SEEDLING DEVELOPMENT AND YIELD OF WINTER WHEAT UNDER LO-TILL AND CONVENTIONAL TILLAGE

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INTRODUCTION

The use of lo-till cultivation in winter wheat (*Triticum aestivum* L.) production may provide important advantages to the farmer. Lo-till requires fewer energy consuming tillage operations, which saves the farmer time and reduces his cultivation energy costs. Surface residue left by lo-till reduces wind and water erosion of topsoil. This surface residue aids in the conservation of moisture in the soil profile by reducing evaporation from the soil surface and by increasing water infiltration at the surface. In some regions, this increased conservation of soil moisture over dry summers may allow earlier planting in the fall.

The use of lo-till cultivation, however, can create a new set of production problems for the farmer. The crop residue left on the soil surface may harbor insects and diseases. Increased soil moisture can aid seed germination and plant establishment, but it can also provide a more favorable environment for some pathogens. Weeds that have been controlled through cultivation in the past now must be controlled with herbicides. Perhaps most important to the producer, yields from lo-till cultivation in Oklahoma have tended to be lower than yields obtained under conventional tillage.

The difference between conventional and lo-till cultivation is often most visually apparent during early plant growth and development. Early lo-till wheat stands may appear sparse and patchy. Later the plants may be able to compensate to some degree, but the effect of a poor beginning on final yields is unknown. It is possible that the lo-till plants are at a disadvantage during early growth and development, so much so that they are not able to fully compensate in latter stages of growth. In contrast, if water is the factor limiting growth, then the lo-till plants may receive better emergence and growing conditions.

The winter wheat cultivars that are presently used in production have been selected for conventional tillage management. Characteristics that might better enable plants to perform well under lo-till conditions have not been selected for; such traits may have been selected against. If there is a significant difference in the quality of the seedbed and early growth environment that is provided by the two tillage systems, then it may be feasible to select for plants that are more competitive under lo-till conditions. Lo-till might favor cultivars that can germinate at slightly lower temperatures, cultivars that are more resistant to pathogens favored under lo-till conditions, or cultivars with longer coleoptiles, cultivars that are better able to push through the straw residue on the surface. Whatever the adaptive mechanism, it may be possible to identify cultivars better suited to lo-till production.

Before selecting for superior early growth performance under lo-till conditions, it is more practical to determine whether there is in fact a significant difference in plant performance under the two tillage systems. Two techniques have been developed which could make it possible to quantify environmental influences on the early growth and development of winter wheat. First, the quality of the preemergent seedbed environment can be evaluated by comparing the plants' mainstem leaf stages (Klepper et al., 1982). Second, the relative level of environmental stress experienced by young plants may be examined by comparing the percent of plants that develop a specific tiller. The presence or absence of tillers indicates whether or not the wheat plant was subjected to significant stress during the tiller's time of development. These measurements have been utilized to compare the early growth environment provided by lo-till and conventional tillage systems (Wilkins, 1982).

The study of these two measurements, mainstem leaf stage and percent tiller formation, has been largely limited to one cultivar, Stephens, a soft white winter wheat that is grown in the Pacific Northwest. Before these measurements are applied to winter wheat cultivars grown in the Southern Great Plains, these measurements, and the assumptions on which they are based, need to be tested for the cultivars and environmental conditions common to this region. Accordingly, growth chamber experiments were designed to evaluate these measurements using 10 winter wheat cultivars grown in the Southern Great Plains; Stephens was included in the study for comparison with the original work done by Klepper et al. (1982). These cultivars were grown under environmental chamber conditions considered favorable for plant growth, to provide a "standard" for evaluating plant performance under less favorable conditions. Further growth chamber studies were designed to test these measurements on winter wheat cultivars grown under different moisture regimes.

Since there was little available information on the natural variation of these measurements under field conditions, plant samples were removed from an earlier study in order to determine an optimum sampling strategy. The measurements were then applied to a field study of 10 winter wheat cultivars grown under both conventional and lo-tillage systems, to determine if there were significant treatment effects or a significant cultivar x tillage environment interaction for these measurements. Yields and yield components obtained in this latter study were similarly analyzed.

The remainder of this thesis is divided into a comprehensive Literature Review and five self-contained sections. Each of these sections are separate and complete manuscripts that will be submitted to either the Agronomy Journal or Crop Science. The format of these manuscripts conforms to the appropriate journal's requirements. The manuscripts are followed by comprehensive Conclusions and References sections.

LITERATURE REVIEW

When winter wheat cultivars and tillage systems are compared, some measurement standard of plant performance must exist. Typically, the success of a crop has been measured in terms of its grain yield. Wheat yields obtained under lo-till cultivation have tended to be variable; lo-till yields are sometimes lower than yields obtained under conventional tillage (Knisel et al., 1961; Bond et al., 1971; Tucker et al., 1971; Bauer and Kucera, 1978), and sometimes the same or higher (Gates et al., 1981; Allan, 1982; Ciha, 1982). Yield reflects all the environmental factors that affect plant performance. Yield alone, however, is not an adequate measure of plant performance, since by itself it provides no clues as to why it is variable or if and when the plants were kept from reaching their maximum yield potential.

Wheat yields may be reduced by environmental stress. The nature and extent of yield reducing stress will be determined by the magnitude of the stress and the time in the plant's development that it occurs. Environmental stress in any of the morphological stages has the potential of severely reducing final yields (Salter and Goode 1967; Hsiao et al., 1976; Spiertz, 1978; Frank and Bauer, 1982). Water stress in the preemergent seedbed environment, for example, may reduce wheat germination, cause poor stands and shallow root development (Taylor and McCall, 1936; Nitty and Fitzpatrick, 1969).

Drought or temperature stress during tillering can reduce the number of tillers formed, thereby reducing photosynthetic surface area and the total number of wheat heads formed (Peterson et al., 1982; Eastham et al., 1984).

The choice of tillage system may affect the amount and timing of environmental stress. Lo-till cultivation can produce both beneficial and harmful effects. Because of higher moisture retention under lo-till cultivation (Greb et al., 1967; Smika and Wicks, 1968), lo-till should tend to provide for better germination and early root development (Finney and Knight, 1973; Ellis and Barnes, 1978; R.E. Phillips, 1981; Richard and Passioura, 1981). Increased moisture retention in the soil profile may be especially important in areas prone to severe drought. Increased soil moisture retention may allow earlier planting in such areas, allowing for better stand establishment and increased fall forage production.

Crop residue may increase rainfall infiltration into the soil profile; it may also trap snow cover during the winter months (Aase and Siddoway, 1980). Lo-till cultivation, however, does not increase water infiltration and storage in all environments (Black and Power, 1965; Cochran et al., 1982; Cox et al., 1986). In addition, environmental stresses induced by lo-till may so reduce plant development that the plants are not able to compensate for yield reducing stresses in later development (Chevalier and Ciha, 1986). Both the benefits and problems engendered by lo-till management may be dependent on the thickness and position of the straw residue (Papendick et al., 1973; Van Doren and Allmaras, 1978; Smika, 1983). The relative benefits of the two tillage systems may also be determined by a site's geographical and climatic conditions, such as the timing and amount of rainfall (Blevins et al., 1971; Izaurralde et al., 1986).

In addition to increasing soil moisture retention, straw residue may also reduce soil temperature (Aase and Siddoway, 1980). Straw residue acts as an insulating boundary; it has a higher reflectivity and lower thermal conductivity than the soil (M.D. Johnson and Lowery, 1985). Lo-till may also reduce soil temperatures by producing different thermal properties in the plow layer, compared to conventional tillage (Potter et al., 1985). Lower seedbed temperatures may slow germination and emergence of wheat planted in cooler weather, as in the later fall or early spring. Soil temperature may be lowered enough by straw residue that plant development is sufficiently hindered to reduce grain yields (Anderson and Russell, 1963). The amount and distribution of straw residue left on the surface will determine how much soil temperature is affected, and whether or not the effect will be great enough to influence yields (Black, 1970; Van Doren and Allmaras, 1978; Gauer et al., 1982).

Lo-till cultivation may cause additional problems. Straw cover may prevent adequate seed contact with the soil (Lynch et al., 1981; Izaurralde et al., 1986). The straw cover may also reduce light available to the emerging plants, reducing the chances of successful plant establishment (Rickman et al., 1985). Tillage systems also affect soil compaction and aeration (Power, et al., 1984), but the impact of these physical conditions of the soil on wheat development has not been conclusively resolved (Siddoway, 1963; vanOuwerkerk and Boone, 1970; Taylor, 1971).

The measurements of wheat yield components, such as seed weight, kernels per head, and heads per unit area, can provide some insight into the timing of yield limiting stress. Low seed weight indicates possible stress during grain filling. A low number of heads per meter row suggests stress during tillering and jointing. Yield components can reflect differences in the quality of the growth environment provided by different tillage systems. Ciha (1982) found, for spring wheat, that tillage environment did not significantly affect heads per unit area, or seeds per head, but that tillage did influence the number of spikelets per head and 100-seed weight. Allan (1982) found that wheat kernel weight decreased under conservation tillage.

Yield component measurements are not, however, definitive. Selecting to improve total wheat yields by increasing one of the yield components alone has proven disappointing in the past. Borojevic and Williams (1982) found significant correlations between yield components and final yields, but the relative contribution of each component varied greatly among cultivars. Increases in one yield component are often offset by reductions in the others (Knott and Talukdar, 1971; Gebeyehou et al., 1982; Frederick and Marshall, 1985).

Another measurement used to evaluate wheat performance is stand, the number of plants per unit area. Stand provides an insight into how many of the seeds developed into plants. Stand establishment may depend in part on genetically controlled plant characteristics (Allan, 1980). It may be that there are genetically controlled traits that make plants more vigorous in establishing plant stand under lo-till conditions, making it possible to select for these traits. Stand measurement, however, provides no information on uniformity of emergence; as a result, stand may be misleading in some cases. Under dry conditions, for example, a few seeds may germinate immediately while the rest lie dormant, germinating latter when water becomes available (Wilkins, 1982). In this case, genetic differences would be obscured by environmental variation. Stand will not indicate uneven developmental progress. An alternative is to monitor emergence daily until all plants are up, but this is not always easy to determine and it is time consuming.

