental stress, especially under conditions of sufficient, plant-available N supply and higher accumulated soil N content, with related higher mineralization rates (St-Martin et al., 2017; Macholdt et al., 2020).

The response to N fertilizer rates was environment-specific. Linear regression equations were all significant, and significant differences in both slopes and intercepts were found in both winter wheat (Figure 4.4A and Table 4.4 and 4.6A) and grain sorghum (Figure 4.4B and Table

4.5 and 4.6A). The yield stability was lowest in 0 kg N ha^{-1} and highest in 67 kg N ha^{-1}, as evidenced by differences in R^2 of the linear regression equation. This yield stability ranking of 67>45 and 22> 0 kg N ha^{-1} was evident in this study for both crops. Mineral N fertilization has a positive effect on plant growth, root growth (Forde, 2002) and root density (Rasmussen et al., 2015), providing benefits for plants with regard to water and nutrient uptake capacity. For winter wheat, the most stable yields were obtained in all N fertilizer rates that had CT treatments compared to NT, which agreed with Macholdt and Honermeier (2019), who reported that NT had neutral or even negative effects on the yield stability of a wheat production system. They suggested that this fact could be due to root distribution with different tillage practices. Another study suggested that the root length density with CT was higher than in NT in the upper soil layer (0 to 5 cm), similar to NT from 5 to 10 cm, and lower than in NT from 10 to 30 cm (Qin et al., 2004). However, for grain sorghum, the equations did not show a clear trend in the intercept and slope components as related to the evaluated treatments.

For winter wheat, there were significant differences and greater slopes or intercepts with CT within N fertilizer rates 0, 22, 45, and 67 kg N ha^{-1} compared to NT (Figure 4.4A, 4.5A, 4.6A, and 4.7A, and Table 4.6A). The most stable yields were obtained in 67 kg N ha^{-1} treated under CT, were highly significant (Table 4.6), and had a greater intercept and slope when compared to those of NT (Figure 4.8 and Table 4.4). Fertilizer can increase wheat yield and its stability by improving the soil fertility and reducing the variability (Chen et al., 2018). There were not significant differences in slopes or intercepts among tillage practices within N fertilizer rates 0, 22, 45, and 67 kg N ha^{-1} for grain sorghum (Figure 4.4B, 4.5B, 4.6B, and 4.7B, and Table 4.6B). It is important to mention this experiment study had not received P fertilizer or liming since it started in 1965, as an adequate P supply from soil or applying fertilizer during early crop development is critical for plant growth and resulting in crop growth and yield (Grant et al., 2001; Armstrong et al., 2015). According to McBeath et al. (2012), adding P fertilizer would help to accelerate utilization of soil P not just from the soil surface, but also from subsoil. Though, adding both N and P fertilizers had increased overall root growth, that would have helped the crop to maintain more of soil P (Armstrong et al., 2015).

Conclusion and Summary

The data created from this long-term experimental study of winter wheat-grain sorghum-fallow production systems showed temporal variability in yield for both crops, which was evident with all treatment combinations. Results of using analysis of variance indicated tillage practices were a significant factor for predicting yield in 24 out of 31 years (77% of years) for winter wheat in 17 out 30 years (57% of years) for grain sorghum. N fertilizer rate was a significant factor for predicting yield in 31 out of 31 years (100% of years) for winter wheat in 27 out 30 years (90% of years) for grain sorghum during the study periods at significant level of 0.05. There was lowest yield variability with NT into each N fertilizer rates compared CT or RT for winter wheat, but highest for grain sorghum. The amount of precipitation and distribution throughout the growing season or during the preceding fallow period, was the most important factor influencing winter wheat and grain sorghum yields and determining N fertilizer responses. Stability analysis was useful to untangle year to year yield variability as influenced by the temporal variability and the year × treatments (e.g., tillage practices or N fertilizer rates) interaction was highly significant ($P < 0.0001$). Yield stability analysis of winter wheat indicated that NT system responded poorly or equally compared to intensive tillage practices of CT or RT in the low yielding environments less than 1 Mg ha^{-1}. In high yielding environments (i.e., more than 1 Mg ha^{-1}, and we note that “high yielding” is within the context of this experiment), CT or

RT seem to produce higher yield than NT system. In general, treatments receiving N application were more stable and greater than unfertilized control for winter wheat and grain sorghum crops. Overall, stability analysis indicated that the integrated use of tillage practices with N fertilizer application were generated suitable yield across all the environments than NT, in increasing and sustaining the productivity of winter wheat yield.

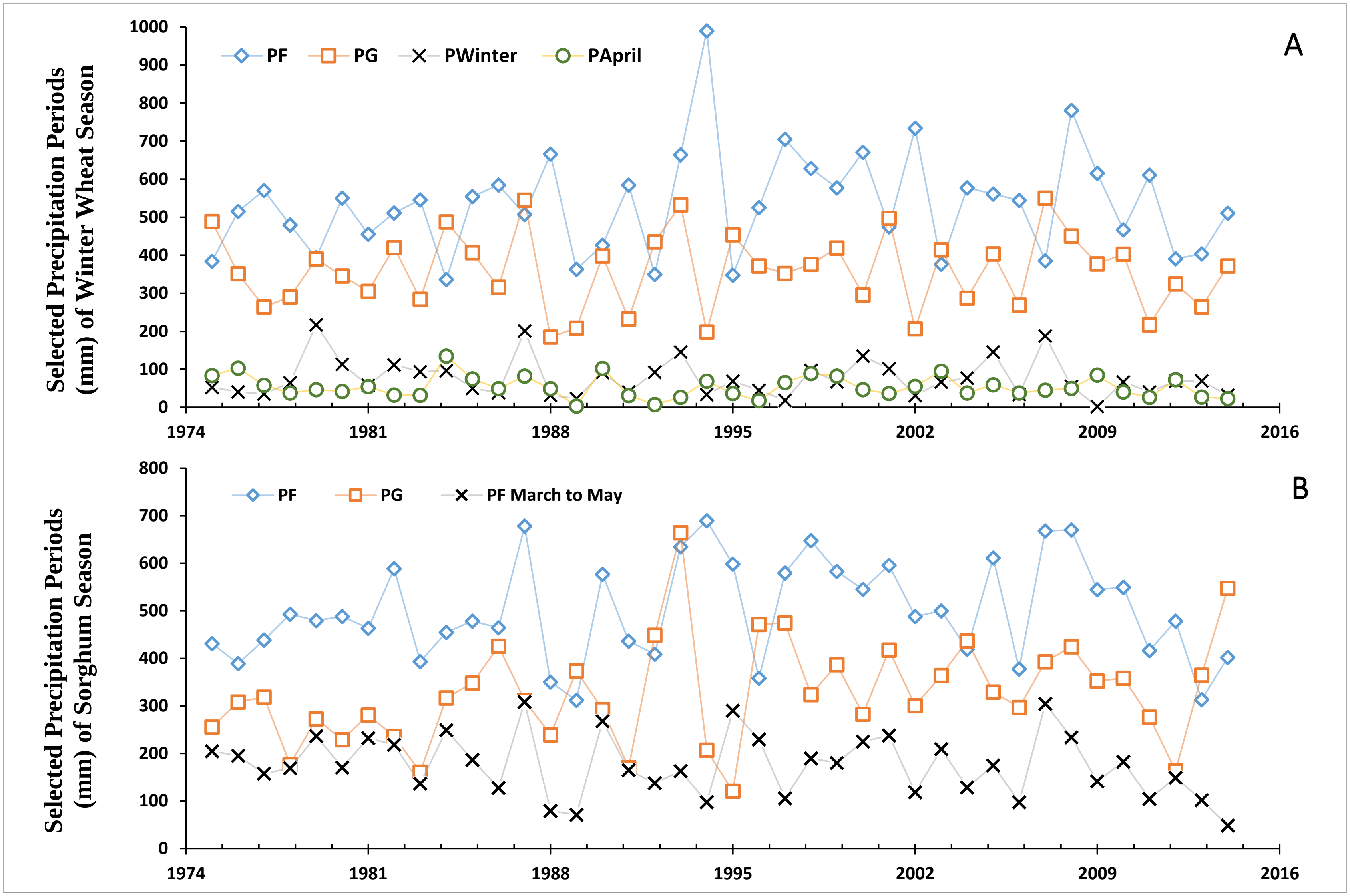


Figure 4.1 Selected precipitation periods during fallow period (PF), in the growing season (PG), and sum of March to May, January to March (PWinter) and April (PApril) of each given year for winter wheat (A) and grain sorghum (B) in Hays, KS

