TILLAGE EFFECTS ON WHEAT GROWTH IN A WHEAT PASTURE PLUS GRAIN PRODUCTION SYSTEM

By

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CHAPTER I

INTRODUCTION

In the Southern Great Plains, hard red winter wheat (Triticum aestivum L.) is a source of high quality fall and winter forage. In Oklahoma, 30 to 60% of the 7 million acres of hard red winter wheat are grazed during its vegetative growth stage in fall, winter, and early spring. In the spring, before the jointing stage, livestock are removed to allow reproductive development for grain production.

Oklahoma receives snow and rain during this grazing period of October through late February or early March. As a result, the soil in the wheat pastures may be soft and plastic and create soil conditions which have the potential for compaction due to animal grazing.

It is a concern that with the increase in conservation tillage, soil compaction due to the effects of animal traffic may reduce wheat forage and grain yields. This is because under no-till or other conservation tillage practices, wheat fields are not moldboard plowed or are plowed infrequently and the compaction created by grazing may not be alleviated by alternative tillage practices or by soil shrinkage and swelling as soil moisture changes. Soil compaction in return may affect the favorableness of the rooting zone, restricting root development and therefore reducing both forage and grain yields.

Soil compaction created by animal traffic has been shown to be a factor influencing root growth and yields in crops of maize, cotton and wheat. The objectives of this study were:

(1) To determine if soil compaction from grazing stocker cattle affects wheat growth or production (forage and grain) in subsequent wheat crops.

(2) To evaluate the effectiveness of tillage practices in alleviating soil compaction from the previous wheat crop as a growth limiting factor.

CHAPTER II

LITERATURE REVIEW

The success or failure of a crop production system often depends on the seedbed environment created by weather history, previous tillage practices, and planting equipment used for seeding (Wilkins et al., 1982). A harsh seedbed environment may kill the seedling or stress it severely enough to limit the plant's productive potential. Factors such as soil temperature, moisture, compaction, concentrations of chemicals, and aeration can independently or interactively cause harsh seedbeds and result in poor plant stands.

Ciha (1982) found that average grain yields of soft white spring wheat with no-tillage and conservation tillage were significantly greater than yields using conventional tillage. No-tillage increased test weights while reducing tillage operations significantly reduced the number of spikelets per head, but increased the 100-seed weight. Yields obtained for winter wheat under reduced tillage have not been consistently different than yields obtained under conventional tillage (Nipp, 1987).

A straw mulch in any quantity up to 4480 kg/ha can be employed on the soil surface without encountering deleterious effects on spring and winter wheat (Anderson and Russell, 1964). A plant residue mulch influences soil temperature and net radiation by reflecting incident radiant energy, by insulation, and by reducing evaporation. Blevins et al. (1971) monitored soil moisture under conventional, no-tillage and second year no-tillage. These three methods of management showed no-tillage to be higher in volumetric moisture content to a depth of 45 cm. Beyond a depth of 60 cm, systems of tillage or management had very little effect on soil moisture contents during the growing season.

Under no-tillage conditions, the decreased evaporation and greater ability of the soil to store moisture results in a water reserve which can carry the crop through periods of short-term drought without detrimental moisture stresses developing in the plants. During more prolonged droughts soil profiles of both conventional and no-tillage plots are depleted of soil water. The moisture conservation in no-till systems resulted in higher corn yield during years of either poor or favorable rainfall distribution. Cochran et al. (1982) found increased wheat yields arise from less stirring of the soil and lower evaporative loss of water under surface crop residues.

From various perennial pasture sites with clay loam and sandy loam soils in Pennsylvania, compaction from grazing was found to be limited mostly to the surface 2.5 cm layer. Bulk densities in the surface 2.5 cm layer ranged from 1.54 g cm^{-3} to 1.91 g cm^{-3} for heavily grazed sites and from 1.09 g cm^{-3} to 1.51 g cm^{-3} for ungrazed and lightly grazed sites (Alderfer and Robinson, 1947). From an experiment conducted in Oklahoma, sandy range plots that had been subjected to heavy grazing had an average soil bulk density at the 10 cm to 15 cm depth of 1.72 g cm^{-3} while ungrazed exclosures had only 1.56 g cm^{-3} (Rhoades et al., 1964).

Even though reducing tillage may help conserve soil water, it may result in greater compaction. The extent of soil compaction which occurs as a result of animal traffic on wheat pasture was studied in three locations in Oklahoma in the 1986-87 growing season. Cattle grazed wheat until the early joint stage of growth, and measurements of soil strength, soil moisture, and bulk density were taken before initiation of grazing and immediately after grazing termination. Increases in both the bulk density and the soil strength of the grazed areas were found in all three sites, although the depth to which the differences were measured varied from site to site (Krenzer et al., 1989). Animal traffic increased bulk density by as much as 16% and soil strength by 270% in surface zones. The data indicated that compaction does result from grazing wheat pasture and may extend to a depth where some tillage practices may not eliminate it and wheat growth could affected.

Lull (1959) defined soil compaction as packing together of soil particles by instantaneous forces exerted at the soil surface resulting in an increase in soil bulk density through a decrease in pore space. Soil compaction is a major factor which influences root growth and crop yields (Gerald et al., 1982).

Soil moisture content, in addition to influencing compactability, is also an important variable in evaluating soil strength data. Soil strength is the resistance pressure of a soil to penetration by an object, such as a plant root, and can be measured with a penetrometer (Krenzer et al., 1989). Mirreh and Ketcheson (1972) and Hughes et al. (1966) found that by increasing the bulk density and decreasing the soil matric potential (soils getting drier), the soil strength increased. They indicated that the expression of soil resistance was a function of both bulk density and matric pressure, and that the resistance behavior of soils is predictable only in relation to both variable simultaneously.

One of the obvious adverse effects of compaction is the impedance of root growth. Root distribution and root growth of maize was significantly affected by soil compaction (Raghavan et al., 1979). Other research indicated a decrease in root penetration of cotton was associated with an increase in soil bulk density from 1.65 g cm^{-3} to 1.75 g cm^{-3} (Taylor and Gardner, 1963). In Australia, spring wheat grown in soil having a bulk density of 1.52 g cm^{-3} in the 0 to 20 cm depth had less root growth than that grown in soil having bulk density of 1.32 g cm^{-3} (Reeves et al., 1984). Taylor and Gardner (1963) also found a highly significant negative linear correlation (r = -0.96) between the soil strength and percentage of cotton root penetration. Cotton root elongation rate was inversely related to soil strength, when all other plant growth conditions were non-limiting (Taylor, 1971). Ericksson et al. (1974) reported root growth of wheat seedlings was progressively reduced when the soil was subjected to surface pressure in excess of 200 kPa and the limiting penetration resistance for root growth was reported to be between 800 and 5,000 kPa.