Wheat plants can be evaluated in terms of the time it takes for the plant to reach the different morphological stages. A plant delayed during a morphological stage may have been stressed during that period. This too may prove misleading. Plants may not develop primarily in response to the passing of chronological time. Rather, plants may respond more to environmental factors, such as the accumulation of light or heat. If plants develop in response to accumulated heat, then it could be incorrect to simply compare plants based on the number of days required to reach a growth stage; it would be incorrect if the plants come from separate environments in which different amounts of heat were accumulated by the plants within those days.

If plants are developing in response to some environmental factor, such as light or heat, then these parameters could be measured directly. The amount of heat or light that is available in an environment could be measured. The relative quality of the growth environment could be evaluated on the basis of the level of the parameter that is provided. However, a plant-centered measurement of environmental stress is more useful than measurements of the environment itself (Klepper, 1984). Environmental measurements provide important standards of reference, but it is difficult to determine the exact physical environment experienced by each plant. Even when good environmental measurements are obtained, the plants' phenotypic response may be quite variable. (R.J. Baker et al., 1968; Campbell and Lafever, 1977; Chaudhary and Paroda, 1979).

Each of the measurements so far described provide some insight into plant performance, but each lacks the quality of measuring quantitatively the degree to which environmental stresses have hindered plant development. Several semi-quantitative systems for describing wheat development have been devised. These systems provide a numerical value to the different morphological stages. A popular example is the Feekes scale, but there are a number of variations (Large, 1954; Zadoks et al., 1974; Tottman and Makepeace, 1979). These systems, however, cannot be used for direct comparisons between plants, as these scales are not linear. That is, a value of "4" does not necessarily mean that a plant is twice as far along as one with a value of "2". As well, these measurements do not provide a quantitative reflection of environmental influences.

A more quantitative measurement of wheat development was devised by Haun (1973). Of 5 scales used in the Great Plains, Haun's scale has been found to be the most sensitive to changes in plant morphology (Bauer et al., 1983). Haun developed the use of main stem leaves (MSL) as units of measurement, units that develop in a linear response to accumulated heat. Klepper et al. (1982) combined Haun's scale with the labelling system developed by Jewiss (1972). Leaves are numbered in the order of their appearance (Fig. 1.). The first leaf is L1.

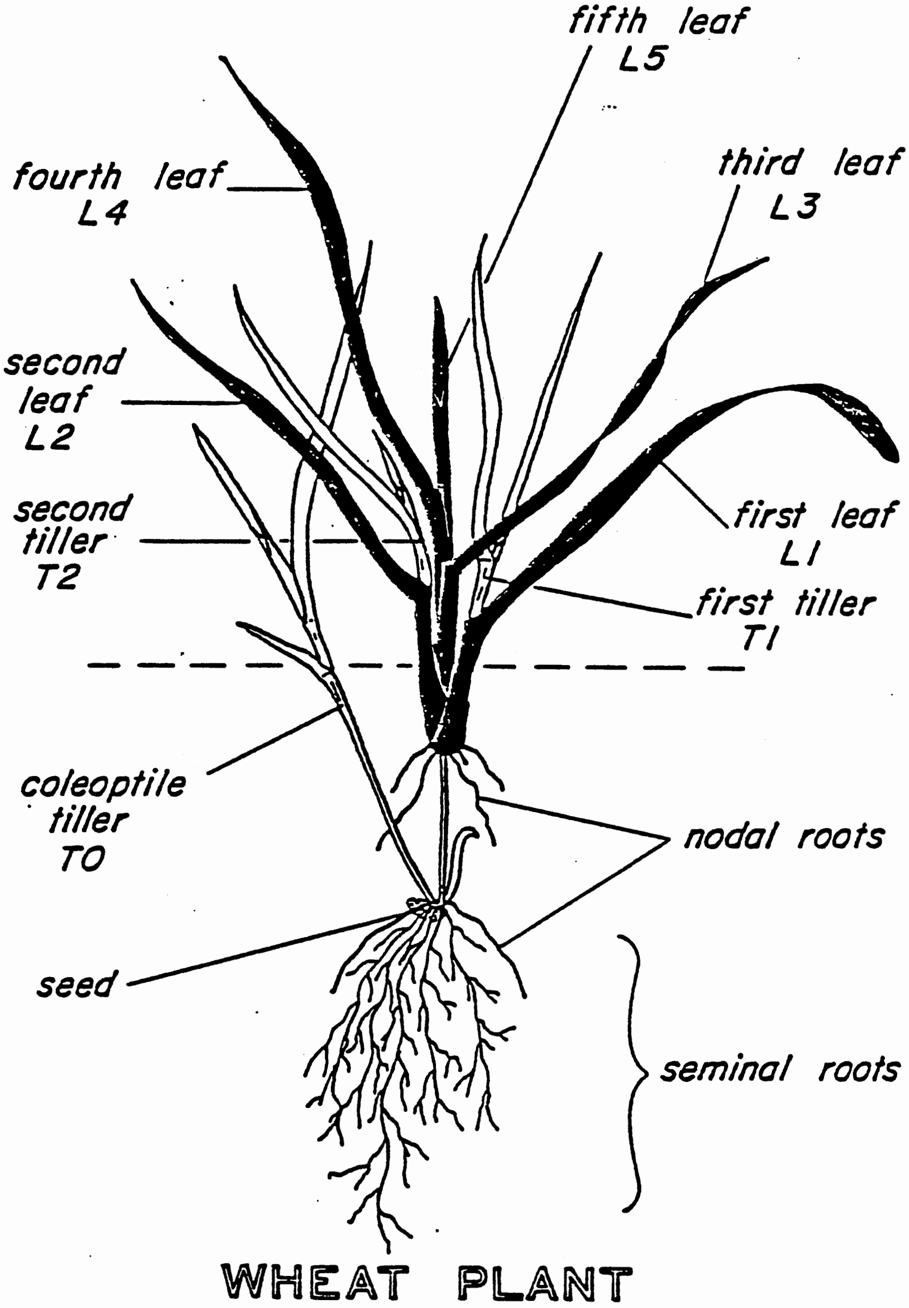

Figure 1. A well-developed wheat seedling showing the leaf and tiller identification system described by Klepper et al. (1982).

The second leaf (L2) emerges through the leaf sheath formed by L1, and so forth. The leaf that is in the process of emerging from the leaf sheath is measured as a decimal fraction of the antecedent fully emerged leaf. In Fig. 1., leaf five (L5) appears to be 4/10th the length of leaf four (L4). The MSL stage is therefore 4.4.

Since tillers form from axillary buds at the base of each leaf, the tillers are labelled according to the leaf base from which they arise (Fig. 1.). Tiller one (T1) emerges from the axillary bud at the base of leaf one (L1). The coleoptile tiller is labelled "T0" and forms from the bud at the base of the coleoptile.

Klepper's goal was to develop a plant measurement that would be precise in its determination of plant part and that would be linear (Klepper et al., 1982), so that a plant with a value of "5.0" would be known to be twice as far along as a plant with a value of "2.5". This requires that some aspect of plant growth must be shown to develop in a linear response to some known variable. Klepper's plant growth measurements, as Haun's, requires that the plants develop in a linear response to accumulated heat. Accumulated heat is thought by many to be the primary determinant of plant development (Bauer et al., 1984). The use of accumulated heat as a "clock" for measuring plant development has been criticized for not having a developed theoretical basis (Wang, 1960), but the relation of heat units to plant development has been empirically tested (Cross and Zadock, 1972; Bunting, 1976; Hay and Wilson, 1982; Nield, 1982). Other environmental factors may also influence the size and health of the main stem leaves (Klepper, 1984), but short of killing the plant, the appearance of MSL should be be linearly related to the heat accumulated (Fig. 2).

Accumulated heat is measured in "growing degree-days " (GDD):

$$GDD = \sum_{i=1}^{n} [(T_i max + T_i min)/2 - T_b)]$$

Where $T_i$max is the maximum daily temperature, $T_i$min is the daily minimum temperature and T_b is a minimum base temperature, below which growth does not occur. If $T_i$min is less than T_b, then T_b is utilized. Temperatures between 0 C and 4.6 C have been used as the base temperature. The base temperature is usually estimated by extrapolating from observed linear responses (J.T. Baker et al., 1986). Growth response is plotted on the y-axis against temperature on the x-axis. The observed line is extrapolated to its interception with the temperature axis. If response to accumulated heat is to be compared between experiments, the base temperature response needs to be consistent. Hay and Wilson (1982) suggest a base temperature of 0 C for leaf appearance and 2.5 C for leaf extension; Klepper et al. (1982) used a base temperature of 3 C; Nuttonson (1958) used 4.4 C; Davidson and Campbell (1983) calculated a base temperature of 4.6 C in growth chamber studies and 2.4 C under field conditions. A fair amount of support has been developed for the use of 0 C as a base temperature (Gallagher, 1979; Kemp and Blacklow, 1982; C.K. Baker and Gallagher, 1983; Bauer et al., 1984; J.T. Baker et al., 1986). Baker et al. (1986) observed that base temperature estimates fluctuated between -1.5 to +0.8 C, but these estimates were not significantly different from 0 C at the 5% level of confidence. Temperature measurements in these studies are often based on air temperature, Hay and Wilson (1982) suggest that the best linear relation between leaf