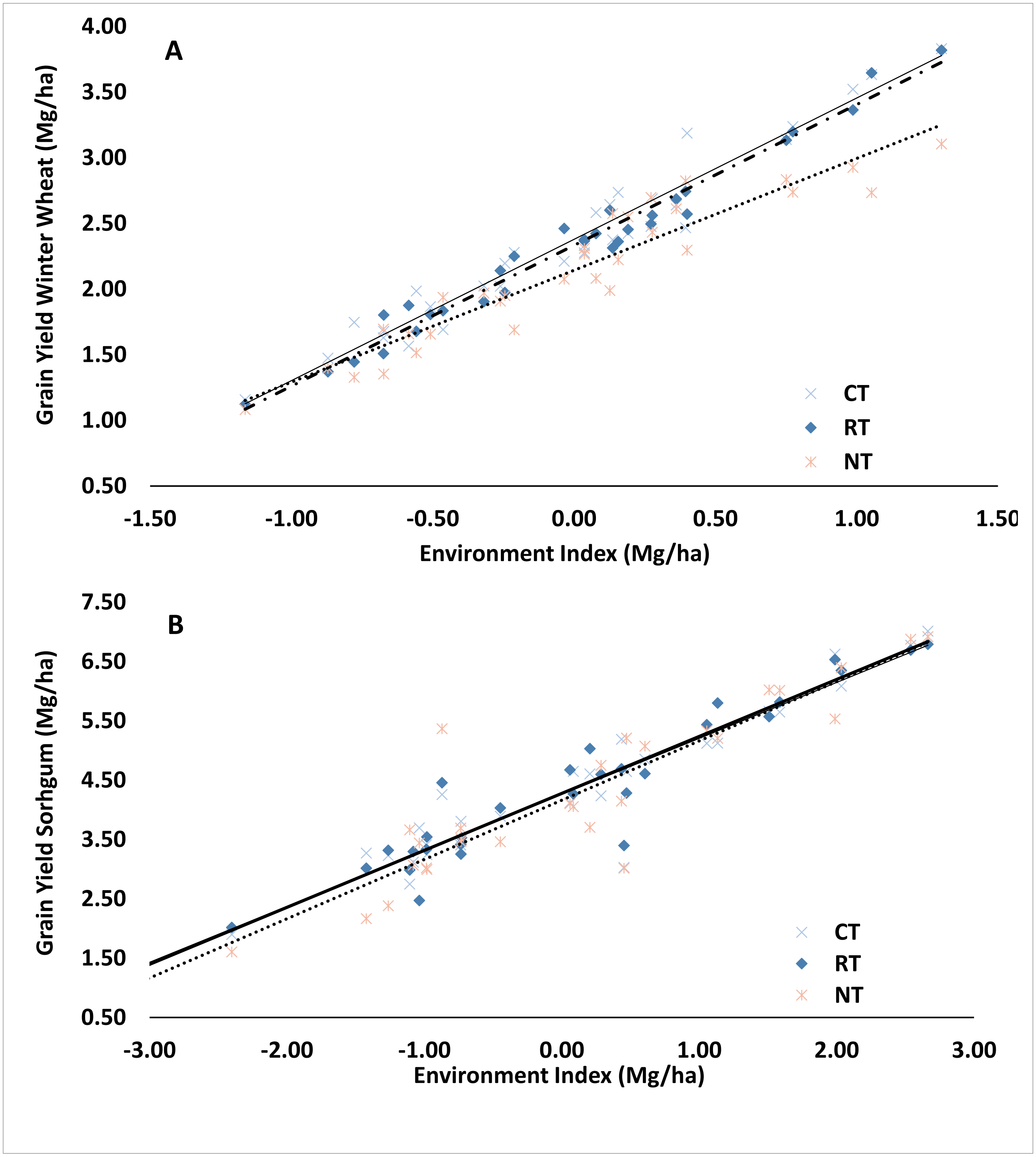


Figure 4.2 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by tillage practices across N fertilizer rates in Hays, KS, 1975-2014

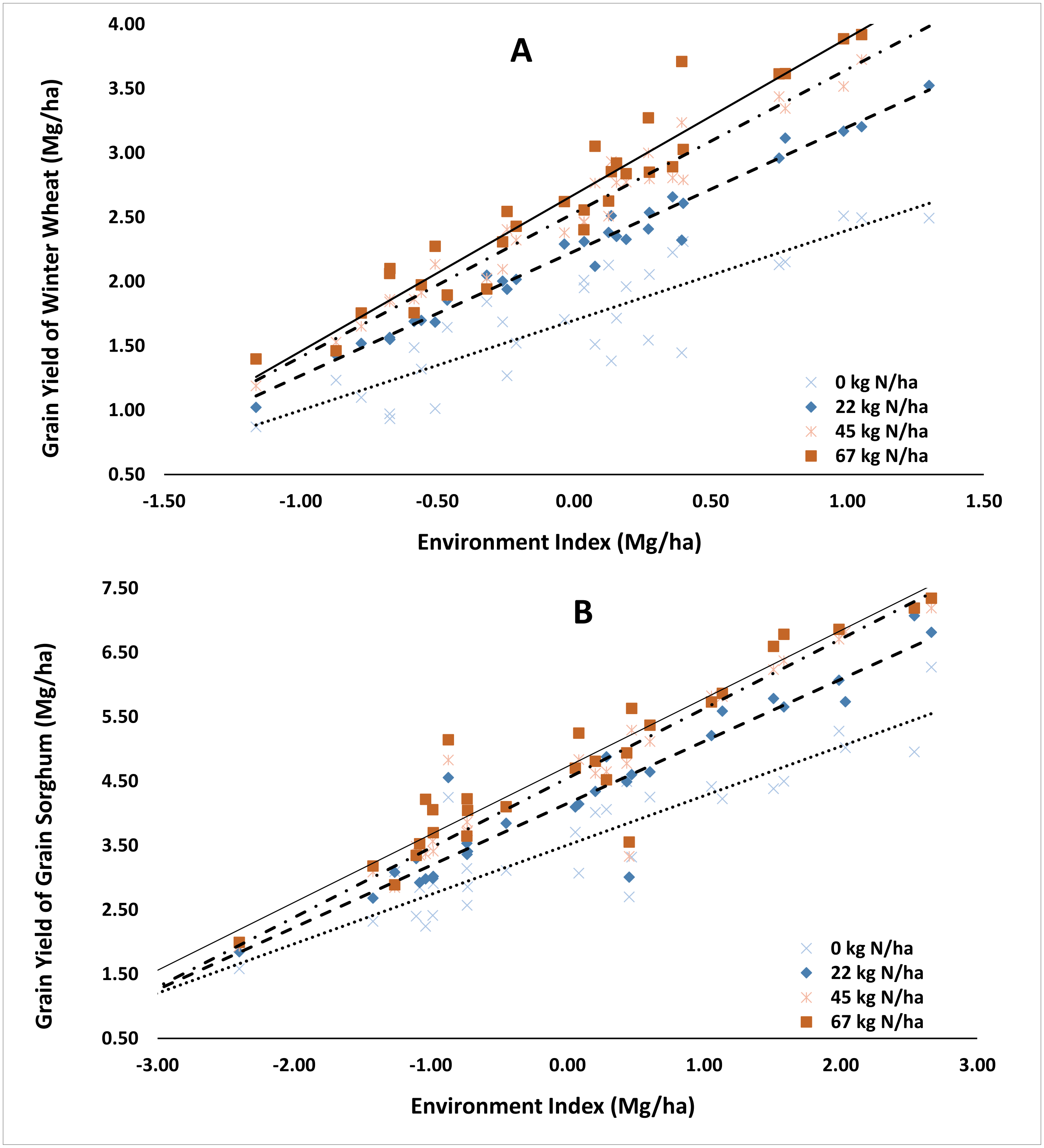


Figure 4.3 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by N fertilizer rates across tillage practices in Hays, KS, 1975-2014