Not only does compaction affect root penetration, but also yield. As the bulk density of soil increased from 1.27 to 1.67 g cm^{-3}, the dry matter yield of wheat decreased from 4.50 to 2.94 grams (Nagpal el at., 1967). Carter and Tavernetti (1968) found cotton yields decreased from 1.78 bales/ha to .6 bales/ha when bulk density of soil increased from 1.48 g cm^{-3} to 1.63 g cm^{-3}. Carter and Tavernetti (1968) also found that soil strengths above 2415 kPa decreased cotton yields.

The recent development of a system of leaf and tiller identification permits field quantification of cereal crop vegetative plant development (Klepper et al., 1982). Leaves are numbered in the order of their appearance (Haun, 1973).

The coleoptile is (L0), the first leaf is (L1), the second leaf (L2), and so on. Main stem leaf stage (MSL) is described by counting the number of fully expanded leaves and the fraction of the length of the last leaf. Klepper et al. (1982) called the tiller which developed at the base of the coleoptile "T0", the tiller which developed in the axil of the first foliar leaf "T1", that from the second leaf "T2", that from the third leaf "T3", and so on. Percent tiller formation (%TF) is the percentage of plants having the tiller which is under consideration. Wilkins et al. (1989) used the leaf and tiller identification method as a biological sensor for evaluating tillage and seeding equipment systems and found plant stresses induced by tillage and seeding equipment were detected by the method.

Krenzer et al. (1989), in Oklahoma, found bulk density levels after grazing wheat were as high as 1.57 g cm^{-3}. Since Reeves et al. (1984) and Nagpal et al. (1967) found similar bulk densities reduced wheat root growth and yields, we were interested in determining if soil compaction from grazing livestock affects wheat growth in subsequent crops and in evaluating the effectiveness of tillage practices in alleviating the compaction created by grazing which may limit growth.

CHAPTER III

MATERIALS AND METHODS

The study area consisted of four locations on a farmer's field near Hennessey, Oklahoma. For the first year (1989-90), locations were on a Tabler clay loam (fine, montmorillonitic, thermic Vertic Argiustolls) and on a Bethany silt loam (fine, mixed, thermic Pachic Paleustolls). For the second year (1990-91), two new locations were obtained on a Shellabarger sandy clay loam (fine-loamy, mixed, thermic Udic Argiustolls) and another Bethany silt loam (Table I). Prior to the study, the land was used for combined wheat forage and grain production. At each location, treatments consisted of four tillage systems in a randomized complete block with four replications. The tillage systems were chosen to accomplish different tillage depths (Table II) and leave different levels of crop residue on the soil surface.

The four different tillage systems were:

No-Till

Chisel: chisel plow with duck feet

Para Sub: Parabolic shank subsoiler (Big Ox)

Bent Sub: Bent leg subsoiler (Paratiller)

In the no-till system, the plant material was left on top of the soil and the soil was not disturbed other than by the cut made with the planter during seeding. This system allowed for maximum residue to remain on the soil as well as maximum expression of the previous soil compactive effects.

The chisel plow is a tillage implement that tills the soil to 15-20 cm depth. It had 28 duck-foot type legs on 30 cm spacing each having an 18 cm shovel, thus providing an 8 m working width. Parabolic shanks on the chisel plow incorporate some residue into the soil and leave from 30 to 75% of the plant residue on the surface, while cutting the soil beneath the surface.

The parabolic shank subsoiler (Big Ox) is designed to operate at 25-40 cm working depth. It had eleven parabolic shanks spaced 50 cm apart, resulting in a 5.5 m working width. At the tip of each leg was a 5 cm wide horizontal tooth or chisel. The subsoiler buried some residue during soil inversion, leaving 45 to 60% of plant residue on the soil surface. Sharp, pointed shanks cut through the soil at a desired depth and break the hard pan created by animal or field traffic. This subsoiler had two pneumatic gauge wheels.

The bent leg subsoiler (Paratiller)[1] produces the

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[1]The Tye Company, P.O. Box 218, Lockney, TX 79241, Form 1131R/1 (December, 1987).

greatest depth of tillage without inversion of the soil, leaving around 60 to 90% of the residue on the surface. The subsoiler is designed to operate up to 35-40 cm working depth. It has 4 legs with the top section being vertical and the bottom section having a 45^{o} and to the side. A spring-loaded, 21.5 cm diameter ripple coulter cuts the residue in front of each leg. The legs are spaced 60 cm apart. There are two pneumatic gauge wheels ahead of the legs and adjacent to the coulters.

Tillage of plots was performed in late June or early July. Through the later summer months, a chisel plow with sweeps was run over the tilled plots a couple of times to break up clods and control weeds. Prior to planting, a field cultivator was used for final seedbed preparation. Tillage of the plots was performed by the farmer. Wheat residue and stubble were left standing in the no-till plots.

The winter wheat cultivar '2157' was planted at both locations the first year, 1989-1990. The second year, 1990-1991, the winter wheat cultivar '2180' was planted at both locations (Table I). Seeding rate was 90 kg/ha. Seeding depth was 2.5-3.5 cm. Planting was completed in early to mid September, the normal planting date in Oklahoma for wheat intended to be used for forage as well as grain.

The first year, in early August, Landmaster (Glyphosate at 13.3% + 2,4-D at 11.1%) was applied to all plots (Table III) to control summer weeds which were primarily

Johnsongrass (Sorghum halepense), purslane (Portulaca oleracea), and bearded sprangletop (Leptochloa fasicularis). Finesse (Chlorsulfuron at 62.5% + Metsulfuron Methyl at 12.5%) was applied to all plots to control cheat (Bromus secalinus), a winter annual, immediately after planting. Later Tycor (Ethiozin at 75%), an experimental cheat herbicide was applied. The second year 1990-1991, Lexone (Metribuzin at 75%) was applied to all plots to control Bromus spp. Herbicide was the only weed control practice for the no-till plots. Throughout the summer and immediately prior to planting, only the no-till plots were sprayed with Roundup (Glyphosate at 41%) or Landmaster when weeds or volunteer became a problem.

For the year 1989-1990, plots were preplant broadcasted with ammonium nitrate at a rate of 136 kg N/ha in early fall. For the second year, 18:46:0 (NPK) fertilizer was applied at a rate of 100 kg/ha in seed rows at planting, then urea ammonium nitrate (28:0:0) was applied at 100 kg N/ha one month after planting. Fertilizer was applied at adequate amounts that nutrient deficiencies of the wheat plants would not limit forage or grain yield in any of the tillage systems.

Exclosures were put near the end of plots to maintain areas that were not affected by cattle grazing. These exclosures were made up of welded wire panels and contained an area of 5 by 5 m. Cattle were turned onto the locations in early November for continuous forage grazing until early jointing occurred which is approximately mid March.