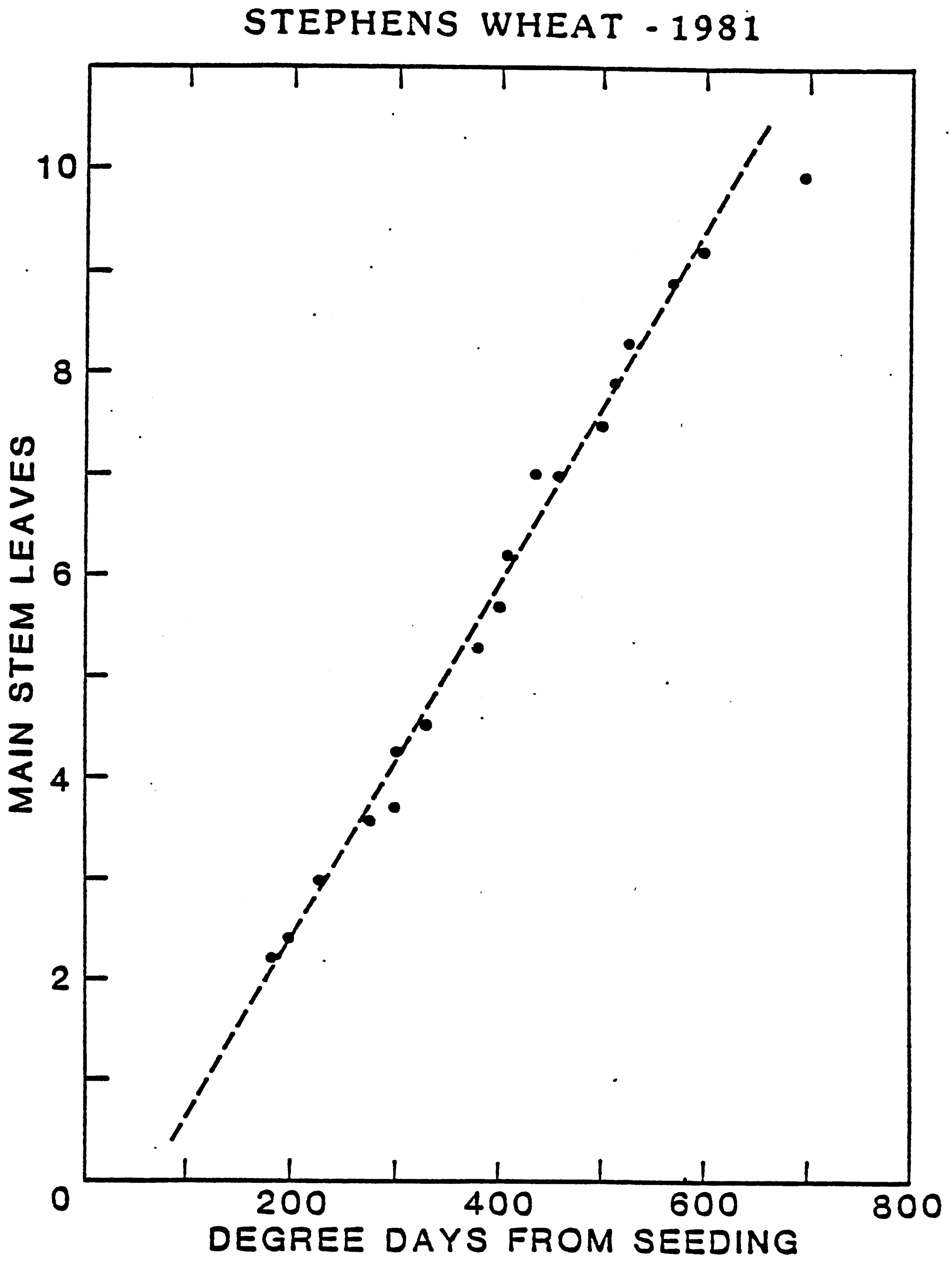

Figure 2. The appearance of leaves on wheat main stems as related to degree-days from seeding. (Klepper, 1984)

development and temperature is obtained by using the soil temperature near the depth of the growing point.

In measuring plant development, Klepper et al. (1982) use the concept of a "phyllochron", similar to that developed by Erickson and Michelini (1957) and later evaluated by Lamoreaux et al. (1978). A phyllochron interval (PI) is the developmental time it takes for the elongation of successive MSL, measured in GDD. The time, in GDD, that it takes to go from a Haun stage of 2.0 to 3.0 would be one phyllochron. A phyllochron, therefore, is the GDD per leaf, which is the inverse of the leaf appearance rate, leaves per GDD (Klepper et al., 1982). The lower the phyllochron value, the faster leaves are appearing. The use of GDD and phyllochrons to measure the timing of the morphological development of wheat has been tested (Klepper et al., 1982; J.T. Baker et al., 1986). Bauer et al. (1984) measured wheat growth from germination to anthesis, finding that GDD provided an excellent estimate of growth rate and growth stage.

Once wheat plants have emerged through the soil surface their development should be linearly related to GDD. A difference in MSL stage would have to correspond to a different time of emergence, since MSL develop at the same rate after emergence. Therefore MSL stage can be used as a tool to measure the quality of the preemergent seedbed environment. If seeds are planted at the same time and at the same depth in different treatment plots, and if the plants in one treatment plot are at a higher average MSL stage, then the plants with the higher MSL stage values had a faster rate of emergence. The plants with a faster rate of emergence had the better seedbed environment.

In addition to measuring MSL stage per plant, MSL can also be summed per meter of row, which incorporates both a measure of rate of emergence with a measure of stand (Wilkins et al., 1982).

If MSL appearance is linearly related to heat accumulated, then all plants seeded at the same time in the same treatment environment will be at the same leaf stage of development, within the range of natural variation. The greater the "spread" of MSL stage values, the more uneven the seedbed environment. Accordingly, MSL leaf measurements can also measure the uniformity of a defined treatment seedbed.

Klepper and associates have studied these measurements primarily using one wheat cultivar, Stephens, in the northwestern United States. They did not determine the degree to which wheat cultivars respond to accumulated heat at different rates. Bagga and Rawson (1977) found that even very similar wheat cultivars develop quite differently, when grown in a uniformly heated environment. Significant cultivar difference have been demonstrated for emergence, coleoptile length and stand establishment (Helmerick and Pfeifer, 1954; Burleigh et al., 1965; Bacaltchuk and Ulrich, 1983). R.J. Baker and Gebeyeheu (1982) observe cultivar differences in the timing and amount of leaf area formation. Bauer et al. (1984) found that spring wheat cultivars had different PI. Until demonstrated, there should not be the assumption that MSL appearance will be uniform across cultivars. A comparison of MSL stage among wheat cultivars might reflect only cultivar, rather than seedbed differences.

Despite the assertions make by Klepper et al. (1982), there has not yet been an adequate demonstration that the linear growth response to accumulated heat holds up under all possible environmental conditions. Klepper and her associates found that the rate of incident photosynthetically active radiation (PAR) did affect MSL appearance rates (Rickman et al., 1985). Other environmental parameters could have similar impacts. The amount of available moisture, for example, might have a significant impact on MSL appearance. General plant development has been shown to halt, even under very moderate water deficits (Angus and Moncur, 1977). Dehydration stress has been shown to reduce leaf initiation rates (Gates, 1968; Clough and Milthorpe, 1975), as well as leaf expansion rates (Boyer, 1968; Acevedo et al., 1971, Watts, 1974). In fact, in the earlier work that led to the development of Haun's measurements, predictive equations of leaf development included moisture and light components (Higgins et al., 1964; Lewis and Haun, 1971). If other environmental factors do affect MSL appearance, contrary to the claims made by Klepper et al. (1982), then MSL stage may reflect the overall quality of the growth environment up to the time of measurement, rather than the quality of the preemergent seedbed environment alone.

Bauer et al. (1984) found that soil water level did not effect MSL appearance, though it did affect tiller formation. However, J.T. Baker et al. (1986) observed a reduction in phyllochron length in plants known to have received less water, meaning that reducing available moisture increased the rate at which MSL appear! Water deficits have been shown to increase canopy temperatures for a wide range of species (Walker and Hatfield, 1979; Idso et al., 1981; Chaudhuri and Kanemasu, 1982). It has been further observed that dehydration causes stomatal closure and reduced transpiration, which leads to higher leaf and canopy temperatures (Slatyer, 1969; Carlson et al., 1972; Ehrler et al., 1978;). Accordingly, J.T. Baker et al. (1986) suggest that water deficits may have induced higher canopy temperatures in the stressed plants, resulting in their higher rate of growth. Contrary to the findings of J.T. Baker et al., however, Leong and Ong (1983) observed a faster rate of leaf appearance in irrigated groundnut (Arachis hypogaea L.) plants, compared with nonirrigated plants that had received less water. It is possible that moisture treatment has a direct effect on wheat MSL appearance, apart from a secondary temperature effect on the plant canopy. In young plants, before the canopy effect has developed, such a moisture treatment effect might be isolated.

Other environmental factors might also affect MSL appearance. The response rate to accumulated heat may itself be affected by the rate at which daylength changes (C.K. Baker et al., 1980; Hay and Wilson, 1982; C.K. Baker and Gallagher, 1983). At high temperatures, as observed by Bauer et al. (1984), a linear growth response to heat may not be maintained. Bauer et al. (1984) found that higher R^2 were obtained when $T_i$max values were restricted to 21 C. J.T. Baker introduced a ceiling temperature of 30 C into the calculation of GDD. Maximum daily temperatures above 30 C were entered into the equation as being 30 C. Regrettably, J.T. Baker et al. (1986) provide no explanation for their choice of a ceiling temperature. If the growth response is not linear at high temperatures, such as those that occur in the southern Great Plains, then MSL stage will not provide the desired linear quantitative measurement scale. MSL development under high temperatures, therefore, needs to be examined to determine if there should be a "ceiling temperature" in the calculation of accumulated heat, and what this ceiling temperature should be.

If MSL appearance proves not to be linear, under definable conditions, the measurement can still be used. Parameters can be defined, within which the measurements are known to be true. For environmental factors such as available moisture, the amount or lack of moisture necessary to affect MSL appearance could be determined. In addition, the response of MSL appearance at different levels of stress could be established. Parameters within which a linear response occurs could be determined and standard curves for the nonlinear portions could be obtained.

In addition to using MSL stage as a measure of plant growth, Klepper et al. (1982) proposed that the percentage of plants that develop a specific tiller indicates if there was environmental stress at the time that tiller was forming. Whether or not an axillary bud develops into a tiller is determined by many factors, including the wheat cultivar, seed size, moisture, soil conditions, planting depth, temperature and irradiance (Percival, 1921; Avery, 1930; McCall, 1934; Taylor and McCall. 1936; Webb and Stephens, 1936; Rawson, 1971; Klepper et al., 1982; Peterson et al., 1982). If the wheat plant is subjected to significant stress during formation of early tillers, then these tillers may not develop. According to Rickman et al. (1983), tillers develop in response to accumulated heat in a fairly fixed sequence. Figure 3 shows the development of leaves and tillers in phyllochron units, showing the "time window" within which a tiller will appear.