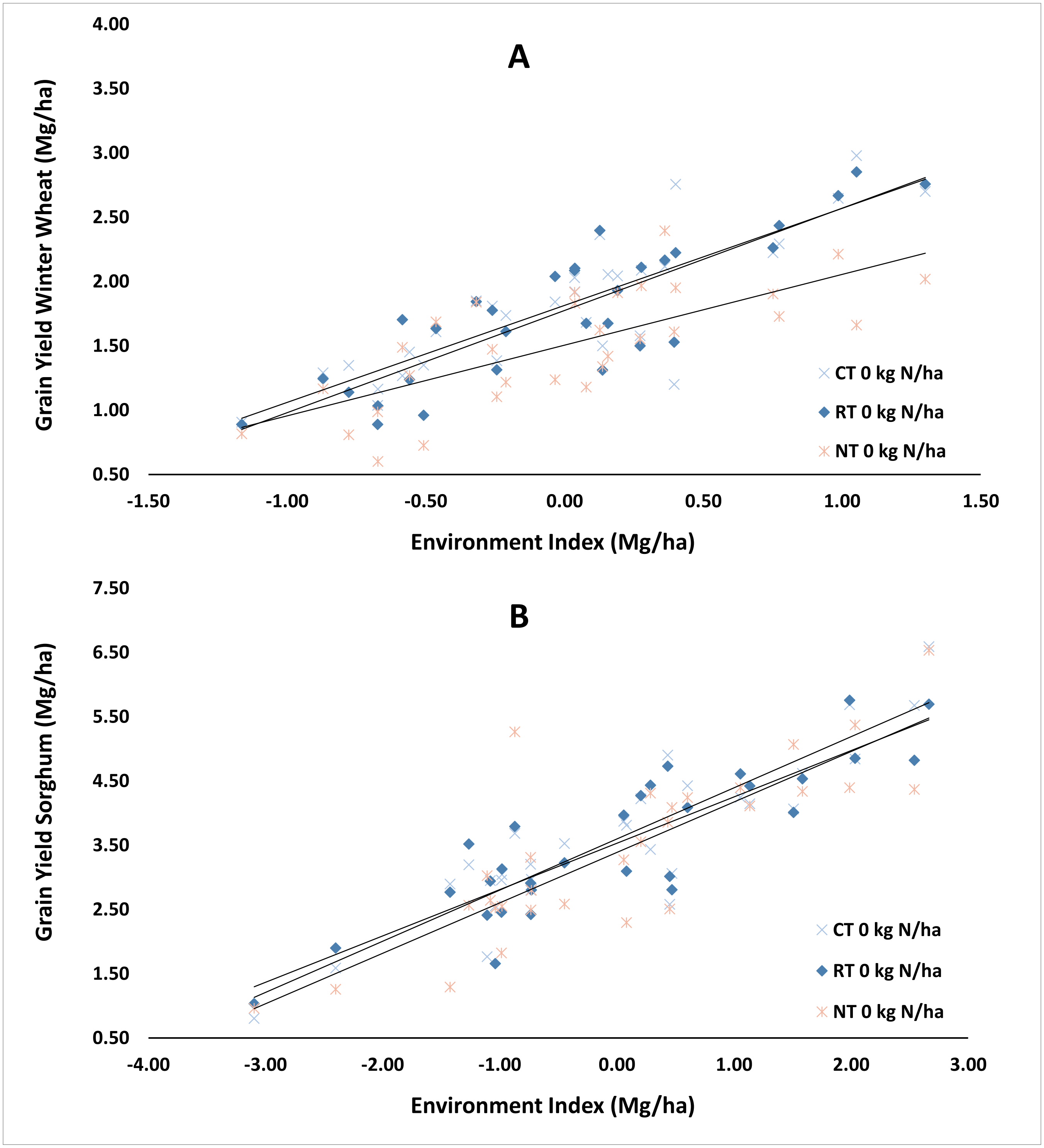


Figure 4.4 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by tillage practices at N fertilizer rate of 0 kg ha^{-1} in Hays, KS, 1975-2014

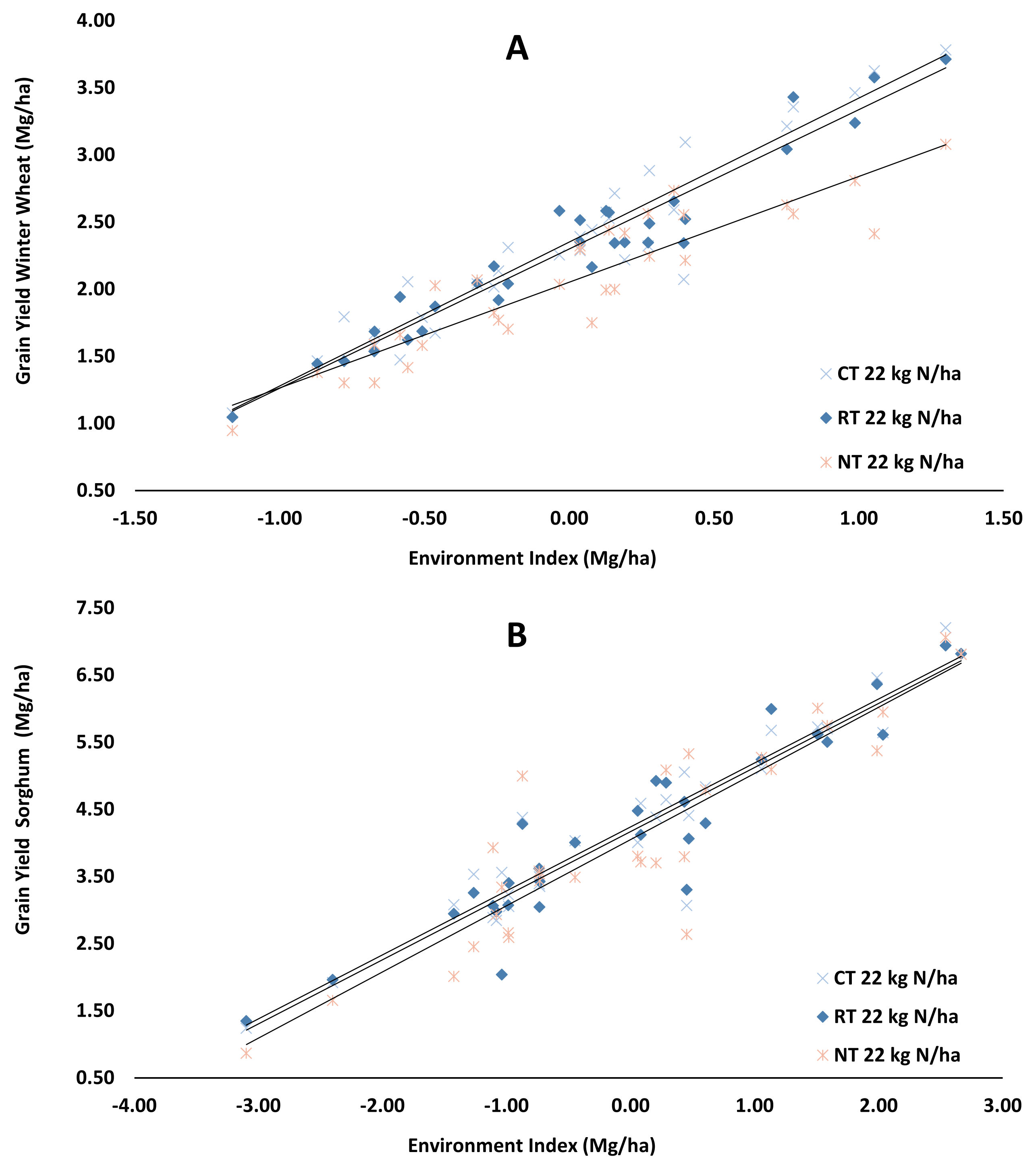


Figure 4.5 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by tillage practices at N fertilizer rate of 22 kg ha^{-1} in Hays, KS, 1975-2014