Measurements taken include (1) plants per unit area, (2) main stem leaf stage, (3) the presence or absence of the coleoptile tiller, tillers T1, T2, etc., and (4) forage yield. Also, at harvest, grain yield and yield components of heads per unit area and test weight per bushel were obtained. Soil strength readings along with soil samples for bulk density and gravimetric water content were taken after harvest but before tillage, and again one day prior to planting, to determine the amount of soil compaction for each plot.

Stand establishment of wheat plants (plants per unit area) was obtained by counting six, one meter rows for each plot after maximum, uniform emergence of plants occurred at each location. These rows were picked randomly throughout the plot at planting. Nine plants in the exclosures were picked at random in the Bethany silt loam location for the first year, and both the Bethany silt loam and the Shellabarger sandy clay loam locations for the second year. These nine plants were observed weekly for leaf and tiller development, to the time of first forage clipping.

Location I, II, and IV were clipped for forage yield (Table I). Location III was not clipped since there was not enough forage for accurate yield determinations. Within the exclosure, an area of 134 cm by 7.3 m was clipped about 6 cm above the soil surface with a Kincaid sicklebar forage harvester for forage yield determinations. Subsamples taken at each clipping were oven dried at 35° C to a constant weight.

An area of 36.5 by 2.4 m was harvested on Location I for grain yield. Location II was not harvested due to hail damage after maturity but prior to harvest. An area of 18.2 by 1.35 m was harvested for both Location III and Location IV (Table I).

A computerized, hydraulically operated tractor-mounted cone penetrometer was utilized in this experiment to determine the soil strength. The force required to press the 30° circular cone through the soil is expressed in kilopascals (kPa). The cone penetrometer was calibrated to push the cone into the ground at a uniform rate of 183 centimeters per minute. The surface reading was measured at the instant the base of the cone was flush with the soil surface. Subsequent readings were taken at 1.5 cm increments. Readings were recorded by a computer. Eight samples were averaged in each plot to obtain soil strength. Data presented were then calculated as follows: for the 0-3 cm zone, sum the value at 0 cm plus 2 times the value at 1.5 cm, plus the value at 3 cm and divide by four; kPa(0-3 cm) = [kPa at 0 cm + 2*kPa at 1.5 cm + kPa at 3 cm]/4.

A total of three sets of soil samples for bulk density and gravimetric water content were taken from near penetrometer reading points and bulked for each depth in each plot. Soil samples were collected to a depth of 45 cm at 3 cm increments. The samples were transported to the laboratory and were weighed immediately and dried at 105° C for 48 hours. The weight of dry soil and the empty can weights were determined. Bulk densities were determined and expressed as g cm^{-3}. The gravimetric water content or mass wetness (w) was determined by dividing the mass of water (M_w) from the soil samples by the mass of solid (M_s) or the dry weight of the soil samples (Hillel, 1982) and expressed in percent; W = (Mw/Ms) * 100.

Analysis of variance was performed on stand; soil moisture, soil bulk density, soil strength; main stem leaf stage; presence or absence of the coleoptile tiller (T0); the presence or absence of tiller one (T1), tiller two (T2), and tiller three (T3); heads per area; forage yield and grain yield. If the F values were significant, orthogonal contrasts: no-till vs tilled treatments, chisel vs para sub and bent sub, and para sub vs bent sub (Steel and Torrie, 1980) were used to compare significant differences among tillage treatments.

CHAPTER IV

RESULTS AND DISCUSSION

Rainfall Data

During the growing season 1989-90, much rainfall was received (Table IV) and water stress was not a limiting factor in the wheat plants growth. In fact, throughout this year, the field was usually so wet that getting into the field to monitor stand, main stem leaf stage, and percent tiller formation was a problem. However, in the next growing season 1990-91, rainfall was limited. After the Bethany location was planted, but before the Shellabarger location was planted, 4.14 cm of rainfall was received; whereas, after planting in the Shellabarger location 1.07 cm of rain was received for the rest of the month. For the month of October, only 2.46 cm of rain fell. The difference in the two locations planting dates and the amount of rainfall received on both has led us to believe that the small rainfall received early on Bethany helped the no-till conserve moisture and produce higher grain yields; whereas, the no-till in the Shellabarger had low moisture which in return resulted in high bulk densities and soil strengths. These high bulk densities and soil strengths may have caused the no-till to have a lower main stem leaf and grain yield as compared to the tilled treatments.

Soil Parameters

Prior to tillage, the soil moisture, bulk density, and soil strength in all locations for both years were not significantly different at all depths except where noted (Tables V, VI, VII, and VIII). Primarily though, differences did not exist prior to initiation of this research.

Prior to planting, soil moisture in Tabler 1989-90 was not affected by tillage with the exception at the depth 0-3 cm where the bent sub treatment had higher soil moisture as compared to the para sub treatment (Table IX). At the depths of 0-3 cm, 6-9 cm, and 15-18 cm, preplant no-till bulk densities were significantly higher than the tilled treatments. At the depths of 6-18 cm and 24-27 cm the chisel treatment had higher bulk densities than the bent sub and para sub treatments (Table X). Preplant no-till soil strengths were significantly higher at 0-9 cm and 15-30 cm as compared to the tilled treatments (Table IX). Consistently, from the depth of 6-33 cm, chisel plowing resulted in higher soil strengths than the bent sub and para sub (Table XI).

In the Bethany 1989-90 location, no-till soil strengths were significantly higher down to 24 cm than tilled treatments (Table XII). Among the tilled treatments, chisel was significantly higher than the para sub and bent sub from depths of 3-33 cm (Table XIII). The bent sub had significantly lower soil strengths than the para sub from 9-36 cm. The no-till and chisel treatments, as expected, had higher soil strengths then bent sub or para sub.

No-till soil moisture in Shellabarger 1990-91 was significantly lower than the tilled soil moisture at the depth of 9-12 cm prior to planting (Table XIV). No-till bulk density was significantly higher than bulk densities in the tilled treatments at the depths of 0-3 cm, 18-21 cm, and 36-39 cm before planting. This trend of higher bulk density in no-till than in the tilled plots was consistent from the surface to 20 cm even though statistical differences were not always significant at P = 0.05. Reeves et al., (1984) and Nagpal et al., (1967) found bulk densities in the range of 1.52 g cm^{-3} to 1.67 g cm^{-3} decreased root growth and yields of wheat. The no-till treatment bulk densities fell in this range from 0-9 cm depth. The tilled treatments bulk densities were lower at these depths. Soil strength for no-till was significantly higher than in tilled plots at all depths except 42-45 cm. Bulk densities generally did not appear to account for differences in the soil strengths at depths greater than 20 cm. Soil moisture also played a role in determining soil strength as was discussed by Mirreh and Ketcheson (1972) and Hughes et al. (1966). There was a trend of more soil moisture in the tilled treatments as compared to the no-till treatment, causing at least some tendency for the soil strength values for tilled treatments to be lower than the no-till treatment. These relationships indicate that wheat plants in the no-till plots could be stressed due to the high values of soil strength from 6 cm down.