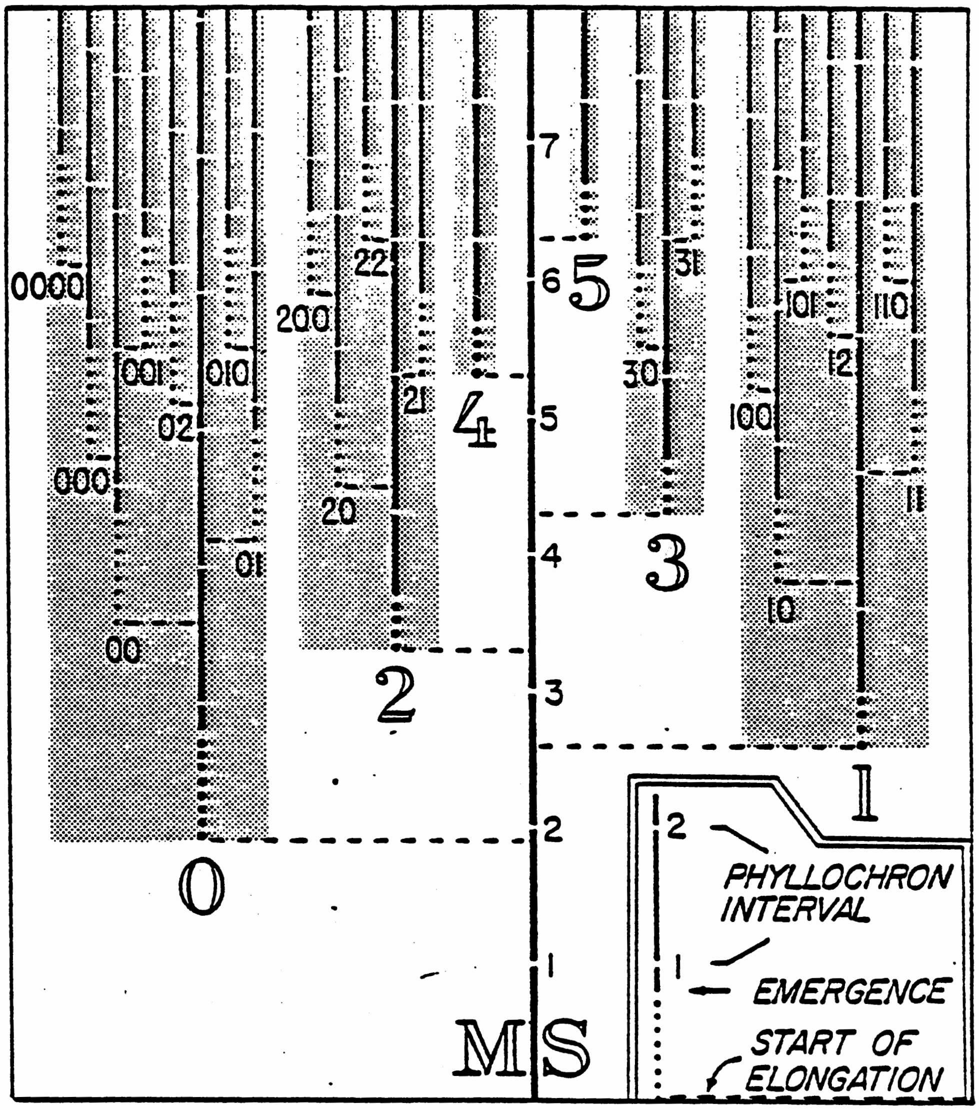

Figure 3 The relationship of leaf and tiller development on unstressed wheat plants. (Each bar represents one phyllochron. The dotted lines show time when the tiller leaves have started enlargement but are not yet visible above the leaf sheath.)
(Klepper, 1984)

A tiller that has not formed, due to environmental stress, may appear a little late if the stress is removed, but after a developmental time window has passed, the tillers will not form at all (Rickman and Klepper, 1984). For example, reduced levels of incident PAR have been shown to reduce tiller formation (Rickman et al., 1985). Similarly, tiller formation has been reduced by lower temperatures (Smika and Ellis, 1971) and water deficits (Stark and Longley, 1986). The absence of a particular tiller, therefore, indicates that stress was present during that developmental time window. There has not been an adequate demonstration, however, what percent of each of these tillers form under favorable conditions, when there is no known stress to the plants. Without knowing the percent tiller formation (%TF) that occurs in the absence of any known stress, it is not possible to determine how much stress has reduced tiller formation in a poor environment. As well, it is not known if there are cultivar differences in the %TF that would form under favorable conditions.

The coleoptile tiller (TO) may not yield as well as the other tillers (Rawson, 1971). Cultivars less likely to form TO, or which are less likely to form TO under stress conditions, may actually produce higher yields since assimilates are kept for higher yielding tillers.

Wilkins et al. (1982) applied both of these measurements, MSL stage and %TF, in a study evaluating tillage and planting system effects on winter wheat development. For the planting treatments, PTO, MSL stage per plant and MSL per meter row had an observed significance level (OSL) of 8.7%, 8.4% and less than 0.1%

respectively. Tillage environments were differentiated with an OSL of 8.2% for MSL stage per plant and 2.8% for the sum of MSL per meter row. Wilkins et al. (1982) conducted their study with only two replications; an increase in the number of replications used could reduce the OSL to the desired 5% level or less for all of the measurements cited. In a related study, Wilkins et al. (1984) found that reduced temperatures and PAR resulted in reduced tiller formation under lo-till compared with conventional tillage.

If MSL stage and %TF are used to demonstrate differences between tillage treatments, then the measured differences between treatments must be larger than the natural variation between plants within a treatment. However, for MSL stage and %TF, there is little information on the error variance, the variation among plants that are treated alike. If the natural variation is high, then the sampling strategy should be designed to minimize random sampling error (Hendricks, 1951). To reduce experimental error, either a larger number of plant samples may be required to detect a treatment difference, or an efficient sampling strategy must be devised that reduces the error variance.

Estimates of error variance, coefficients of variation and treatment x environment interactions can be used to devise a sampling strategy with a high probability of detecting treatment differences (Carter et al., 1983). Before collecting plants to evaluate MSL stage and %TF, samples should be studied to determine the variance of these measurements within uniform treatment units, within experimental units, so that an optimum sampling strategy can be devised.

To estimate variance components in a multiple classification, the mean squares in the standard analysis of variance can be utilized (Crump, 1951). Expected mean square values are calculated and set equal to the observed mean squares. The resulting equation is then solved for the variance components, these calculated variance components are then used as the estimated variance components. In general, the variance of variance components is sufficiently unaffected by non-normality to allow their use as estimates (Kelleher et al., 1958). However, estimates of sampling variance components within experimental units does assume conformity with normal distribution theory. It is therefore prudent to examine the normality and homogeneity of variances throughout the experimental material (Comstock and Robinson, 1951). Confidence limits can then be devised for the variance component estimates.

As demonstrated by Cochran and Cox (1957), a sampling strategy can be developed to detect treatment population differences at a chosen level of significance. The experimenter chooses δ, the chosen level of difference between treatments that is to be detected. In the case of MSL, the choice would be to decide how much of a MSL stage difference between tillage treatments will indicate a significant treatment difference. The experimenter also chooses 'p', the required probability of detecting the desired difference if it exists. As discussed by Geng and Hills (1978), it is then necessary to estimate the standard deviation per unit (s), and the t-values associated with Type I (t_1) and Type II (t_2) errors. T_2 is the tabulated t for probability 2(1 - p). The sample size per treatment (n) can be found by solving the following equation:

$$n \geqq 2\ (s/\delta)^2\ (t_1 + t_2)^2$$

The number of replications needed to detect a significant treatment difference can be calculated with the same basic formula; replace number (n) with replications (r) and replace s with C, the true standard error per plot measured as a percent of the mean (Hatheway, 1958) The tabulated Student t value will depend on the degrees of freedom of the sample size that is to be determined, so this solution requires a trial and error iterative process until the smallest n is identified that satisfies the equation (Geng and Hills, 1978). Alternatively, the F distribution for a measurement can be determined, and power function charts or curves can be generated (Tang, 1938; Pearson and Hartly, 1951). In more elaborate tests of optimum sampling, the same initial logic is followed. The experimenter must choose both δ , the size of difference to be detected, and the acceptable levels of making Type I and Type II errors (Steel and Torrie, 1980).

MSL appearance and %TF measurements may reveal a significant difference in the quality of the early growth environment that is provided to wheat plants by different tillage practices. Plants could then be selected on the basis of their relative ability to perform well in early growth and development under lo-till management, as measured by MSL and %TF. Chevalier and Ciha (1986) observed differences in spring wheat cultivars in MSL stage and %TF, which suggests the possibility of cultivar differences in winter wheat.

Cultivar x tillage interaction for MSL and %TF would indicate the potential for developing a selection program based on these measurements. The importance of identifying genotype x environment interactions for potential breeding programs has been well discussed

(Comstock and Moll, 1963; Matzinger, 1963; Allard and Bradshaw, 1964; Abou-El-Fittouh et al., 1969). The variance components that relate to genotype x location, genotype x year, and genotype x location x year interaction can be combined with estimates of the genetic and error components of variance to calculate the heritability ratio (R.J. Baker et al., 1968). Heritability indicates how much of the observed plant responses to treatment differences will respond to selection.

If plant measurements respond differently among cultivars across environments, then the trait's correspondence to grain yields can be evaluated (Borojevic and Williams, 1982). Significant correlations between high MSL and %TF values should be demonstrated before embarking on a selection program that uses these measurements. As demonstrated by R.J. Baker and Gebeyeheu (1982), in their study of harvest index as a selection tool, a significant treatment effect on the selection measurement does not necessarily correspond to selection for higher yield, under all conditions. Moreover, genotype x environment interaction for yields is often high enough to obscure small increases in yield (R.J. Baker, 1969; Campbell and Lafever, 1977; Brennan and Byth, 1979). The genotype x tillage environment interactions for MSL and %TF have not yet been determined; as with yield, interactions may be large enough to obscure treatment differences. Ideally, cultivar x tillage interaction for yield and yield components could be positively correlated with a similar interaction for the young plant measurements.

MSL and %TF, with some refining and testing, may reveal if and when wheat plants are kept from reaching their full development potential under lo-till management. If these measurements can be shown to be valid under the conditions common to the Southern Great Plains, if some cultivars can be shown to do perform better than others within the lo-till growth environment compared to conventional tillage, and if this higher plant performance can be correlated with higher yield performance, then a necessary first step will have been taken on the road to developing higher yielding lo-till cultivars.