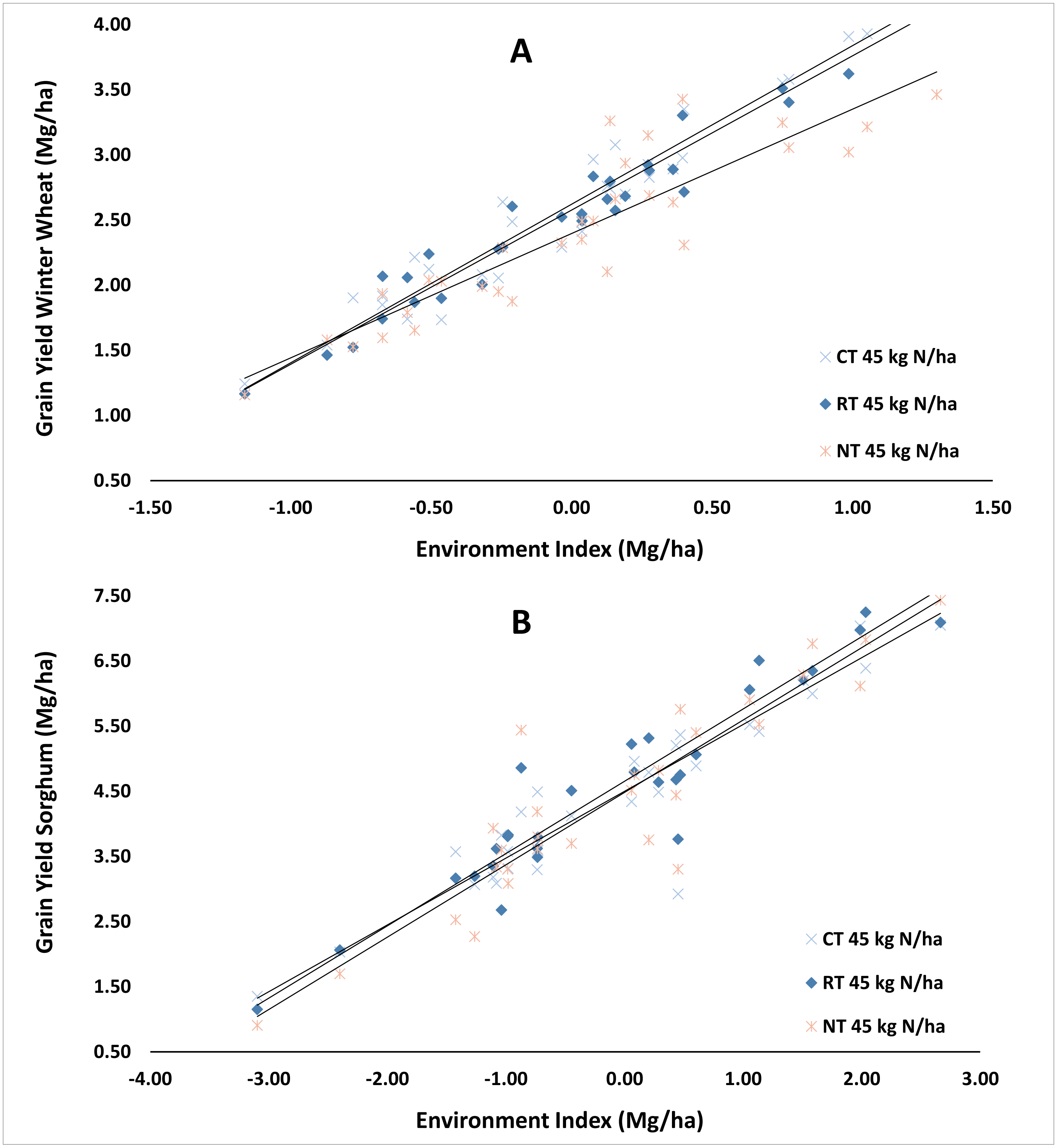


Figure 4.6 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by tillage practices at N fertilizer rate of 45 kg ha^{-1} in Hays, KS, 1975-2014

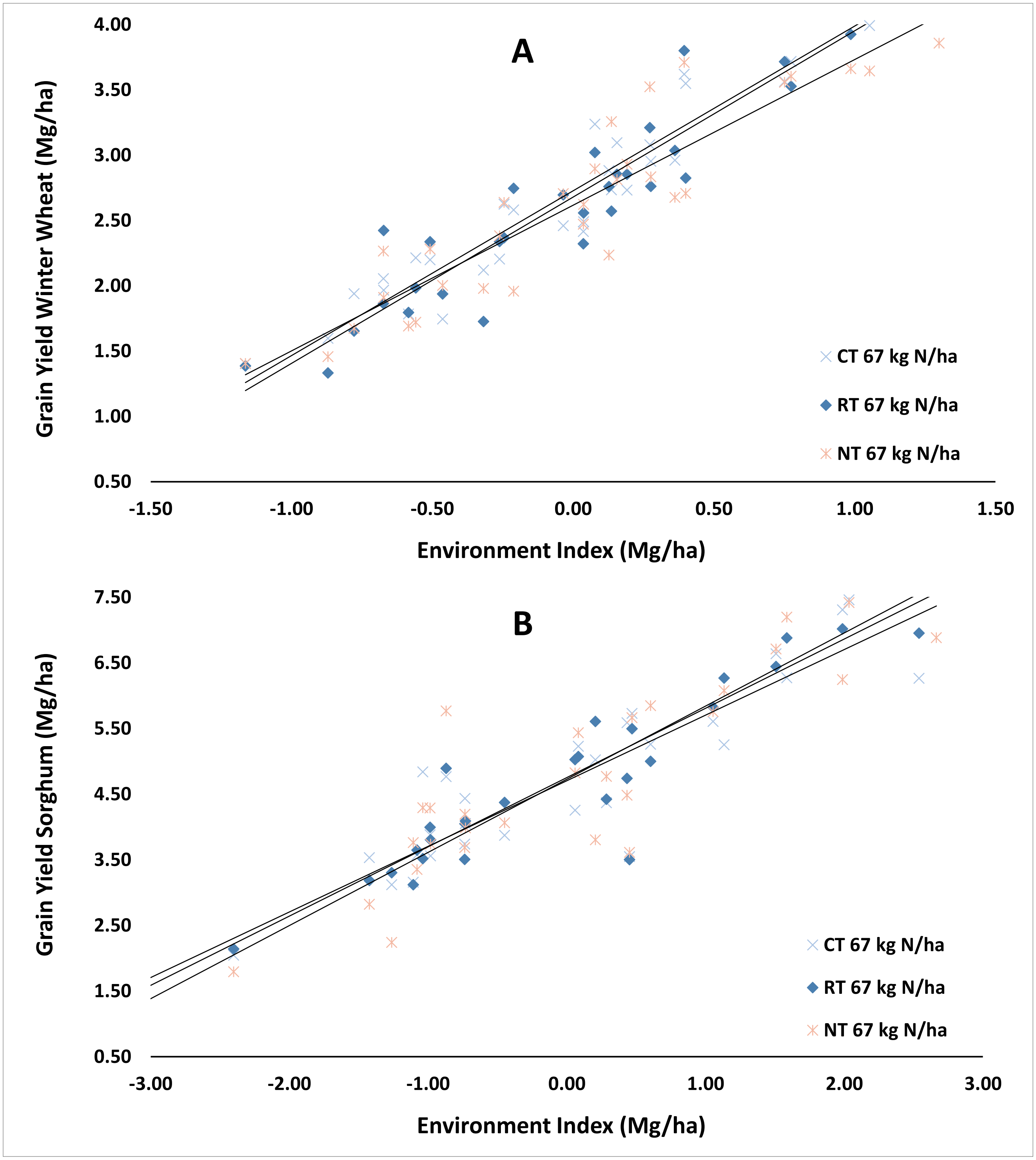


Figure 4.7 Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment index as affected by tillage practices at N fertilizer rate of 67 kg ha^{-1} in Hays, KS, 1975-2014

Table 4.1 The analysis of variance for winter wheat yield and grain sorghum of 404 plots in Hays, KS, with three different constant tillage practices (conventional tillage, reduced tillage, and no-tillage) nested with four nitrogen (N) fertilizer rates (0, 22, 45, and 67 kg N/ ha)

	Yield of winter wheat			**Yield of grain sorghum**		
Treatment factors	DF[†]	F Value	Pr > F	DF[†]	F Value	Pr > F
Year	30	449.4	<0.0001	29	305.4	<0.0001
Tillage	2	104.0	<0.0001	2	2.31	0.1806
Year × tillage	60	16.11	<0.0001	58	6.56	<0.0001
N rate	3	1824	<0.0001	3	306.6	<0.0001
Year × N rate	90	18.58	<0.0001	87	5.80	<0.0001
Tillage × N rate	6	9.34	<0.0001	6	1.50	0.1756
Year × tillage × N rate	180	1.45	0.0003	174	1.04	0.3695

[†] DF indicates degrees of freedom.