In the Bethany 1990-91, although mostly not statistically different, soil moisture tended to be higher through the top 40 cm in no-till versus the tilled prior to planting (Table XV). Bulk density was significantly higher for no-till versus tilled treatments at 0-3 cm, 6-9 cm and 39-42 cm. Also, chisel versus other tillage treatments had a higher bulk density at 0-3 cm depth only. Soil strength was significantly higher for no-till only at the soil surface from 0-9 cm. These parameters suggest that soil moisture was more available in the no-till plots and although bulk density and soil strength were significantly higher on the no-till plots as compared to the tilled treatments, they were not as high as in the Shellabarger and may not have been high enough to create stress.

Postgraze soil measurements for Tabler and Bethany 1989-90 were not different except where noted (Table XVI and XVII). These data were not obtained until after harvest when soil moisture was quite low, which helps explain why the soil strengths are so high. Postgraze data for

Shellabarger 1990-91 indicates that soil moisture, bulk density, and soil strength differences are basically insignificant except at a few depths and tillage treatment combinations (Table XVIII). Postgraze on Bethany 1990-91 shows that soil moisture and bulk density are non-significant different among treatments, although soil strength is still significantly higher for no-till compared to all tilled treatments down to a depth of 12 cm (Table XIX). Due to dry weather and low soil moisture, all soil strength measurements in both the Bethany and Shellabarger soils were quite high in March 1991.

In general the bulk density and soil strength readings preplant indicated that tillage created the anticipated differences in soil strength and bulk densities. No-till was highest, chisel was effective but only in the surface while para sub and bent sub were effective in decreasing soil strength deeper into the soil profile. Soil compaction by cattle grazing the wheat pasture had removed soil bulk densities and soil strength differences created by the previous tillage practices resulting in very similar situations for root growth across tillage treatments from jointing through maturity.

Percent Ground Cover

The percent of plant residue still remaining on the soil after tillage was much higher for the no-till plots as compared to the three tilled treatments (Table XX). This ground cover could help in retaining moisture by reducing evaporation and producing a greater water reserve as noted in the Bethany 1990-91 soil (Table XV), although a similar trend did not occur in the other three sites.

Plant Stand

There was no consistent trend for tillage practice affecting plant stand (Table XXI). On Tabler 1989-90, bent sub treatment had a significantly higher plant stand as compared to the other three treatments. Also, no-till was significantly lower in plant stand as compared to para sub and chisel treatments. No-till had significantly higher plant stands on Shellabarger 1990-91. Bethany 1989-90 and 1990-91 had no significant differences in plant stand. Because plant stands were similar, it is unlikely stand could have been responsible for yield differences discussed later.

Main Stem Leaf Stage (MSL)

Main stem leaf stage was most strongly affected by tillage on Shellabarger 1990-91 (Table XXIII). Everyday that MSL was monitored, except day 36, the no-till was significantly lower than the tilled treatments. Lower main stem leaf stage on no-till might be an indication of poor seedbed environment due to compaction (Klepper et al., 1982). Shellabarger 1990-91 no-till treatment having lower MSL could be related to the significantly higher soil strength values the no-till had compared to the tilled treatments (Table XIV). These higher soil strengths could have reduced root growth and therefore resulted in the plants responding in reduced top growth. Main stem leaf stage was significantly affected by tillage on only one date in Bethany 1989-90 (Table XXII). Bethany 1990-91 had no significant differences in MSL among the four tillage treatments (Table XXIV).

Percent Tiller Formation (%TF)

Even though MSL was affected by tillage on Shellabarger 1990-91, percent tiller formation was not consistently affected at any location. Bethany 1989-90 and 1990-91 had no significant differences in percent tiller formation (Tables XXII and XXIV). Day 29 was the only measurement date on Shellabarger 1990-91 where differences were observed. No-till was significantly lower in %T3 formation as compared to the other three treatments (Table XXIII). Over all three locations tillage did not have a significant affect on percent tiller formation suggesting that there was no statistical difference among the four tillage systems in producing stress strong enough to effect tillering.

Heads per Square Meter

No-till was significantly higher than the three tilled treatments in heads per square meter on Bethany 1990-91 (Table XXV). Shellabarger 1990-91 had no significant differences among tillage treatments, although no-till tended to have less heads per square meter. This suggests that the soil moisture conserved on the no-till plots on Bethany 1990-91 may have increased the heads per square meter on the no-till and the differences in MSL early in the season on the Shellabarger did not influence the number of heads produced. This would be expected since it did not influence tiller production and the differences in soil strength and bulk density had disappeared by the time reproductive growth occurred. Heads per square meter were not obtained for Tabler and Bethany 1989-90.

Yields

Tabler 1989-90 and Bethany 1989-90 had no significant differences among tillage treatments for forage yield (Table XXVI). No-till forage yield on Bethany 1990-91 was significantly higher than the tilled treatments. Soil moisture for the no-till plots tended to be higher at preplant, although not significantly higher, for Bethany 1990-91 (Table XV) which could be why forage yields for no-till where higher.

Tabler 1989-90 had no significant differences among tillage treatments for grain yield (Table XXVII). No-till was significantly lower in grain yield at Shellabarger 1990-91 as compared to the three tilled treatments. This could be the result of the high soil strength readings taken prior to planting (Table XIV). No-till was significantly higher in grain yield at Bethany 1990-91. Again, this could be the result of the trend for higher soil moisture content for the no-till.

Test weight showed no significant differences among tillage treatments at Tabler 1989-90 and Shellabarger 1990-91 (Table XXVIII). No-till was significantly lower in test weight as compared to the three tilled treatments at Bethany 1990-91.

Conclusions

Compaction from grazing cattle can affect wheat growth or production (forage and grain) if soil moisture is limited and bulk densities are high enough to cause soil strengths high enough to reduce growth. Soil strengths in one out of four trials (Shellabarger 1990-91) on the no-till plots may have limited wheat forage and grain yields. Additionally, bulk densities at this location were within the range identified in previous reported research as crop growth limiting. Wheat plants in Shellabarger no-till plots had lower main stem leaf stages, forage and grain yields than in tilled treatments. These data support the hypothesis that soil compaction from grazing reduced crop growth and yield at this location.

Evidence supports that soil compaction has been the cause of limiting plant growth since other variables have been eliminated and soil strength and bulk density differences existed. Visual observations throughout the study indicated no differences existed in the four tillage treatments due to disease or insect damage. Nutrient requirements as stated in the materials and methods were adequately supplied so nutrient deficiences should not have been a growth limiting factor. Percent of the soil surface covered by crop residue after tillage was higher in the no-till plots at all locations, but was not considered to be a growth limiting factor as shown by the Bethany 1990-91 location where the no-till produced higher yields. Plant stand was higher in no-till plots at the Shellabarger 1990-91 location, but the no-till produced lower yields; whereas, plant stand was not different among treatments in the Bethany 1990-91 location and yields in the no-till plots were higher. Therefore, plant stand did not correlate with grain yield differences. This leaves soil compaction as the most likely variable which limited the growth of the wheat plants in the one trial where growth differences occurred.