PART I

MAINSTEM LEAF DEVELOPMENT AND TILLER FORMATION FOR WINTER WHEAT CULTIVARS GROWN IN A CONTROLLED ENVIRONMENT

MAINSTEM LEAF DEVELOPMENT AND TILLER FORMATION FOR WINTER WHEAT CULTIVARS GROWN IN A CONTROLLED ENVIRONMENT[1]

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ABSTRACT

Mainstem leaf (MSL) stage and percent tiller formation (%TF) are measurements that have been used to evaluate the development of wheat (Triticum aestivum L.); the study of these measurements has been limited to several cultivars. This study was conducted to determine whether there are significant differences for these measurements among cultivars commonly grown in the Southern Great Plains. Ten hard red winter wheat cultivars were raised in a growth chamber to determine their rate of MSL appearance and the %TF of the coleoptile (T0), first (T1), second (T2) and third tillers (T3) when the plants are grown in

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the absence of any known stress. The growth chamber was set to a 12 hr day at 25 C and a 12 hr night at 15 C. Light intensity within the chamber averaged about 500 mol $m^{-2}s^{-1}$ photosynthetic photon flux density. Relative humidity averaged 80%. Formation of T0 was quite variable, cultivar differences were not significant. There were significant differences among cultivars for the percent of plants producing T1 and T2. However, all but one of the cultivars formed 90 - 100% of T1, T2 and T3. For the cultivars studied, %TF of T0 may be too variable for detection of treatment differences. For the remaining tillers, less that 90% formation may indicate some level of environmental or treatment stress during tiller formation. There were highly significant differences among cultivars for the MSL leaf stage at 700 growing degree-days and for the number of growing degree-days required per leaf. Experimenters may need to determine the response of MSL appearance to accumulated heat for their specific cultivars before comparing MSL stages across cultivars.

Additional index words: Phyllochron, Phenology, Wheat morphology, Haun scale, *Triticum aestivum* L., Growing degree-days.

INTRODUCTION

Plant measurements have been developed to evaluate the quality of the germination and growth environment provided to winter wheat, Triticum aestivum L. (Klepper et al. 1982; Wilkins et al., 1982; Rickman et al., 1983). Mainstem leaf (MSL) stage is used as a measure of the quality of the preemergent seedbed environment and percent tiller formation (%TF) is used as a measure of the amount of stress experienced during early plant development.

Mainstem leaf stage is based on the labelling system suggested by Haun (1973). Mainstem leaves are numbered according to their order of appearance. The MSL that is in the process of emergence is measured as a decimal fraction of the antecedent fully emerged leaf (illustrated in Klepper et al., 1982). Tillers are labelled according to the leaf with which they are associated. The first tiller (T1) arises from the axillary bud at the base of leaf 1, and so forth. The coleoptile tiller (T0) develops from the coleoptile node.

Klepper et al. (1982) proposed that stress will delay a tiller's appearance. If the stress is sufficient, the tiller will not form at all. The percent of plants with a specific tiller can be used as a measure of the presence or absence of environmental stress during the appropriate time period in the plant's development (Peterson et al., 1982; Rickman et al. 1983). The work done by Klepper and her associates has been largely limited to a soft white winter wheat, Stephens, grown in the Northwestern United States. The first objective of this study is to evaluate %TF for cultivars adapted to the Southern Great Plains, to determine the percent of plants that will form these tillers in the absence of known stress and to establish whether there are cultivar differences.

The use of MSL stage as a measure of the preemergent seedbed environment is based on the observation that mainstem leaves appear in a linear response to accumulated heat (Klepper et al., 1982; Bauer et al., 1984). Accumulated heat is measured in growing degree-days (GDD):

$$GDD = \sum_{i=1}^{n} [(T_i max + T_i min)/2 - T_b]$$

Where $T_i$max is the maximum daily temperature, $T_i$min is the daily minimum temperature and T_b is a minimum base temperature, below which growth does not occur. If $T_i$min is less than T_b, then T_b is utilized. The number of GDD required to complete a MSL stage is called a "phyllochron". A phyllochron interval (PI) is the developmental time it takes for the elongation of successive mainstem leaves, measured in GDD. Phyllochron interval, therefore, measures the GDD required per leaf; the lower the PI value, the faster leaves are appearing. The use of GDD and PI to measure the timing of the morphological development of wheat has been tested (Klepper et al., 1982; J.T. Baker et al., 1986). Bauer et al. (1984) measured spring wheat growth from germination to anthesis, finding that GDD provided an excellent estimate of growth rate and growth stage for spring wheat. Tillers have been shown to develop synchronous with MSL development (Klepper et al., 1982), making it possible to estimate tiller number and leaf stage using MSL stage.

It has been proposed that after a wheat plant emerges from the soil, environmental stress does not influence the rate at which MSL appear, except when appearance ceases altogether under severe stress (Klepper et al., 1982). Mainstem leaf stage may therefore be utilized to measure the quality of the preemergent seedbed environment; in a uniform planting, a plant that reached a higher MSL stage would have emerged earlier than others. Assuming a uniform planting depth, the plants that emerged first would have had the better seedbed environment.

As with %TF, it is necessary to determine whether the observations of MSL development are valid for cultivars grown in the Southern Great Plains, before application of the measurements in the Southern Plains. Cultivars may develop mainstem leaves at different rates. The final objective is to determine if hard red winter wheat cultivars respond differently to accumulated heat.

MATERIALS AND METHODS

Ten hard red winter wheat (Triticum aestivum L.) cultivars were grown in an environmental growth chamber using a randomized complete block design. There were 5 replications within the growth chamber. Within each replication each cultivar was represented by one plant. A border row of plants surrounded the studied cultivars. The entire growth chamber experiment was executed twice.

The ten hard red winter wheat cultivars are adapted to the Southern Great Plains: Chisholm, Mustang, Newton, Osage, Payne, Probrand 835, TAM 105, TAM W-101, Triumph 64 and Vona. These cultivars were chosen to represent a range of plant traits, with particular attention to cultivars that represent a wide range of average plant heights. Stephens, a soft white winter wheat, was included for comparison with the earlier work by Klepper et al. (1982).

The plants were seeded and grown in diatomateous earth in plastic pots, 0.11m wide at the top by 0.14m deep, with a soil volume of approximately $1.33 \times 10^{-3} m^{3}$. Seeds were planted at a depth of 30mm, at a rate of 3 seeds per pot and were thinned to one plant per pot before the plants reached a leaf stage of 1.0.

The growth chamber was set to a 12 hr day at 25 C and a 12 hr night at 15 C. At these temperatures, with a T_b of 0 C, 20 GDD accumulated per day. Light intensity within the chamber averaged about 500 μmol $m^{-2}s^{-1}$ photosynthetic photon flux density. Light was provided by a combination of SHO "cool white" 110-W florescent lamps and 60-W lamps. Relative humidity averaged 80%.

Nutrients were provided by watering with Peter's solution, a commercial greenhouse fertilizer, at a rate of 1.25 g Peter's per liter H_2O (Total N 20%, 5.61% nitrate N, 3.96% ammoniacal N, 10.43% Urea N; available phosphoric acid (P_2O_5) 20%; soluble potash (K_2O) 20%). The pots were watered to capacity with the nutrient solution before planting; after planting, the pots were watered to capacity with solution approximately once every three days.

The MSL stage of the plants was recorded every two days. The presence or absence of the coleoptile, first and second tillers was noted. The plants were allowed to reach a MSL stage of about 6.0, at 700 GDD, allowing ample time for the formation of the tillers studied.

Analysis of variance (ANOVA) and regression were run using PC SAS 6.0. ANOVA was run on the %TF for T0, T1, T2 and T3. Since %TF generates binomial data, tillers are either present or absent, the data was transformed using the arcsine of the square root of %TF (Steel and Torrie, 1980); tiller formation was averaged across replications to generate the %TF values that were then transformed. ANOVA was also run on the transformed values. ANOVA was run on MSL stage at the end of the experiments, at 700 GDD. To determine PI, GDD were regressed against MSL stage for each plant. In Klepper's system, after a plant has reached a MSL stage of 1.0, a leaf that is emerging is measured as a decimal fraction of its antecedent leaf. Partial emergence before reaching a MSL stage of 1.0 is difficult to estimate, since there is no antecedent leaf for comparison. Accordingly, only MSL values greater than or equal to 1.0 were included in the regression. The regression slope estimates, the GDD per leaf, were then analyzed with ANOVA, to determine if there were significant differences in PI among cultivars.

RESULTS AND DISCUSSION

The %TF of T0, T1, T2 and T3 is shown in Table 1. There were no significant ($P < .05$) cultivar interactions between the two executions of the experiment for %TF, except for %T2. The significant execution x cultivar interaction of %T2 was due to variations in tiller formation between executions for TAM W-101 and Osage. These variations did not change their relative ranking of ninth and tenth, respectively, in each of the executions.

The greatest differences among cultivars for %TF occurred with T0, cultivars ranged from 0% to 50% tiller formation. Klepper et al. (1982) report %T0 values ranging from 0% to 75% in different growth environments. In the study by Peterson et al. (1982) of environmental influences on the coleoptile tiller, %T0 values ranged from 0% - 100%, depending on seed weight, irradiance and planting density. Wilkins et al. (1982) obtained %T0 values ranging from 4.5% - 20.6% under different planting and tillage systems, with observed significant levels (OSL) of 8.7% and 33.6% respectively. Despite the relatively large cultivar differences in %T0 in this study, there were no significant differences among cultivars. This was likely because of the sporadic formation of this tiller among replications of the same cultivar and the accordingly large experimental error. The transformed %T0 also failed to show a significant cultivar effect but the transformed values showed an OSL of 7.6% compared to 9.2% in the nontransformed %T0. The potential sensitivity of this tiller to indicate treatment differences may be obscured by its variability, as indicated by the remarkably high CV shown in Table 1. In order to reduce the experimental error associated with this measurement, larger numbers of plant samples may be required.

For growth chamber studies, Klepper et al. (1982) reported values ranging from 75% -100% tiller formation for T1 and 100% for T2 and T3. Reported values were lower under field conditions. Wilkins et al. (1982) observed %T1 values ranging from 52.7% -88.0% under field conditions. In this study, for most of the cultivars, 100% of the plants formed the remaining tillers: T1, T2 and T3. However, TAM W-101 and Newton formed 90% of T1; TAM W-101 formed 90% of T2. Osage performed relatively poorly, and had a significantly lower %TF than all of the other cultivars. Osage formed only 40% of T1, 80% of T2 and 40% of T3. Osage's low %T3 might be associated with a relatively low MSL stage at the end of the experiment (Table 2). The tiller may not have had an adequate chance to develop given the cultivar's relatively delayed morphological state. However, at an average MSL stage of 5.26, most of the plants should have had a chance to develop this tiller, unless Osage develops later than the basic pattern of tiller and mainstem development described by Klepper et al. (1982).