[‡] F value is an output from the statistical model.

§Pr > F is the probability of a greater F-value and indicates a *p-value* for the effect of model on responses at the level of significance. Tests were performed with an α of 0.05.

Table 4.2 Analysis of variance summary of the effects of tillage (TILL), N fertilizer rate (NR), and their interactions on winter wheat grain yield at each year from 1975 to 2014 (Noted: data are missing from 2004 2012 for winter wheat)

year/ factor	**Till**	**N Rate**	**Till x N Rate**	**year/ factor**	**Tillage**	**N Rate**	**Till x N Rate**
		P-value				P-value	
1975	0.0864	<.0001	0.2315	**1991**	0.0137	<.0001	<.0001
1976	0.0004	<.0001	0.0017	**1992**	0.0004	<.0001	<.0001
1977	<.0001	<.0001	0.0008	**1993**	<.0001	<.0001	<.0001
1978	0.0104	<.0001	0.0129	**1994**	<.0001	<.0001	<.0001
1979	<.0001	<.0001	0.0633	**1995**	<.0001	<.0001	<.0001
1980	<.0001	<.0001	0.0021	**1996**	<.0001	<.0001	<.0001
1981	0.0003	<.0001	0.0013	**1997**	0.0002	<.0001	0.0012
1982	<.0001	<.0001	<.0001	**1998**	0.0067	<.0001	<.0001
1983	0.7358	<.0001	0.0241	**1999**	0.2402	<.0001	0.3023
1984	0.0145	<.0001	0.0428	**2000**	0.2170	<.0001	0.0590
1985	0.0350	<.0001	<.0001	**2001**	<.0001	<.0001	0.0019
1986	0.0044	<.0001	0.0007	**2002**	<.0001	<.0001	0.0759
1987	0.0003	<.0001	0.9375	**2003**	0.0007	<.0001	<.0001
1988	<.0001	<.0001	0.0124	**2013**	0.5792	<.0001	0.2117
1989	0.1496	<.0001	0.2369	**2014**	0.5232	0.0098	0.8011
1990	<.0001	<.0001	0.0289				

Table 4.3 Analysis of variance summary of the effects of tillage (TILL), N fertilizer rate (NR), and their interactions on winter wheat grain yield (kg/ha) at each year from 1975 to 2014 (Noted: data are missing from 2003 2012 for grain sorghum)

year/ factor	**Till**	**N Rate**	**Till x N Rate**	**year/ factor**	**Tillage**	**N Rate**	**Till x N Rate**
	P-value				*P-value*		
1975	0.3275	0.0019	0.6868	**1990**	0.0206	<.0001	<.0001
1976	0.4066	0.1838	0.7977	**1991**	<.0001	<.0001	0.0001
1977	0.0898	<.0001	0.9657	**1992**	0.0041	<.0001	0.8465
1978	0.0191	0.2756	0.7962	**1993**	0.0041	<.0001	0.3428
1979	0.1631	<.0001	0.0046	**1994**	<.0001	<.0001	<.0001
1980	0.0015	<.0001	0.1353	**1995**	<.0001	<.0001	<.0001
1981	0.3117	<.0001	0.1070	**1996**	<.0001	<.0001	<.0001
1982	0.4993	<.0001	0.1310	**1997**	0.0119	<.0001	0.0002
1983	<.0001	<.0001	<.0001	**1998**	<.0001	<.0001	<.0001
1984	0.0011	<.0001	0.2972	**1999**	0.2910	<.0001	0.0349
1985	0.9687	<.0001	0.2138	**2000**	0.9381	0.0001	0.0001
1986	0.8885	<.0001	0.0779	**2001**	<.0001	<.0001	0.0001
1987	<.0001	<.0001	0.0005	**2002**	0.1164	<.0001	0.0629
1988	0.0020	<.0001	0.1014	**2013**	0.6835	<.0001	0.0685
1989	0.0172	<.0001	0.7007	**2014**	0.2963	0.1424	0.3126

Table 4.4 Linear regression analysis of grain yield stability of winter wheat on environment index in 404 plots in Hays, KS, with three different constant tillage practices (CT, RT, and NT) nested with four nitrogen rates (NR) (0, 22, 45, and 67 kg N/ ha), and their interaction

Treatment	Max	Min	Intercept†	Std. error‡	Slope	Std. error‡	Root MSE	R^2 *	C.V.§
CT	4.68	0.81	2.38^{a}	0.02	1.08	0.04	0.48	0.64	33
RT	5.17	0.76	2.33^{a}	0.03	1.07	0.04	0.46	0.66	33
NT	4.14	0.45	2.14^{b}	0.02	0.85	0.04	0.54	0.46	34
N 0	3.14	0.45	1.70^{d}	0.02	0.70	0.03	0.36	0.56	32
N 22	4.38	0.91	2.24^{c}	0.02	0.97	0.03	0.30	0.79	29
N 45	4.61	1.13	2.53^{b}	0.02	1.12	0.03	0.30	0.83	29
N 67	5.17	1.13	2.68^{a}	0.02	1.22	0.03	0.33	0.83	29
CT N0	3.01	0.81	1.82^{a}	0.03	0.75	0.05	0.33	0.65	30
RT N0	3.14	0.76	1.78^{a}	0.03	0.79	0.05	0.32	0.69	32
NT N0	2.50	0.45	1.51^{b}	0.03	0.55	0.05	0.35	0.47	31
CT N22	4.38	1.01	2.35^{a}	0.03	1.07	0.04	0.28	0.84	29
RT N22	4.12	1.00	2.30^{a}	0.02	1.04	0.03	0.22	0.89	28
NT N22	3.40	0.91	2.05^{b}	0.02	0.79	0.04	0.26	0.76	26
CT N45	4.61	1.18	2.62^{a}	0.03	1.22	0.04	0.27	0.87	29
RT N45	4.45	1.13	2.58^{a}	0.02	1.19	0.05	0.22	0.91	28
NT N45	3.89	1.14	2.40^{b}	0.03	0.96	0.05	0.32	0.76	27
CT N67	4.68	1.27	2.73^{a}	0.03	1.26	0.05	0.33	0.84	30
RT N67	5.17	1.13	2.68^{ab}	0.03	1.27	0.05	0.31	0.86	30
NT N67	4.17	1.22	2.62^{b}	0.03	1.12	0.05	0.33	0.80	28

†Significant differences in yield within each factor or interaction are indicated, where any yields with different letters are significantly different at the $P < 0.05$ level

‡Std. error indicates standard error

§C.V. is presented the coefficient of variability of the mean

*R^2 is the coefficient of determination and indicates a significant linear regression model of yield with environment mean at the with an α of 0.05.

Table 4.5 Linear regression analysis of grain yield stability of grain sorghum (Mg ha^{-1}) on environment index in 404 plots in Hays, KS, with three different constant tillage practices (CT, RT, and NT) nested with four nitrogen rates (NR) (0, 22, 45, and 67 kg N/ ha), and their interaction