Two variables existed between the Shellabarger site where plant growth was reduced in no-till plots and the other sites where no growth differences occurred. The Shellabarger site had the least rainfall from planting until reproductive development. This may have resulted in high soil strength limiting root growth. The second variable is soil texture. Shellabarger has the sandiest texture. From this study it cannot be concluded whether both texture and timing of rainfall are responsible for the growth limitation or if one is more important than the other.

The tillage practices used in this study effectively alleviated soil compaction resulting from grazing the previous wheat crop as a growth limiting factor. Even in the Shellabarger 1990-91 location, where no-tillage resulted in reduced growth, the chisel plow, which tilled the soil at only 15 cm deep, was effective in overcoming compaction as a plant growth limiting factor as indicated by main stem leaf measurements and yields.

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APPENDIX

TABLE I

LOCATIONS, PLANTING AND HARVEST DATES USED IN THE TILLAGE AND COMPACTION EVALUATIONS

Location	Year	Soil Series	Planting Date	Forage Clipping Date	Grain Harvest Date
I	1989-90	Tabler	September 7	November 9	June 11
II	1989-90	Bethany	September 7	November 9	-
III	1990-91	Shellabarger	September 25	-	May 29
IV	1990-91	Bethany	September 14	November 29	May 29

TABLE II

TILLAGE DEPTHS (cm) AT FOUR ENVIRONMENTS

Location	Chisel	Para Sub	Bent Sub
Tabler 1989-90	10-15	25-30	40
Bethany 1989-90	10-15	25-30	40
Shellabarger 1990-91	10-15	25-30	30
Bethany 1990-91	10-15	25-30	25

TABLE III

HERBICIDES APPLIED ACROSS ALL TILLAGE TREATMENTS

Herbicide	Location	Rate Applied*	Date Applied
Glyphosate +	I & II	504 g/ha	August 9, 1989
2,4-D		420 g/ha	
Chlorsulfuron +	I & II	13 g/ha	September 8, 1989
Metsulfuron Methyl		3 g/ha	
Ethiozin	I & II	560 g/ha	October 1, 1989
Metribuzin	III	560 g/ha	November 20, 1990
	IV	560 g/ha	November 5, 1990

* Rate Applied is the grams of active ingredient per hectare.

TABLE IV

PRECIPITATION RECEIVED DURING GROWING SEASONS AT HENNESSEY, OK.*

Month	Year	
	1989-90	1990-91
	-------- cm -------	
July	6.20	5.11
August	19.05	6.71
September	7.37	7.39
October	6.93	2.46
November	.15	3.94
December	.38	1.42
January	M	.56
February	9.60	.08
March	12.19	3.20
April	10.49	2.72
May	10.44	M
June	3.33	M

M = Data that is missing

* From (NOAA, 1989-1991)

TABLE V

PRETILLAGE SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN TABLER TILLAGE PLOTS 1989-90

Depth (cm)	Soil moisture % by weight	Bulk density $g\ cm^{-3}$	Soil strength kPa
0-3	13.8	1.25	895
3-6	15.7	1.47	1351
6-9	14.9	1.52	1654
9-12	14.7	1.50	1947
12-15	15.0	1.55	2101
15-18	15.9	1.57	2092
18-21	17.3	1.55	1957
21-24	18.8	1.57	1791
24-27	19.9	1.54	1659
27-30	20.8	1.56 c p	1573
30-33	21.6	1.54	1529
33-36	21.9	1.58	1523
36-39	22.1	1.56	1511
39-42	22.1	1.60	1478
42-45	21.9	1.59	1468

c Orthogonal contrast chisel significantly higher than other tilled treatments at the 0.05 probability level.

p Orthogonal contrast bent sub significantly lower than para sub at the 0.05 probability level.

TABLE VI

PRETILLAGE SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN BETHANY TILLAGE PLOTS 1989-90

Depth (cm)	Soil moisture % by weight	Bulk density g cm^{-3}	Soil strength kPa
0-3	13.2	1.32	1668
3-6	9.3	1.50	3296
6-9	9.2	1.50	4079
9-12	10.4	1.50	4257
12-15	11.1	1.54	4133
15-18	11.3	1.54	3899
18-21	12.6	1.61	3645
21-24	14.6	1.53	3254
24-27	16.3	1.57	2754
27-30	18.0	1.53	2357
30-33	18.6	1.54	2069
33-36	19.8	1.57	1910
36-39	20.2	1.57	1864
39-42	20.6	1.56	1832
42-45	21.2	1.52	1804

No significant differences based on F-test at 0.05 probability level.

TABLE VII

PRETILLAGE SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN SHELLABARGER TILLAGE PLOTS 1990-91

Depth (cm)	Soil moisture % by weight	Bulk density g cm^{-3}	Soil strength kPa
0-3	5.3	1.42	2406
3-6	7.1	1.54	3770
6-9	7.8	1.63	4339
9-12	8.7	1.62	4627
12-15	8.2	1.67 cc	4817
15-18	8.6	1.65	4961
18-21	8.3	1.61	5168
21-24	9.2	1.59	5346
24-27	10.5	1.55 n c	5358
27-30	11.0	1.50	5232
30-33	10.9	1.49	5033
33-36	11.1	1.47	4814
36-39	11.7	1.49	4625
39-42	10.7	1.52	4514
42-45	11.1	1.54	4456

c, cc Orthogonal contrast chisel significantly lower than para sub treatment at the 0.05 or 0.01 probability levels, respectively.

n Orthogonal contrast no-till significantly higher than tilled treatments at the 0.05 probability level.

TABLE VIII

PRETILLAGE SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN BETHANY TILLAGE PLOTS 1990-91

Depth (cm)	Soil moisture % by weight	Bulk density g cm^{-3}	Soil strength kPa
0-3	7.7	1.33	2224
3-6	9.8	1.48	3217
6-9	9.9	1.49	3912
9-12	9.0	1.52	4898
12-15	8.4	1.57	5969
15-18	8.2	1.60	6698
18-21	8.8	1.51	6958
21-24	10.2	1.52	7032
24-27	11.6	1.48	6996
27-30	12.0	1.50	6684
30-33	13.5	1.47	6203
33-36	14.5	1.51	5721
36-39	15.3	1.51	5258
39-42	15.9	1.50	4857
42-45	16.3	1.53	4660

No significant differences based on F-test at 0.05 probability level.