With the exception of Osage, cultivars did not show a difference in the formation of T1, T2 and T3. These tillers did not show the variability of T0 and therefore might be more usable in detecting environmental effects; however, reduced variability may be associated with reduced sensitivity to treatment differences. The transformed values for T1, T2 and T3 showed exactly the same responses as the nontransformed values.

The MSL stage means of the cultivars at the end of the experiments, at 700 GDD, are shown in Table 2. There were significant MSL stage differences between executions of the experiment, but there was no significant execution x cultivar interaction. There were highly significant ($P < 0.01$) differences among cultivars. Mainstem leaf stage means ranged from a high of 6.39, for TAM W-101, to a low of 5.26 for Osage. However, the next lowest mean MSL stage was 5.93, for Vona; therefore, most of the cultivars were within half a leaf stage at 700 GDD. When the recently emerged plants were thinned to 1 plant per pot, selection was made so that all plants were very near a MSL stage of 1.0, so that cultivar differences in emergence was not being measured. Only Osage was significantly slow in emergence, so that it was behind the other cultivars when thinning took place. The differences in the MSL stage of the remaining cultivars at 700 GDD suggests the cultivars respond to accumulated heat at different rates.

The R^2 obtained by regressing GDD against MSL stage for each cultivar was consistent with the values obtained by Bauer et al., 1984. Except for Osage, each of the of the cultivars had an R^2 between 0.95 - 0.98; Osage had an R^2 of 0.93. The PI estimates generated by the regression showed a highly significant difference between executions and highly significant execution x cultivar interaction. Accordingly, the cultivar PI means are shown separately for each execution (Table 2). Baker et al. (1986) observed PI of 106 - 115 under nonirrigated field conditions. In these experiments, there were highly significant differences among cultivars. There are changes in the relative ranking of cultivars between executions of the experiments; however, most of these changes are shifts of only one or two positions in rank. The most dramatic differences between executions were associated with Osage and Newton, both of which showed much lower PI in the second execution of the experiment.

Statistically significant cultivar differences in MSL response to accumulated heat detected in a growth chamber study may not be practically meaningful for field studies. If Osage and Vona are not considered, the PI values in the first execution ranged from a high of 106.14 to a low of 96.68, with a difference of 9.46. In the second execution, the difference between the highest PI (100.3) and the lowest (90.56) was 9.74. Newton showed the highest difference between executions, 10.25 , Stephens showed a difference of 8.71, the rest of the cultivars were within 3 - 4 PI. If the PI values are translated into their inverse form, leaves per GDD, these values have more obvious meaning. A difference of 100.3 and 96.68 PI, as occurred in the first execution, is equivalent to the difference of 0.0099 MSL/GDD and 0.0103 MSL/GDD, or an absolute difference of 0.00044 MSL/GDD. At this rate, 1000 GDD would be required to observe a MSL stage difference of 0.4, which corresponds with the observed differences in MSL stage in this study. A difference of 0.4 MSL stage among cultivars could obscure treatment differences. This variance among cultivars could have a greater effect if MSL stage values obtained for one cultivar are used to extrapolate the timing of tiller formation or tiller leaf stage values of other cultivars.

It was hoped that the model of mainstem and tiller development worked out by Klepper and her associates with Stephens could be applied to a number of cultivars. In this study, small but significant differences are shown to exist among cultivars in the response of mainstem leaves to accumulated heat. Seven of the hard red winter wheat cultivars showed relative uniformity in PI, among each other and among executions. Three of the hard red winter wheat cultivars (Osage, Vona, and Newton) were relatively variable in PI. The model developed by Klepper and her associates is certainly usable; however, depending on the precision that is required, experimenters may need to test the response of mainstem leaves to accumulated heat for their particular cultivars and environments before extrapolating other plant development measurements on the basis of MSL stage.

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Table 1. Winter wheat cultivars' percent tiller formation for the coleoptile (%T0), first (%T1), second (%T2) and third (%T3) tillers, averaged over 5 replications and 2 executions of the experiment.

	Percent Tiller Formation			
Cultivar	%T0	%T1	%T2	%T3
Chisholm	10 a+	100 a	100 a	100 a
Mustang	46 a	100 a	100 a	100 a
Newton	30 a	90 a	100 a	100 a
Osage	20 a	40 b	80 a	40 b
Payne	20 a	100 a	100 a	100 a
Probrand 835	50 a	100 a	100 a	100 a
TAM 105	0 a	100 a	100 a	100 a
TAM W-101	20 a	90 a	90 a	100 a
Triumph 64	17 a	100 a	100 a	100 a
Vona	0 a	100 a	100 a	100 a
Stephens	10 a	100 a	100 a	100 a
CV, %	188.9	18.7	12.5	11.8

+ Means within a column followed by the same letter do not differ significantly at the 0.05 level of probability, based on Duncan's Multiple Range Test.

Table 2. Winter wheat cultivars' mainstem leaf (MSL) stage (averaged over 5 replications and two executions) and phyllochron interval (PI) (averaged over 5 replications).

	MSL Stage	PI	
Cultivar	at 700 GDD	Execution 1	Execution 2
Chisholm	6.23 ab+	100.66 b	95.02 abc
Mustang	6.05 bcd	103.10 b	98.22 ab
Newton	6.20 abc	100.78 b	90.56 c
Osage	5.26 e	126.11 a	94.30 abc
Payne	6.34 a	96.68 b	93.35 bc
Probrand 835	6.35 a	97.66 b	94.92 abc
TAM 105	5.98 cd	104.99 b	97.96 ab
TAM W-101	6.39 a	97.78 b	94.10 abc
Triumph 64	6.23 ab	97.86 b	95.35 abc
Vona	5.93 d	117.47 a	100.30 a
Stephens	6.04 bcd	106.14 b	97.43 ab
CV, %	3.62	7.82	4.38

+ Means within a column followed by the same letter do not differ significantly at the 0.05 level of probability, based on Duncan's Multiple Range Test.

PART II

MOISTURE TREATMENT EFFECTS ON WINTER WHEAT MAINSTEM LEAF APPEARANCE AND TILLER FORMATION

MOISTURE TREATMENT EFFECTS ON WINTER WHEAT MAINSTEM LEAF APPEARANCE AND TILLER FORMATION[1]

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ABSTRACT

Mainstem leaf (MSL) stage and percent tiller formation (%TF) are measurements that have been used to evaluate the development of wheat (<u>Triticum aestivum</u> L.). The use of MSL stage is based on the assumption that the linear relation of leaf appearance to accumulated heat is unaffected by other environmental parameters. In this study, young wheat plants were subjected to different watering regimes to determine: (i) if differences in available moisture affects the linear response of leaf appearance to accumulated heat, measured in growing

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degree-days (GDD); (ii) if the chosen moisture treatments induced a difference in %TF; and (iii), whether these moisture treatments affected the timing of tiller appearance. Four winter wheat cultivars were raised in a growth chamber under two moisture treatments. Measurements were taken of MSL appearance, and %TF and appearance of the coleoptile (T0), first (T1), second (T2) and third tillers (T3). The growth chamber was set to a 12 hr day at 25 C and a 12 hr night at 15 C. Light intensity within the chamber averaged about 500 mol $m^{-2}s^{-1}$ photosynthetic photon flux density. Relative humidity averaged 80%. Once plants reached a mainstem leaf stage of 1.0, plants were subjected to either a low moisture (LM) or high moisture (HM) treatment. Leaf psychrometer thermocouple readings taken at the end of the experiment showed significant leaf water potential differences: LM plants averaged -607.4 kPa and HM plants averaged -286.9 kPA. At the end of the experiment, the average MSL stage of the LM plants (5.5) was significantly lower than the average MSL stage of the HM plants (6.2). The LM plants required a significantly higher average number of GDD per leaf (101.9), compared to 86.9 GDD per leaf for the HM plants. Moisture treatment did not significantly effect the linearity of the MSL appearance response to accumulated GDD. Moisture treatment significantly affected %TF for T0: the HM plants formed 45.7% compared to 0% for the LM plants. Moisture treatment did not significantly affect %TF of T1, T2 or T3; however, the number of GDD required for appearance of these tillers was significantly increased under the LM treatment. Moisture treatment did not significantly influence the MSL stage at which each tiller appeared. Tiller appearance was therefore delayed in terms of

GDD, but not in terms of the morphological stage of the plant. It appears that MSL measurements made on individual plants, or within a uniform environment, may be safely used to extrapolate tiller leaf stage. However, since moisture treatment as well as accumulated heat affects the rate of MSL appearance, MSL stage may reflect more of the overall quality of the plants' growth environment up to the time of measurement, rather than the pre-emergent seedbed environment alone as previously suggested.

Additional index words: Phyllochron, Phenology, Wheat morphology, Haun scale, *Triticum aestivum* L., Growing degree-days.

INTRODUCTION

In winter wheat (Triticum aestivum L.) production, the choice between lo-till or conventional tillage may significantly affect the quality of the plants' early growth environment. Measurements developed by Klepper et al. (1982) have been used to evaluate the effect of tillage on germination and plant development; mainstem leaf (MSL) stage is used as a measure of the quality of the preemergent seedbed environment and percent tiller (%TF) formation is used as a measure of the amount of stress experienced during early plant development (Klepper et al. 1982; Wilkins et al., 1982).

Mainstem leaf (MSL) stage is based on the labelling system suggested by Haun (1973). Mainstem leaves have been observed to appear in a linear response to accumulated heat, measured in growing degree-days (GDD) (Klepper et al., 1982; Bauer et al., 1984). The number of GDD required to complete a MSL stage is called a phyllochron. A phyllochron interval (PI) is the developmental time it takes for the elongation of successive mainstem leaves, the GDD per leaf. The use of GDD and PI to measure the timing of the morphological development of wheat has been tested (Klepper et al., 1982; Bauer et al., 1984; J.T. Baker et al., 1986).