Treatment	**Max**	**Min**	**Intercept†**	**Std. error‡**	**Slope**	**Std. error‡**	**Root MSE**	**R^2 ***	**C.V.§**
CT	10.5	0.75	4.27^{a}	0.04	0.97	0.03	0.80	0.74	37
RT	9.80	0.97	4.28^{a}	0.04	0.98	0.03	0.78	0.75	37
NT	10.4	0.58	4.16^{a}	0.04	1.05	0.03	0.88	0.73	41
N 0	8.1	0.58	3.54^{d}	0.04	0.78	0.03	0.72	0.70	37
N 22	9.7	0.77	4.17^{c}	0.03	1.00	0.02	0.61	0.84	36
N 45	10.5	0.77	4.55^{b}	0.03	1.12	0.03	0.64	0.85	37
N 67	10.4	0.89	4.70^{a}	0.04	1.10	0.03	0.69	0.83	36
CT N0	8.08	0.75	3.62^{a}	0.07	0.81	0.05	0.73	0.71	37
RT N0	6.80	0.97	3.56^{ab}	0.06	0.73	0.04	0.65	0.71	34
NT N0	7.94	0.58	3.44^{b}	0.07	0.83	0.05	0.77	0.69	40
CT N22	8.70	1.11	4.27^{a}	0.05	0.97	0.04	0.59	0.84	35
RT N22	7.97	1.25	4.18^{a}	0.05	0.97	0.04	0.54	0.86	35
NT N22	9.68	0.77	4.06^{a}	0.06	1.04	0.04	0.67	0.82	39
CT N45	10.5	1.31	4.51^{a}	0.06	1.06	0.05	0.68	0.82	36
RT N45	9.78	1.11	4.65^{a}	0.05	1.13	0.04	0.60	0.88	36
NT N45	8.69	0.77	4.48^{a}	0.06	1.16	0.04	0.64	0.87	39
CT N67	8.79	1.34	4.68^{a}	0.06	1.04	0.05	0.70	0.81	34
RT N67	8.05	1.52	4.75^{a}	0.05	1.09	0.04	0.54	0.89	34
NT N67	10.4	0.89	4.66^{a}	0.07	1.17	0.05	0.80	0.81	39

†Significant differences in yield within each factor or interaction are indicated, where any yields with different letters are significantly different at the $P < 0.05$ level

‡Std. error indicates standard error

§C.V. is presented the coefficient of variability of the mean

*R^2 is the coefficient of determination and indicates a significant linear regression model of yield with environment mean at the with an α of 0.05.

Table 4.6 Differences in slopes and intercepts for treatment of tillage practices (CT, RT, and NT), N fertilizer rates (NR) (0, 22, 45, and 67 kg N/ ha) regression equations of winter wheat for 31 years and grain sorghum for 30 year of the study periods; in 404 plots in Hays, KS

Crops	**A-Winter Wheat**				**B-Grain Sorghum**			
Comparison	**t-intercept**		**t-slope**		**t-intercept**		**t-slope**	
	t-calc	PR> |t|	t-calc	PR> |t|	t-calc	PR> |t|	t-calc	PR> |t|
Tillage practices								
CT vs. RT	1.14	0.2649	0.07	0.9428	-0.28	0.7833	-0.32	0.7487
CT vs. NT	7.29	<.0001	4.05	0.0003	2.00	0.0546	-2.02	0.0533
RT vs. NT	4.54	<.0001	4.08	0.0003	2.29	*<.0001*	-1.73	0.0935
N fertilizer rates								
0 vs. 22	-22.15	*<.0001*	-6.44	*<.0001*	-12.57	*<.0001*	-5.75	*<.0001*
0 vs. 45	-34.31	*<.0001*	-10.14	*<.0001*	-19.69	*<.0001*	-8.93	*<.0001*
0 vs. 67	-38.63	*<.0001*	-12.02	*<.0001*	-22.00	*<.0001*	-8.14	*<.0001*
22 vs. 45	-13.67	*<.0001*	-4.16	*0.0003*	-8.10	*<.0001*	-3.63	*<.0001*
22 vs. 67	-19.31	*<.0001*	-6.48	*<.0001*	-10.96	*<.0001*	-2.93	*0.0065*
45 vs. 67	-6.29	*<.0001*	-2.52	*0.0173*	-3.07	*0.0046*	0.55	0.5845
Tillage practices and N fertilizer rates								
0 CT vs. 0 RT	0.95	0.3514	-0.58	0.5671	0.71	0.4815	1.32	0.1970
0 CT vs. 0 NT	7.22	*<.0001*	2.79	*0.0091*	1.85	0.0748	-0.22	0.8302
0 RT vs. 0 NT	6.42	*<.0001*	3.40	*0.0019*	1.26	0.2168	-1.51	0.1419
22 CT vs. 22 RT	1.62	0.1158	0.64	0.5270	1.26	0.2184	-0.00	0.9994
22 CT vs. 22 NT	8.74	*<.0001*	4.84	*0.0091*	2.53	*0.0171*	-1.09	0.2851
22 RT vs. 22 NT	8.06	*<.0001*	0.73	0.9428	1.56	0.1305	-1.13	0.2668
45 CT vs. 45 RT	1.43	0.1635	0.60	0.5506	-1.78	0.0863	-130	0.2057
45 CT vs. 45 NT	5.98	*<.000*	4.08	*0.0003*	0.32	0.7545	-1.70	0.1019
45 RT vs. 45 NT	5.19	*<.0001*	3.88	*0.0005*	2.19	0.0371	-0.47	0.6451
67 CT vs. 67 RT	1.20	0.2398	-0.18	0.8612	-0.77	0.4506	-0.95	0.3520
67 CT vs. 67 NT	2.65	*0.0127*	2.05	*0.0490*	0.21	0.8324	-1.88	0.0702
67 RT vs. 67 NT	1.54	0.1341	2.29	*0.0290*	0.94	0.3568	-1.21	0.2374

Table 4.7 Linear regression analysis over 31-yr study periods (1975 through 2014) of winter wheat yields as a function of N fertilizer rate (N rate, Kg N ha^{-1}), total precipitation of fallow (PF, from Nov. to September) and through growing season precipitation of PWinter (Jan. through March) and PApril (summed of April.),by each tillage practices (CT, RT, and NT)

Tillage	**Variables**	**Regression coefficient**	***p*-value**	**Regression statistic**
CT	**Intercept**	419	0.0032	
	N rate	13.4	<.0001	
	PF	1.4	<.0001	
	PWinter	6.4	<.0001	
	PApril	5.4	<.0001	
	R^2[†]			0.40
	p[‡]			<.0001
	Cp[¶]			5.0000
RT	**Intercept**	484	0.0004	
	N rate	13.3	<.0001	
	PF	1.2	<.0001	
	PWinter	7.0	<.0001	
	PApril	4.1	<.0001	
	R^2[†]			0.42
	p[‡]			<.0001
	Cp[¶]			5.0000
NT	**Intercept**	598	<.0001	
	N rate	16.4	<.0001	
	PF	0.90	<.0001	
	PWinter	4.8	<.0001	
	PApril	4.5	<.0001	
	R^2[†]			0.46
	p[‡]			<.0001
	Cp[¶]			5.0000

[†] The Coefficient of determination

[‡] The probability that the regression or regression coefficient was significant

[¶] The Cp is Mallows' Cp statistic.

Table 4.8 Linear regression analysis over 30-yr study periods (1975 through 2014) grain sorghum yields as a function of N fertilizer rate (N rate, kg N ha^{-1}), total fallow precipitation (PF, mm, from March through May) and growing season precipitation (PG, mm, from June through October) for each tillage practices (CT, RT, and NT) over four growing seasons at Hays, KS

Tillage	Variables	Regression coefficient	*p*-value	Regression statistic
CT	**Intercept**	1678	<.0001	
	N rate	15.3	<.0001	
	PG	4.9	<.0001	
	PF	2.8	0.0068	
	***R*²†**			0.19
	***p*‡**			<.0001
	***Cp*¶**			4.0000
RT	**Intercept**	2071	<.0001	
	N rate	18.0	<.0001	
	PG	3.7	<.0001	
	PF	2.4	0.0224	
	***R*²†**			0.15
	***p*‡**			<.0001
	***Cp*¶**			4.0000
NT	**Intercept**	1909	<.0001	
	N rate	18.2	<.0001	
	PG	5.1	<.0001	
	***R*²†**			0.20
	***p*‡**			<.0001
	***Cp*¶**			2.2617

† The Coefficient of determination

‡ The probability that the regression or regression coefficient was significant

¶ The Cp is Mallows' Cp statistic.

References

Allison, P. D. 1999. Multiple Regression: A Primer. Thousand Oaks, CA: Pine Forge Press. p. 142.

Armstrong, R. D., Dunsford, K., McLaughlin, M. J., McBeath, T., Mason, S., and Dunbabin, V. M. 2015. Phosphorus and nitrogen fertiliser use efficiency of wheat seedlings grown in soils from contrasting tillage systems. *Plant and soil*, *396*(1-2), 297-309.

Boyer, J.S., 1982. Plant productivity and environment. *Science*, *218*(4571), pp.443-448.