TABLE IX

PREPLANT SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN TABLER TILLAGE PLOTS 1989-90

Depth (cm)	Soil moisture % by weight		Bulk density $g\ cm^{-3}$		Soil strength kPa	
	No-till	Till	No-till	Till	No-till	Till
0-3	10.1	9.3 pp	1.61**	1.41	1351**	819
3-6	17.1	16.6	1.60	1.54	1482**	926
6-9	17.8	18.1	1.66*	1.57 +	1287**	914 +
9-12	18.4	18.7	1.68	1.59 +	1137	891 +
12-15	18.6	19.3	1.66	1.65 +	1078	850 +
15-18	19.1	19.7	1.72**	1.62 +	1089*	812 +
18-21	20.5	20.2	1.65	1.60	1072**	791 +
21-24	21.3	21.7	1.61	1.60	1109**	825 +
24-27	21.4	22.3	1.64	1.60 +	1200**	922 +
27-30	22.1	22.7	1.60	1.59	1248**	1019 +
30-33	23.7	22.8	1.62	1.61	1277	1089 +
33-36	23.7	22.7	1.56	1.59	1385	1152
36-39	24.0	22.8	1.57	1.59	1418	1224
39-42	24.0	23.0	1.53	1.58	1486	1281
42-45	23.7	23.3	1.65	1.62	1520	1291

pp Orthogonal contrast bent sub significantly higher than para sub treatment at the 0.01 probability level.

*, ** Orthogonal contrast no-till vs tilled treatments significant at the 0.05 or 0.01 probability levels, respectively.

+ Among tilled treatment differences were significantly different, see Tables X and XI for details.

TABLE X

ORTHOGONAL CONTRASTS FOR BULK DENSITIES IN TABLER TILLAGE PLOTS 1989-90

Depth (cm)	Orthogonal Contrasts					
	No-till	Till†	Chisel	Others‡	Para sub	Bent sub
0-3	1.61**	1.41	1.37	1.45	1.50	1.39
3-6	1.60	1.54	1.54	1.53	1.50	1.56
6-9	1.66*	1.57	1.58	1.57	1.52*	1.61
9-12	1.68	1.59	1.68*	1.55	1.50	1.60
12-15	1.66	1.65	1.76**	1.61	1.60	1.61
15-18	1.72**	1.62	1.67*	1.59	1.62	1.56
18-21	1.65	1.60	1.64	1.59	1.63	1.54
21-24	1.61	1.60	1.66	1.58	1.60	1.55
24-27	1.64	1.60	1.64*	1.59	1.64**	1.53
27-30	1.60	1.59	1.65	1.57	1.61	1.53
30-33	1.62	1.61	1.61	1.61	1.63	1.59
33-36	1.56	1.59	1.60	1.58	1.62	1.54
36-39	1.57	1.59	1.58	1.60	1.59	1.60
39-42	1.53	1.58	1.57	1.59	1.61	1.56
42-45	1.65	1.62	1.68	1.59	1.50	1.68

*, ** Orthogonal contrast significant at the 0.05 or 0.01 probability levels, respectively.

† Till is the average of chisel, para sub, and bent sub.

‡ Others is the average of para sub and bent sub.

TABLE XI

ORTHOGONAL CONTRASTS FOR SOIL STRENGTHS IN TABLER TILLAGE PLOTS 1989-90

Depth (cm)	Orthogonal Contrasts					
	No-till	Till†	Chisel	Others‡	Para sub	Bent sub
0-3	1351**	819	793	832	730	934
3-6	1482**	926	948	916	821	1010
6-9	1287**	914	1098*	822	782	862
9-12	1137	891	1178**	748	760	735
12-15	1078	850	1170**	691	750	631
15-18	1089*	812	1105**	665	772	558
18-21	1072**	791	1061**	656	789**	523
21-24	1109**	825	1070**	703	851**	554
24-27	1200**	922	1130**	819	986**	651
27-30	1248**	1019	1206**	925	1085**	765
30-33	1277	1089	1249*	1010	1150*	869
33-36	1385	1152	1288	1084	1215	953
36-39	1418	1224	1338	1168	1257	1079
39-42	1486	1281	1385	1229	1253	1205
42-45	1520	1291	1397	1238	1233	1243

*, ** Orthogonal contrast significant at the 0.05 or 0.01 probability levels, respectively.

† Till is the average of chisel, para sub, and bent sub.

‡ Others is the average of para sub and bent sub.

TABLE XII

PREPLANT SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN BETHANY TILLAGE PLOTS 1989-90

Depth (cm)	Soil moisture % by weight		Bulk density $g\ cm^{-3}$		Soil strength kPa	
	No-till	Till	No-till	Till	No-till	Till
0-3	7.3	8.2	1.60	1.51	1662**	797
3-6	11.2*	12.8	1.65**	1.55	1810**	989 +
6-9	12.5	13.7	1.64	1.64	1837**	1105 +
9-12	13.4	14.7	1.69*	1.58	1851**	1209 +
12-15	14.1	14.9	1.80	1.76	1837**	1310 +
15-18	14.6	15.6	1.72	1.67c pp	1797**	1386 +
18-21	15.1	15.8	1.72	1.65	1738**	1408 +
21-24	16.1	17.4	1.72	1.68	1610*	1381 +
24-27	17.4	18.1	1.70	1.67	1385	1276 +
27-30	18.4	19.3	1.59	1.58	1258	1198 +
30-33	19.2	19.7	1.66	1.64	1255	1210 +
33-36	19.7	20.3	1.66	1.62	1316	1250 +
36-39	19.9	20.8	1.61	1.60	1388	1308
39-42	21.9	20.9	1.57	1.59	1442	1382
42-45	22.2	21.0	1.69	1.72	1480	1400

*, ** Orthogonal contrast no-till vs tilled treatments significant at the 0.05 or 0.01 probability levels, respectively.

+ Among tilled treatment differences were significantly different, see Table XIII for details.

c Orthogonal contrast chisel significantly higher than other tillage treatments at the 0.05 probability level.

pp Orthogonal contrast bent sub significantly lower than para sub treatment at the 0.01 probability level.

TABLE XIII

ORTHOGONAL CONTRASTS FOR SOIL STRENGTHS
IN BETHANY TILLAGE PLOTS 1989-90

Depth (cm)	Orthogonal Contrasts					
	No-till	Till†	Chisel	Others‡	Para sub	Bent sub
0-3	1662*	797	827	782	748	816
3-6	1810**	989	1143*	913	951	874
6-9	1837**	1105	1441**	938	1075	800
9-12	1851**	1209	1692**	968	1157*	778
12-15	1837**	1310	1847	1042**	1288**	796
15-18	1797**	1386	1856**	1152	1455**	849
18-21	1738**	1408	1806**	1210	1565**	854
21-24	1610**	1381	1664**	1240	1530**	949
24-27	1385	1276	1444**	1192	1409**	975
27-30	1258	1198	1308*	1144	1365**	922
30-33	1255	1210	1292*	1169	1343**	995
33-36	1316	1250	1335	1208	1369**	1046
36-39	1388	1308	1387	1269	1413	1124
39-42	1442	1382	1435	1356	1469	1242
42-45	1480	1400	1416	1393	1514	1272

*, ** Orthogonal contast significant at the 0.05 or 0.01 probability levels, respectively.