It has been proposed that after a wheat plant emerges from the soil, environmental stress does not influence the rate at which mainstem leaves appear, except when appearance ceases altogether under severe stress (Klepper et al., 1982). Mainstem leaf stage may therefore be utilized to measure the quality of the preemergent seedbed environment; in a uniform planting, a plant that reached a higher MSL stage would have emerged earlier than others, given that leaf appearance proceeds at a constant linear rate after emergence. Assuming a uniform planting depth, the plants that emerged first would have had the better seedbed environment.

The linear growth response to accumulated heat has not been tested under a broad range of environmental conditions. The rate of incident photosynthetically active radiation (PAR) does affect MSL appearance rates (Rickman et al., 1985). Other environmental parameters, such as the amount of available moisture, could have similar effects.

Bauer et al. (1984) found that soil water level did not affect MSL appearance, though it did affect tiller formation. However, J.T. Baker et al. (1986) observed a reduction in PI in plants receiving less water, meaning that reduced moisture availability actually increased the rate at which MSL appear. They suggest that dehydration stress may have induced higher canopy temperatures, resulting in a higher rate of growth. However, Leong and Ong (1983) observed a faster rate of leaf appearance in irrigated groundnut (Arachis hypogaea L.) plants, compared with nonirrigated plants. It is possible, that reduced moisture availability has a direct effect on wheat MSL appearance, apart from a secondary temperature effect on the plant canopy. In young plants, before the canopy effect has developed, such a moisture effect might be isolated. If other environmental factors do affect MSL appearance, then MSL stage may reflect the overall quality of the growth environment up to the time of measurement, rather than the quality of the preemergent seedbed environment alone.

In addition to using MSL stage as a measure of plant growth, Klepper et al. (1982) proposed that tiller formation can indicate stress in the plant environment. If a wheat plant is subjected to significant stress during initiation of a tiller, then the tiller's appearance may be delayed. If the stress is sufficient, the tiller will not form at all. The percent of plants with a specific tiller can therefore be used as a measure of the presence or absence of environmental stress during the appropriate time period in the plants' development (Peterson et al., 1982; Rickman et al. 1983).

Both of these plant measurements, MSL and %TF, have potential as tools for evaluating the relative quality of the growth environments provided by different tillage systems (Wilkins, 1982). However, it was not known whether the linear response of MSL to accumulated heat would be maintained under the environmental extremes common to the Southern Great Plains. Since lo-till and conventional tillage may provide different levels of soil moisture to developing plants, it is especially important to determine if moisture does affect the linear response of MSL to GDD, if MSL stage is to be used to evaluate the seedbed quality of these tillage regimes. In this experiment, four cultivars were subjected to two watering regimes to determine whether moisture treatment could effect MSL appearance, PI, %TF and the timing of appearance of early tillers.

MATERIALS AND METHODS

Winter wheat plants were grown in an environmental growth chamber using a randomized complete block design with a split-plot layout. Four cultivars made up the main unit treatments. Two watering regimes made up the subunits, consisting of a high moisture (HM) and a low moisture (LM) treatment. One plant was grown per pot. There were seven replications within the experiment, the entire experiment was executed twice, with rerandomization of the treatments with the second run of the experiment.

The cultivars that made up the main unit treatment were Chisholm, TAM W-101, TAM 105 and Stephens. The first three are popular hard red winter wheat cultivars commonly grown in the Southern Great Plains. Stephens, a soft white winter wheat, was included for comparison with the earlier work by Klepper et al. (1982).

The growth chamber was set to a 12 hr day at 25 C and a 12 hr night at 15 C. With these temperatures and using a base temperature of 0 C, 20 GDD accumulated per day. Light intensity within the chamber averaged about 500 μmol $m^{-2}s^{-1}$ photosynthetic photon flux density. Light was provided by a combination of SHO "cool white" 110-W florescent lamps and 60-W lamps. Relative humidity averaged 80%.

The plants were seeded and grown in diatomateous earth in plastic pots, 0.11m wide at the top by 0.14m deep, with a soil volume of approximately 1.33 x $10^{-3}m^{3}$. Seeds were planted at a depth of 30mm, at a rate of 3 seeds per pot and were thinned to one plant per pot before the plants reached a leaf stage of 1.0.

Nutrients were provided with Osmocote (14/14/14), a commercial greenhouse slow release fertilizer in solid pellet form, at a rate of 10 g per pot. The Osmocote was thoroughly mixed into the diatomite planting medium. A slow release solid fertilizer was utilized in order to minimize confounding between the amount of moisture and nutrients provided. If nutrients were provided in a watering medium then plants receiving more moisture would also receive more nutrients. With the solid nutrients already added, the better watered plants may still have greater access to nutrients, but the level of confounding is more comparable to the conditions that would exist under normal field conditions. The pots were watered to capacity before planting, after which they were kept moist by watering to capacity approximately once every three days.

Once the plants reached a leaf stage of 1.0, the HM plant-pots continued to be well watered as before. Watering of the LM plant-pots ceased until the plants reached visible wilting. The LM plant-pots were then watered to capacity once; the plants were allowed to dry until visibly wilting a second time. The experiment was terminated at the end of the second cycle, at which time the relative effects of the moisture treatments were evaluated using leaf-cutter psychrometer thermocouples, similar to those described by Brown (1976). Psychrometer samples were excised from the last leaf to fully emerge; the 24 mm^2 leaf samples discs were cut near the longitudinal and lateral center of the leaf and sealed in the psychrometer's volume chamber.

Throughout the experiment the MSL stage and the %TF of the coleoptile (T0), first (T1) and second (T2) tillers were monitored to determine the number of GDD required to reach emergence and each succeeding leaf stage. The MSL stage at the end of each of the two moisture treatment cycles was also recorded.

Analysis of variance (ANOVA) and regression were run using SAS 5.0 on an IBM 3081K mainframe and PC SAS 6.0. ANOVA was run on the MSL stage at the end of the first and second cycles and on the leaf water potentials. The PI of each plant's mainstem was calculated by regressing GDD against MSL stage; the regression coefficient estimates were used as the PI (GDD per leaf) for each plant. ANOVA was run on these calculated PI.

A treatment difference in plant PI would indicate a different response rate of MSL to GDD, but would not indicate when plant development was significantly affected. ANOVA was therefore run on the GDD required to reach each successive MSL stage. Moisture treatment could effect the rate at which mainstem leaves respond to accumulated heat; or, after an initial effect on MSL response to GDD, the plants might adjust to the moisture treatment and regain their original response rate (Eastham, et al., 1984). The number of GDD to complete each phyllochron interval was calculated. Phyllochron interval 2 (PI2) was determined to be the number of GDD required for the plant to develop from a MSL stage of 1.0 to 2.0, and so forth. ANOVA was run on the PI of each stage, to determine whether the effect of moisture treatment on the response of MSL stage to accumulated heat changed through the course of the plants' development. To test the linearity of GDD required for MSL formation under each moisture treatment, MSL stage was treated as an additional split-plot, with MSL stage as the sub-subunit within the moisture subunit.

The percent of plants that formed T0, T1, T2 and T3 was evaluated using ANOVA for each tiller. Since %TF generates binomial data, tillers are either present or absent, the data was transformed using the arcsine of the square root of %TF (Steel and Torrie, 1980); tiller formation was averaged across replications to generate the %TF values that were then transformed. ANOVA was also run on the transformed values. Since moisture treatment could significantly delay tiller appearance, the number of GDD required for each tiller to appear was also analyzed. If moisture treatment reduces the rate of MSL appearance, a delay in tiller appearance may be due to a delay in the total morphological development of the plant, rather than an independent delay of the tiller. Since plant development was evaluated on the GDD required to reach each MSL stage, there was no direct measurement of the MSL stage at the time each tiller appeared. However, the number of GDD that had passed at the time of each tiller's emergence was recorded. Linear interpolation between the GDD required to reach each of the recorded MSL stages can be utilized to estimate the MSL stage at the time of tiller emergence. ANOVA was run on the estimated MSL stage at the time of tiller emergence.

RESULTS AND DISCUSSION

Moisture treatment had a highly significant ($P < 0.01$) effect on MSL appearance (Table 1). By the end of the first cycle, the LM plants showed a highly significant reduction in MSL stage; the MSL stage of the LM plants was 3.9, the HM plants had a MSL stage of 4.4. Mainstem leaf measurements made at the end of the first and second cycles showed the same responses: cultivar and moisture treatments were significant ($P < 0.05$) or highly significant; there were no significant interactions. The highly significant cultivar response was due to one cultivar, TAM 105, which reached a significantly lower MSL stage than the other cultivars. The MSL stages at the end of the second cycle are shown in Table 1, averaged over cultivars, replications and executions of the experiment.

Leaf water potentials (LWP) taken at the end of the second cycle (Table 1) were significantly lower in the LM plants. Moisture treatment means are averaged over cultivars, replications and executions, as there were no significant interactions for these variables. The leaf water potential of the LM plants (-607.4 kPa) indicates only a mild water deficit (Eastham et al., 1984). Visually, all of the plants appeared healthy with only a slight wilting. Stephens had a significantly ($P < 0.05$) lower leaf water potential than all other cultivars. This cultivar difference in leaf water potential did not correspond with a reduced cultivar MSL stage.

An R^2 of 0.959 was obtained for the HM plants and 0.962 for the LM plants when GDD were regressed against MSL stage; these results are consistent with the work done by Klepper et al. (1982) and Bauer et al. (1984). The PI, the regression coefficients of GDD regressed against MSL, are shown in Table 1. The slope representing the GDD required per MSL for the LM plants is significantly higher than that of the HM plants.

The observed PI values for the LM plants correspond with the report by Bauer et al. (1984) that approximately 100 GDD per leaf were required under normal field conditions. Baker et al. (1986) observed PI values of 106 - 115 GDD under nonirrigated field conditions, significantly lower than values of 113 - 126 GDD observed under irrigated conditions. In their study, lower moisture conditions were associated with an increase in the response of mainstem leaves to accumulated heat. Their estimates of PI were based on MSL stage measurements made up until the flag leaf ligule appeared. They suggest that reduced moisture may have induced higher canopy temperatures, which in turn caused the higher rate of MSL appearance. In this study, measurements were made on wheat plants that did not surpass a MSL stage of 6.0. The results of this study suggest that moisture treatment can have an independent and direct effect on the response of mainstem leaves to accumulated heat, opposite to that of the induced temperature effect observed in latter development.