Camara, K. M., Payne, W. A., and Rasmussen, P. E. 2003. Long-term effects of tillage, nitrogen, and rainfall on winter wheat yields in the Pacific Northwest. Agronomy journal, 95(4), 828-835.

Chauhan, B. S., Singh, R. G., and Mahajan, G. 2012. Ecology and management of weeds under conservation agriculture: a review. *Crop Protection*, *38*, 57-65.

Chen, H., A. Deng, W. Zhang, W. Li, Y. Qiao, T. Yang, C. Zheng, C. Cao, and Chen, F. 2018. Long-term inorganic plus organic fertilization increases yield and yield stability of winter wheat. The Crop J. 6:589-599.

Cornish, P. S. 1987. Effects of direct drilling on the phosphorus uptake and fertilizer requirements of wheat. *Australian Journal of Agricultural Research*, *38*(4), 775-790.

Cossani, C.M. and Sadras, V.O., 2018. Water–nitrogen colimitation in grain crops. In *Advances in Agronomy* (Vol. 150, pp. 231-274). Academic Press.

Crossa, J. 1988. A comparison of results obtained with two methods for assessing yield stability. Theoretical and applied genetics, 75(3), 460-467.

Daigh, A. L., Dick, W. A., Helmers, M. J., Lal, R., Lauer, J. G., Nafziger, E., and Cruse, R. 2018. Yields and yield stability of no-till and chisel-plow fields in the Midwestern US Corn Belt. *Field Crops Research, 218*, 243-253.

Darlington, R. B. 1968. Multiple regression in psychological research andpractice. *Psychological bulletin*, *69*(3), 161.

Eberhart, S. t, and Russell, W. A. 1966. Stability parameters for comparing varieties 1. Crop Science, 6(1), 36–40.

Finlay, K. W., and Wilkinson, G. N. 1963. The analysis of adaptation in a plant-breeding programme. *Australian journal of agricultural research*, *14*(6), 742-754.

Forde, B. G. 2002. The role of long-distance signalling in plant responses to nitrate and other nutrients. Journal of experimental botany, 53(366), 39-43.

Gaudin, A. C., Tolhurst, T. N., Ker, A. P., Janovicek, K., Tortora, C., Martin, R. C., and Deen, W. 2015. Increasing crop diversity mitigates weather variations and improves yield stability. *PloS one*, *10*(2), e0113261.

Govaerts, B., Sayre, K. D., and Deckers, J. 2005. Stable high yields with zero tillage and permanent bed planting?. *Field crops research*, *94*(1), 33-42.

Grant, C. A., Flaten, D. N., Tomasiewicz, D. J., and Sheppard, S. C. 2001. The importance of early season phosphorus nutrition. Canadian Journal of Plant Science, 81(2), 211-224.

Grover, K. K. 2008. *Long-term cropping systems effects on soil aggregate stability, corn grain yields, and yield stability*. (Dissertation, Doctor of Philosophy, The Pennsylvania State University).

Halvorson, A. D., and Reule, C. A. 1994. Nitrogen fertilizer requirements in an annual dryland cropping system. *Agronomy Journal*, *86*(2), 315-318.

Halvorson, A. D., Wienhold, B. J., and Black, A. L. 2001. Tillage and nitrogen fertilization influence grain and soil nitrogen in an annual cropping system. *Agronomy Journal*, *93*(4), 836–841.

Hobbs, P. R., Sayre, K., and Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *363*(1491), 543–555.

Hofmeijer, M. A., Krauss, M., Berner, A., Peigné, J., Mäder, P., and Armengot, L. 2019. Effects of reduced tillage on weed pressure, nitrogen availability and winter wheat yields under organic management. *Agronomy*, *9*(4), 180.

Howeler, R.H., Ezumah, H.C. and Midmore, D.J. 1993. Tillage systems for root and tuber crops in the tropics. *Soil and Tillage Research*, *27*(1-4), pp.211-240.

Hu, Q., and Buyanovsky, G. 2003. Climate effects on corn yield in Missouri. Journal of Applied Meteorology, 42(11), 1626-1635.

Jaenisch, B.R., de Oliveira Silva, A., DeWolf, E., Ruiz-Diaz, D.A. and Lollato, R.P., 2019. Plant population and fungicide economically reduced winter wheat yield gap in Kansas. *Agronomy Journal*, *111*(2), pp.650-665.

Karlen D.L., E.G. Hurley, S.S. Andrews, C.A. Cambardella, D.W. Meek, M.D. Duffy, and A.P. Mallarino. 2013. Crop rotation effects on soil quality at three northern corn/soybean belt locations. Agron. J. 98: 484-495.

Lightfoot, C. W. F., Dear, K. B. G., and Mead, R. 1987. Intercropping sorghum with cowpea in dryland farming systems in Botswana. II. Comparative stability of alternative cropping systems. *Experimental agriculture*, *23*(4), 435-442.

Logan, T. J., Lal, R., and Dick, W. A. 1991. Tillage systems and soil properties in North America. Soil and Tillage Research, 20(2–4), 241–270.

Lollato, R.P., Bavia, G.P., Perin, V., Knapp, M., Santos, E.A., Patrignani, A. and DeWolf, E.D. 2020. Climate-risk assessment for winter wheat using long-term weather data. *Agronomy Journal*.

Lollato, R.P., Edwards, J.T. and Ochsner, T.E., 2017. Meteorological limits to winter wheat productivity in the US southern Great Plains. *Field Crops Research, 203*, pp.212-226.

Lollato, R.P., Figueiredo, B.M., Dhillon, J.S., Arnall, D.B. and Raun, W.R., 2019. Wheat grain yield and grain-nitrogen relationships as affected by N, P, and K fertilization: a synthesis of long-term experiments. *Field Crops Research*, *236*, pp.42-57.

López-Bellido, R. J., and López-Bellido, L. 2001. Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. Field Crops Research, 71(1), 31-46.

Macholdt, J., and Honermeier, B. 2019. Stability analysis for grain yield of winter wheat in a long-term field experiment. *Archives of Agronomy and Soil Science*, *65*(5), 686-699.

Maeoka, R.E., Sadras, V.O., Ciampitti, I.A., Diaz, D.R., Fritz, A.K. and Lollato, R.P. 2020. Changes in the Phenotype of Winter Wheat Varieties Released Between 1920 and 2016 in Response to In-Furrow Fertilizer: Biomass Allocation, Yield, and Grain Protein Concentration. *Frontiers in plant science*, *10*, p.1786.

Mantel, N. 1970. Why stepdown procedures in variable selection. *Technometrics*, *12*(3), 621-625.

McBeath, T. M., McLaughlin, M. J., Kirby, J. K., and Armstrong, R. D. 2012. The effect of soil water status on fertiliser, topsoil and subsoil phosphorus utilisation by wheat. Plant and Soil, 358(1-2), 337-348.

McConkey, B. G., Curtin, D., Campbell, C. A., Brandt, S. A., and Selles, F. 2002. Crop and soil nitrogen status of tilled and no-tillage systems in semiarid regions of Saskatchewan. *Canadian Journal of Soil Science*, *82*(4), 489-498.

Montemurro, F. 2009. Different nitrogen fertilization sources, soil tillage, and crop rotations in winter wheat: effect on yield, quality, and nitrogen utilization. Journal of Plant Nutrition, 32(1), 1–18.

Munaro, L.B., Hefley, T.J., DeWolf, E., Haley, S., Fritz, A.K., Zhang, G., Haag, L.A., Schlegel, A.J., Edwards, J.T., Marburger, D. and Alderman, P., 2020. Exploring long-term variety performance trials to improve environment-specific genotype× management recommendations: A case-study for winter wheat. *Field Crops Research*, *255*, p.107848.

Nielsen, D. C., and Halvorson, A. D. 1991. Nitrogen fertility influence on water stress and yield of winter wheat. *Agronomy journal*, *83*(6), 1065-1070.

Nielsen, D. C., and Vigil, M. F. 2010. Precipitation storage efficiency during fallow in wheat-fallow systems. *Agronomy Journal*, *102*(2), 537–543.

Nielsen, D. C., and Vigil, M. F. 2018. Wheat yield and yield stability of eight dryland crop rotations. *Agronomy Journal*, *110*(2), 594-601.