† Till is the average of chisel, para sub, and bent sub.

‡ Others is the average of para sub and bent sub.

TABLE XIV

PREPLANT SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN SHELLABARGER TILLAGE PLOTS 1990-91

Depth (cm)	Soil moisture % by weight		Bulk density $g\ cm^{-3}$		Soil strength kPa	
	No-till	Till	No-till	Till	No-till	Till
0-3	11.3	10.8	1.51**	1.23	1404**	213
3-6	11.1	11.3	1.62	1.40	2144**	425
6-9	10.5	11.3	1.57	1.44	2698**	749
9-12	10.4*	11.2	1.63	1.54	3186**	1195
12-15	11.0	11.2	1.67	1.59	3436**	1621
15-18	10.7	11.2	1.71	1.67	3536**	1898
18-21	11.1	11.4	1.74**	1.57	3517**	2100
21-24	12.1	12.3	1.59	1.57	3461**	2204
24-27	12.8	14.0	1.57	1.53	3259*	2167
27-30	13.4	14.7	1.54	1.54	3066*	2050
30-33	13.6	14.6	1.55	1.51	2930*	1984
33-36	13.6	14.3	1.46	1.52	2844**	1971
36-39	13.2	14.1	1.47*	1.55 c	2858**	2025
39-42	13.1	14.0	1.52	1.54	2910**	2105
42-45	12.9	13.8	1.52	1.53	2725	2149

*, ** Orthogonal contrast no-till vs tilled treatments significant at the 0.05 or 0.01 probability levels, respectively.

c Orthogonal contrast chisel significantly higher than other tilled treatments at the 0.05 probability level.

TABLE XV

PREPLANT SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN BETHANY TILLAGE PLOTS 1990-91

Depth (cm)	Soil moisture % by weight		Bulk density $g\ cm^{-3}$		Soil strength kPa	
	No-till	Till	No-till	Till	No-till	Till
0-3	14.1**	10.0	1.26*	1.13 c	785**	131
3-6	13.9	12.4	1.47	1.26	1326**	310
6-9	14.2	12.5	1.59**	1.40	1674**	706
9-12	14.2**	12.0	1.55	1.48	1750	1235
12-15	14.4	12.0	1.53	1.53	1733	1686
15-18	14.7	12.4	1.51	1.50	1669	1986
18-21	14.8	13.3	1.52	1.52	1658	2137
21-24	16.4	14.4	1.50	1.46	1711	2287
24-27	17.8	15.6	1.49	1.47	1831	2517
27-30	18.6	16.0	1.50	1.46	2007	2656
30-33	18.9	17.0	1.46	1.58	2092	2705
33-36	19.2	17.3	1.48	1.50	2176	2711
36-39	19.4	17.7	1.50	1.49	2281	2696
39-42	18.5	17.9	1.51**	1.41	2398	2755
42-45	18.3	18.0	1.46	1.44	2516	2822

*, ** Orthogonal contrast no-till vs tilled treatments significant at the 0.05 or 0.01 probability levels, respectively.

c Orthogonal contrast chisel significantly higher than other tilled treatments at the 0.05 probability level.

TABLE XVI

POSTGRAZE SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN TABLER TILLAGE PLOTS 1989-90

Depth (cm)	Soil moisture % by weight		Bulk density $g\ cm^{-3}$		Soil strength kPa	
	No-till	Till	No-till	Till	No-till	Till
0-3	12.2	11.7	1.29	1.29	2259	2151
3-6	14.1	14.1	1.52	1.42	3901	3285
6-9	13.0	12.7	1.54	1.52	4721	4088
9-12	11.7	12.4	1.49	1.50	5101	4901
12-15	11.7	12.6	1.61	1.58	5358	5500
15-18	11.1	12.6	1.55	1.57	5573	5688
18-21	11.8	13.3	1.58	1.56	5694	5589
21-24	12.8	15.0	1.55	1.50	5611	5327
24-27	13.5	16.2	1.52	1.50	5225	5077
27-30	14.4	16.9	1.52	1.52	4789	4634
30-33	15.3	17.6	1.52	1.48	4412	4328
33-36	16.3	18.0	1.57	1.52	4118	4025
36-39	17.5	18.3 p	1.50	1.52	3880	4829
39-42	18.7	18.6	1.48	1.54	3664	3672
42-45	17.6	17.8	1.49	1.58	3515	3556

p Orthogonal contrast bent sub significantly lower than para sub treatment at the 0.05 probability level.

TABLE XVII

POSTGRAZE SOIL STRENGTH IN BETHANY TILLAGE PLOTS 1989-90

Depth (cm)	Soil strength kPa	
	No-till	Till
0-3	2859	3123
3-6	4466	4257
6-9	4777	4571
9-12	4969	5051
12-15	5334	5576
15-18	5719	5896
18-21	6168	6013 cc
21-24	6365	5896 cc
24-27	6019	5471
27-30	5444	5028
30-33	4806	4600
33-36	4250	4234
36-39	3847	3969
39-42	3617	3783
42-45	3449	3650

cc Orthogonal contrast chisel significantly higher than other tillage treatments at the 0.01 probability level.

TABLE XVIII

POSTGRAZE SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN SHELLABARGER TILLAGE PLOTS 1990-91

Depth (cm)	Soil moisture % by weight		Bulk density $g\ cm^{-3}$		Soil strength kPa	
	No-till	Till	No-till	Till	No-till	Till
0-3	5.9	5.8	1.39	1.39	1107	881
3-6	7.1	6.6	1.69*	1.60 p	2820*	2181
6-9	7.0	6.5	1.59	1.53	4448	3787
9-12	7.2	6.9	1.60	1.56	5298	4864
12-15	7.9	7.0	1.63	1.56	5507	5187
15-18	7.6	8.7	1.66	1.56	5472	5164
18-21	8.1	7.5	1.56	1.58	5357	5235cc
21-24	8.4	8.2	1.64	1.56	5203	5329
24-27	9.9	9.8	1.58	1.55	5146	5188
27-30	11.6	11.0	1.52	1.51	4845	4903
30-33	12.1	11.2	1.51	1.49	4268	4573
33-36	12.3	11.9	1.47	1.46	3784	4345
36-39	12.4	11.5	1.45	1.48	3490	4239
39-42	12.8	11.7	1.43	1.50	3438	4220
42-45	13.3	11.8	1.47	1.50	3434	4170

* Orthogonal contrast no-till vs tilled treatments significant at the 0.05 probability level.

p Orthogonal contrast bent sub significantly higher than other tillage treatments at the 0.05 probability level.

cc Orthogonal contrast chisel significantly higher than para sub treatment at the 0.01 probability level.

TABLE XIX

POSTGRAZE SOIL MOISTURE, BULK DENSITY, AND SOIL STRENGTH IN BETHANY TILLAGE PLOTS 1990-91

Depth (cm)	Soil moisture % by weight		Bulk density $g\ cm^{-3}$		Soil strength kPa	
	No-till	Till	No-till	Till	No-till	Till
0-3	4.4	4.4	1.45	1.36	1627**	979
3-6	6.4	6.3	1.61	1.58	3200**	2110
6-9	7.1	6.9	1.51	1.46	4771**	3473
9-12	7.3	7.1	1.51	1.55	5553*	4338
12-15	7.6	7.4	1.57	1.50	5707	4824 p
15-18	7.6	7.8	1.51	1.49	5574	5183
18-21	9.0	8.2	1.55	1.54	5545	5432
21-24	11.0	9.8	1.53	1.47	5447	5607
24-27	12.0	11.4	1.46	1.47	5178	5776
27-30	12.9	12.4	1.46	1.51	4788	5748
30-33	14.2	13.7	1.46	1.46	4424	5425
33-36	15.0	14.4	1.42	1.42	4163	4999
36-39	16.0	15.1	1.44	1.44 cc	3977	4705
39-42	16.4	15.7	1.47	1.47	3842	4540
42-45	16.5	16.1	1.51	1.50	3635	4371

*, ** Orthogonal contrast no-till vs tilled treatments significant at the 0.05 or 0.01 probability levels, respectively.

p Orthogonal contrast bent sub significantly lower than other tillage treatments at the 0.05 probability.

cc Orthogonal contrast chisel significantly lower than para sub treatment at the 0.01 probability.

TABLE XX

PERCENT GROUND COVER AFTER PRIMARY TILLAGE IN FOUR LOCATIONS*

	Location			
Tillage	Tabler 1989-90	Bethany 1989-90	Shellabarger 1990-91	Bethany 1990-91
No-till	93	88	92	93
Chisel	40	32	44	58
Para sub	47	59	60	60
Bent sub	64	61	78	75
LSD (0.05)	8	7	8	5

* From (Keklıkci, 1991)

TABLE XXI

TILLAGE EFFECTS ON FINAL PLANT STAND (Plt/m^2) AVERAGED OVER DRILLS*

	Location			
Tillage	Tabler 1989-90	Bethany 1989-90	Shellabarger 1990-91	Bethany 1990-91
No-till	124 c+	246a	234a	220a
Chisel	178 b	231a	210ab	218a
Para sub	176 b	228a	207 b	209a
Bent sub	214a	245a	203 b	205a

\+ Means within location with the same letter are not significantly different at the 0.05 level using Duncan's multiple range test.

* From (Keklikci, 1991)

TABLE XXII

MEAN VALUES FOR MSL, %T0, %T1, %T2, AND %T3
ACROSS FOUR TILLAGE TREATMENTS
FOR BETHANY 1989-90

Day	MSL	%T0	%T1	%T2	%T3
14	1.9				
16	2.3	1			
19	2.6	1	8		
28	4.5*	4	48	75	30
35	5.8	4	50	80	85
42	6.6	4	50	80	90
50	7.4	4	50	83	90

* Significant difference based on F-test at the 0.05 probability level with tillage treatment means for MSL being: No-till = 4.7
Chisel = 4.7
Para sub = 4.1
Bent sub = 4.4.

TABLE XXIII

MEAN VALUES FOR MSL, %T0, %T1 THROUGH %T6 ACROSS FOUR TILLAGE TREATMENTS FOR SHELLABARGER 1990-91

	MSL								
Day	No-till	Till	%T0	%T1	%T2	%T3	%T4	%T5	%T6
15	2.4*	2.5	4	4					
22	4.0**	4.3	4	99	86	3			
29	4.9*	5.3	4	99	86	71**†	2		
36	5.8	6.2	4	99	86	95	43		
45	6.4*	6.9	4	99	86	98	65	9	
52	7.4*	7.8	4	99	86	98	87	35	1
64	8.7**	9.1	4	99	86	98	89	49	16
79	9.1*	9.5	4	99	86	98	89	59	20

*, ** Orthogonal contrast no-till vs tilled treatments significant at the 0.05 or 0.01 probability levels, respectively.

† No-till had 39 %T3 vs tilled treatments which had 81 %T3.

TABLE XXIV

MEAN VALUES FOR MSL, %T0, %T1 THROUGH %T7 ACROSS FOUR TILLAGE TREATMENTS FOR BETHANY 1990-91

Day	MSL	%T0	%T1	%T2	%T3	%T4	%T5	%T6	%T7
21	4.2	8	90	75					
27	4.9	8	90	98	38				
34	6.1	8	90	98	98	25			
41	6.8	8	93	98	100	65	3		
48	7.5	8	93	98	100	65	3		
57	8.3	8	93	98	100	90	23	3	
64	9.1	8	93	98	100	90	43	8	1
76	10.1	8	93	98	100	90	45	10	1

No significant differences based on F-test at 0.05 probability level.

TABLE XXV

TILLAGE EFFECTS ON
HEADS PER SQUARE METER

	Location	
Tillage	Shellabarger 1990-91	Bethany 1990-91
	------- Heads m^{-2}	-------
No-till	235	209**
Chisel	267	174
Para Sub	308	180
Bent Sub	250	170

** Orthogonal contrast no-till vs tilled treatments significant at the 0.01 probability level.

TABLE XXVI

TILLAGE EFFECTS ON FORAGE YIELD

	Location		
Tillage	Tabler 1989-90	Bethany 1989-90	Bethany 1990-91
	------------ kg/ha ------------		
No-till	171	101	578**
Chisel	182	101	269
Para Sub	321	52	274
Bent Sub	303	93	333

** Orthogonal contrast no-till vs tilled treatments significant at the 0.01 probability level.

TABLE XXVII

TILLAGE EFFECTS ON GRAIN YIELD

Tillage	Location Tabler 1989-90	 Shellabarger 1990-91	 Bethany 1990-91
	-------------	kg/ha	---------------
No-till	1005	1607**	1064*
Chisel	1170	1988	791
Para Sub	1207	2072	750
Bent Sub	1205	1823	980

*, ** Orthogonal contrast no-till vs tilled treatments significant at the 0.05 or 0.01 probability levels, respectively.

TABLE XXVIII

TILLAGE EFFECTS ON TEST WEIGHT

Tillage	Location Tabler 1989-90	 Shellabarger 1990-91	 Bethany 1990-91
	--------------	kg cm^{-3}	--------------
No-till	782	781	756**
Chisel	779	785	769
Para Sub	770	794	767
Bent Sub	771	791	773

** Orthogonal contrast no-till vs tilled treatments significant at the 0.01 probability level.

VITA

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