Obour, A. K., Mikha, M. M., Holman, J. D., and Stahlman, P. W. 2017. Changes in soil surface chemistry after fifty years of tillage and nitrogen fertilization. *Geoderma*, *308*, 46-53.

Obour, A. K., Stahlman, P. W., and Thompson, C. A. 2015. Wheat and Grain Sorghum Yields as Influenced by Long-term Tillage and Nitrogen Fertilizer Application. *Int. J. Soil Plant Sci.*, *7*, 19–28.

Pan, G., Smith, P., and Pan, W. 2009. The role of soil organic matter in maintaining the productivity and yield stability of cereals in China. *Agriculture, Ecosystems & Environment*, *129*(1-3), 344-348.

Patrignani, A., Knapp, M., Redmond, C. and Santos, E., 2020. Technical overview of the Kansas Mesonet. *Journal of Atmospheric and Oceanic Technology*, pp.1-49.

Piepho, H. P. 1998. Methods for comparing the yield stability of cropping systems. *Journal of Agronomy and Crop Science*, *180*(4), 193-213.

Pieri, L., Ventura, F., Vignudelli, M., and Rossi, P. 2011. Nitrogen balance in a hilly semi-agricultural watershed in Northern Italy. *Italian Journal of Agronomy*, e12-e12.

Pittelkow, C. M., Liang, X., Linquist, B. A., Van Groenigen, K. J., Lee, J., Lundy, M. E., and Van Kessel, C. 2015. Productivity limits and potentials of the principles of conservation agriculture. *Nature*, *517*(7534), 365-368.

Plett DC, Ranathunge K, Melino VJ, Kuya N, Uga Y, and Kronzucker H. J. 2020. The intersection of nitrogen nutrition and water use in plants: new paths toward improved crop productivity. J Exp Bot, 71 (15), 4452–4468.

Qin, R., Stamp, P., and Richner, W. 2004. Impact of tillage on root systems of winter wheat. Agronomy Journal, 96(6), 1523-1530.

Rasmussen, I. S., Dresbøll, D. B., and Thorup-Kristensen, K. 2015. Winter wheat cultivars and nitrogen (N) fertilization—effects on root growth, N uptake efficiency and N use efficiency. European Journal of Agronomy, 68, 38-49.

Rasmussen, P. E., and Rohde, C. R. 1991. Tillage, soil depth, and precipitation effects on wheat response to nitrogen. Soil Science Society of America Journal, 55(1), 121-124.

Rattalino Edreira, J.I., Mourtzinis, S., Conley, S.P., Roth, A.C., Ciampitti, I.A., Licht, M.A., Kandel, H., Kyveryga, P.M., Lindsey, L.E., Mueller, D.S. and Naeve, S.L., 2017. Assessing causes of yield gaps in agricultural areas with diversity in climate and soils. *Agricultural and Forest Meteorology*, *247*, pp.170-180.

Raun, W. R., and Barreto, H. J. 1993. Use of stability analysis for long-term soil fertility experiments. *Agronomy Journal*, *85*(1), 159–167.

Rice, C. W., and Smith, M. S. 1984. Short-term immobilization of fertilizer nitrogen at the surface of no-till and plowed soils. Soil Science Society of America Journal, 48(2), 295-297.

Sainju, U. M., Ghimire, R., and Pradhan, G. P. 2019. Improving dryland cropping system nitrogen balance with no-tillage and nitrogen fertilization. *Journal of Plant Nutrition and Soil Science*, *182*(3), 374-384.

Sainju, U. M., Lenssen, A. W., Caesar-TonThat, T., Jabro, J. D., Lartey, R. T., Evans, R. G., and Allen, B. L. 2012. Dryland soil nitrogen cycling influenced by tillage, crop rotation, and cultural practice. *Nutrient Cycling in Agroecosystems*, *93*(3), 309-322.

Sainju, U. M., Stevens, W. B., Caesar-TonThat, T., and Montagne, C. 2014. Nitrogen dynamics affected by management practices in croplands transitioning from conservation reserve program. *Agronomy Journal*, *106*(5), 1677-1689.

SAS Institute. 2014. SAS user’s guide: Statistics. Version 9.4. SAS Inst., Cary, NC.

Schlegel, A. J., Assefa, Y., Haag, L. A., Thompson, C. R., and Stone, L. R. 2018. Long-term tillage on yield and water use of grain sorghum and winter wheat. Agronomy Journal, 110(1), 269-280.

Schlegel, A.J., Dhuyvetter, K.C., Thompson, C.R. and Havlin, J.L., 1999. Agronomic and economic impacts of tillage and rotation on wheat and sorghum. *Journal of production agriculture*, *12*(4), pp.629-636.

Sharpley, A. N., and Smith, S. J. 1994. Wheat tillage and water quality in the Southern Plains. Soil and Tillage Research, 30(1), 33-48.

Smith, C. W., and Kucera, M. 2018. Effects on soil water holding capacity and soil water retention resulting from soil health management practices implementation - A review of the literature posted to the NRCS soil health website as of 11/2020. Natural Resources Conservation Service (NRCS), United States Department of Agriculture (USDA).

Soil Survey Staff. 2010. Keys to Soil Taxonomy, 11th Ed. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC, USA.

Staggenborg, S.A., Whitney, D.A., Fjell, D.L. and Shroyer, J.P., 2003. Seeding and nitrogen rates required to optimize winter wheat yields following grain sorghum and soybean. *Agronomy Journal*, *95*(2), pp.253-259.

St-Martin, A., Vico, G., Bergkvist, G., and Bommarco, R. 2017. Diverse cropping systems enhanced yield but did not improve yield stability in a 52-year long experiment. Agriculture, Ecosystems & Environment, 247, 337-342.

Stone, M. 1974. Cross-validatory choice and assessment of statistical predictions. *Journal of the Royal Statistical Society: Series B (Methodological)*, *36*(2), 111-133.

Tannura, M.A., S.H. Irwin, and D.L. Good. 2008. Weather, technology, and corn and soybean yields in the U.S. corn belt. Tech. Rep. 2008-01. Dep. Agric. Cons. Econ., Univ. of Illinois, Urbana-Champaign, IL.

Teasdale, J. R., and Rosecrance, R. C. 2003. Mechanical versus herbicidal strategies for killing a hairy vetch cover crop and controlling weeds in minimum-tillage corn production. *American journal of alternative agriculture*, 95-102.

Thomas, G. A., Dalal, R. C., and Standley, J. 2007. No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. *Soil and Tillage Research*, *94*(2), 295–304.

Thompson, C. A., and Whitney, D. A. 1998. Long-term tillage and nitrogen fertilization in a west central Great Plains wheat-sorghum-fallow rotation. *Journal of production agriculture*, *11*(3), 353-359.

Thompson, C. A., and Whitney, D. A. 2000. Effects of 30 years of cropping and tillage systems on surface soil test changes. *Communications in soil science and plant analysis*, *31*(1-2), 241-257.

Triplett, G. B., and Dick, W. A. 2008. No-tillage crop production: A revolution in agriculture!. *Agronomy journal*, *100*(Supplement_3), S-153.

Troeh, F. R., Hobbs, J. A., and Donahue, R. L. 1980. *Soil and water conservation for productivity and environmental protection*. Prentice-Hall, Inc.

Unger, P. W., Schomberg, H. H., Dao, T. H., and Jones, O. R. 1997. Main content area Tillage and crop residue management practices for sustainable dryland farming systems. *Annals of Arid Zone*, *36*(3), 209–232.

Van Eerd, L. L., Congreves, K. A., Hayes, A., Verhallen, A., and Hooker, D. C. 2014. Long-term tillage and crop rotation effects on soil quality, organic carbon, and total nitrogen. *Canadian Journal of Soil Science*, *94*(3), 303-315.

Wienhold, B. J., and Halvorson, A. D. 1999. Nitrogen mineralization responses to cropping, tillage, and nitrogen rate in the northern Great Plains. *Soil Science Society of America Journal*, *63*(1), 192-196.

Yates, F., and Cochran, W. G. 1938. The analysis of groups of experiments. *The Journal of Agricultural Science*, *28*(4), 556-580.

Zhuang, J., McCarthy, J. F., Perfect, E., Mayer, L. M., and Jastrow, J. D. 2008. Soil water hysteresis in water-stable microaggregates as affected by organic matter. *Soil Science Society of America Journal*, *72*(1), 212-220.