To determine when the effects of moisture treatment on MSL leaf appearance became significant, the number of GDD required to reach successive MSL stages were evaluated, shown in Table 2. The plants designated for HM treatment required more GDD from seeding to reach MSL stage 1.0, though the difference was not significant. This means that the designated HM plants were behind the designated LM plants when the moisture treatments were initiated at stage 1.0. After watering was reduced, the LM plants slowed in MSL appearance and the LM plants required a greater number of GDD to reach 2.0, though the difference was still not significant. The LM plants required a significantly greater total number of GDD to reach stage 3.0, a difference that persisted through stages 4.0 and 5.0. Many of the LM plants did not reach MSL stage 6.0. Cultivar x moisture treatment interactions were significant in MSL stage 4.0 and 5.0, but these interactions reflect only minor changes in magnitude, rather than any change in relative ranking of cultivars or moisture treatment.

Cultivars did not show a significant difference in the GDD accumulated to reach emergence, but there was a highly significant cultivar effect in the number of GDD required to reach MSL stage 1.0 and successive stages. TAM 105 required a significantly higher number of GDD than the other cultivars to reach each MSL stage. Differences among the other cultivars were present in MSL stages 1.0 and 2.0, but these differences were not significant by MSL stage 3.0 or following stages.

The LM plants required a significantly higher number of GDD to reach MSL stage 3.0, and succeeding stages (Table 2). This does not indicate, however, if the LM plants' MSL response to GDD continued to fall below that of the HM plants, or if the response rate leveled off as the plants adjusted to the moisture treatments. The number of GDD required to go from one MSL stage to the next, the PI for each leaf stage, was measured directly. The average PI for each stage was 87.3 in the HM plants and 101.5 in the LM plants. There was a highly significant moisture effect by PI2, with the LM plants taking 11 more GDD than the HM plants. The significant moisture effect was maintained through PI3 and PI4, as the difference between the LM and HM plants increased from 17 to 25 GDD. However, by PI5, the difference between the moisture treatments dropped to a nonsignificant difference of 4 GDD. This response suggests an initial moisture treatment effect on PI, that is later overcome as the plant adjusts; or, it may simply reflect a delayed growth response to the watering at the end of the first cycle. In either case, moisture treatment effected a difference in PI from one stage to the next.

The analysis of GDD as a subunit within moisture treatment showed significant moisture x leaf stage interaction for the linear, quadratic and cubic components. Analysis was therefore run for each moisture treatment separately. Even though the LM plants required progressively more GDD to complete each MSL stage through PI4, this difference was not sufficient to show a significant departure from linearity. Moisture treatment did effect the rate at which mainstem leaves respond to accumulated heat, but moisture treatment did not significantly effect the linearity of the response as the plants went through varying levels of moisture availability.

The percent of plants that formed the coleoptile (%TO), first (%T1), second (%T2) and third (%T3) tillers is shown in Table 3. the transformed %TF values showed the same trends as the nontransformed data; only the nontransformed data will be discussed. The observed %TF was consistent with the range of results reported in earlier work (Klepper et al., 1982; Peterson et al., 1982, Wilkins et al., 1982; Rickman et al., 1983). The LM plants had significantly fewer TO. There was no significant moisture treatment effect on %T1, %T2 or %T3. The coleoptile tiller was therefore the most sensitive to moisture treatment, consistent with the work done by Klepper et al. (1982). These results, like the leaf water potential measurements, suggests some moisture effect, given the difference in T0, but not a severe effect, as seen by the lack of a moisture effect in the percent of plants forming the other tillers.

There was a significant cultivar effect for %T0 and %T1. Chisholm formed 35.7% T0 and TAM W-101 formed 21.5% T0, both significantly higher than the 7.1% T0 formed by the remaining cultivars. Stephens formed a significantly lower %T1 (89.3%) than all of the other cultivars, each of which formed 100% T1.

While the percent of plants that formed T1, T2 and T3 was not significantly affected by moisture treatment, there was a highly significant moisture effect on the GDD required for tiller appearance (Table 4). There was a highly significant cultivar effect for T1, T2 and T3. TAM 105 required a significantly higher number of GDD for each tiller to appear.

Estimated MSL stage at tiller appearance is shown in Table 5. Estimated MSL stage for appearance of T1 and T2 were not significantly affected by moisture treatment. Reduced watering reduced the MSL stage at which T3 appeared, though only slightly. Klepper et al. (1982) found that stress can delay the production of a tiller relative to the phyllochron "window" within which it will develop. In these experiments, reduced watering delayed tiller appearance measured in GDD; however, reduced watering did not significantly delay tiller appearance in relation to MSL stage. It appears, therefore, that tillers continue to appear synchronous with MSL development, even under different moisture treatments.

CONCLUSIONS

The effects of moisture treatment on plant MSL appearance, as observed in this study, suggest that moisture treatments can effect the rate at which mainstem leaves respond to accumulated heat, separate from the secondary effects of increased canopy temperatures, suggested by Baker et al. (1986). Moisture treatment was shown to significantly effect MSL stage, leaf water potential and PI. Accordingly, MSL stage may not measure the preemergent seedbed environment alone, as has been previously suggested. Mainstem leaf stage can still be used to compare the growth environments provided by different tillage systems, but it reflects the overall environment up to the time of measurement, rather than just the preemergent seedbed environment. The effect of moisture treatment on MSL appearance could be especially confounding in field studies in which soil moisture levels are not consistent across the study.

Moisture treatment initiated at MSL stage 1.0 had a significant impact on the number of GDD required to reach stage 3.0. The LM treatment caused a significant increase on the number of GDD required to complete PI2; this increase continued through PI3 and PI4, but dropped dramatically in PI5. Despite these variations, the response of mainstem leaves to accumulated heat in the LM did not differ significantly from linearity.

The moisture treatments applied in this study affected the number of plants that formed T0, but not T1, T2 or T3; these results, as well as the measured LWP, suggest that the moisture treatments differences were small Moisture treatment did significantly increase the number of GDD required before tillers appeared. However, moisture treatment did not effect tiller appearance in relation to MSL stage, indicating that tiller formation is synchronous with MSL development, even under low moisture conditions.

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Table 1. Moisture treatment effect on winter wheat mainstem leaf (MSL) stage, leaf water potential (LWP) and phyllochron interval (PI), averaged over 4 cultivars, 7 replications and 2 executions of the experiment.

Moisture	Measurements		
	MSL stage	LWP	PI
	- - MSL - -	- - kPa - -	- - GDD/leaf - -
High Moisture	6.2	-286.9	86.93
Low Moisture	5.5	-607.4	101.89
Difference	0.7 **	320.5 **	- 14.96 **
CV, %	4.5	64.2	8.5

** Moisture treatment means within the measurement column are significantly different at the 0.01 level of probability.

Table 2. Moisture treatment effect on the growing degree-days (GDD) required by winter wheat plants to reach successive mainstem leaf (MSL) stages, averaged over 4 cultivars, 7 replications and 2 executions of the experiment.

	MSL Stage				
Moisture	1.0	2.0	3.0	4.0	5.0
	- - - - - - - - - -		GDD	- - - - - - - - - - - -	
High Moisture	183	273	354	435	527
Low Moisture	179	279	377	479	567
Difference	4	- 6	- 23 **	- 44 **	- 40 **
CV, %	6.7	6.2	7.2	5.1	4.5

*,** Moisture treatment means within the growth stage column are significantly different at the 0.05 and 0.01 levels of probability, respectively.

Table 3. Moisture treatment effect on the percent of winter wheat plants that formed coleoptile (T0), first (T1), second (T2) and third (T3) tillers, averaged across 4 cultivars, 7 replications and 2 executions of the experiment.

	Tiller			
Moisture	T0	T1	T2	T3
	- - - - - - - -	%	- - - - - - - -	
High Moisture	35.7	98.2	100.0	96.4
Low Moisture	0.0	96.4	96.4	94.6
Difference	37.7 **	1.8	3.6	1.8
CV,%	---	15.9	13.6	18.1

** Moisture treatment means within the tiller column are significantly different at the 0.01 level of probability.

Table 4. Moisture treatment effect on winter wheat tiller emergence, in growing degree-days (GDD), averaged across 4 cultivars, 7 replications and 2 executions of the experiment.

	Tiller			
Moisture	T0	T1	T2	T3
	GDD			
High Moisture	366	351	414	504
Low Moisture	---	376	454	536
Difference	---	- 25 **	- 40 **	- 32 **
CV,%	---	9.9	6.9	5.5

** Moisture treatment means within the tiller column are significantly different at the 0.01 level of probability.

Table 5. Moisture treatment effect on winter wheat estimated mainstem leaf (MSL) stage at tiller appearance, averaged across 4 cultivars, 7 replications and 2 executions of the experiment.

	Tiller			
Moisture	T0	T1	T2	T3
	- - - - - - -	MSL Stage	- - - - - - - - -	
High Moisture	3.4	2.9	3.9	4.8
Low Moisture	---	3.0	3.8	4.7
Difference	---	- 0.1	0.1	0.1 *
CV,%	---	12.1	9.6	4.1

* Moisture treatment means within the tiller column are significantly different at the 0.05 level of probability.

PART III

OPTIMUM SAMPLING FOR EVALUATING MAINSTEM LEAF STAGE AND PERCENT OF EARLY TILLERS FORMED IN FIELD GROWN WINTER WHEAT

OPTIMUM SAMPLING FOR EVALUATING MAINSTEM LEAF STAGE AND PERCENT OF EARLY TILLERS FORMED IN FIELD GROWN WINTER WHEAT[1]

By T.L. Nipp, R. McNew and E.G. Krenzer,Jr.[2]

ABSTRACT

Mainstem leaf (MSL) stage and percent tiller formation (%TF) are measurements that have been used to evaluate the development of wheat (Triticum aestivum L.). This study was conducted to determine sampling strategies that would provide enough data to allow for a 90% probability of detecting cultivar and tillage effects on MSL stage and %TF of the coleoptile (T0), first (T1) and second (T2) tillers. Winter wheat plant samples were taken out of an ongoing genotype x tillage study during the 1983 - 1984 growing season, conducted at two locations in Oklahoma: the South Central Research Station at Chickasha, on a McLain silt loam (Pachic Argiustoll, fine, mixed,

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thermic); and, the Oklahoma State University North Stillwater Research Farm, on a Pulaski sandy loam (Typic Ustifluvent, fine, mixed, thermic). Conventional tillage (CT) was performed with a moldboard plow, with additional disking performed as required for weed control. Lo-till (LT) consisted of undercutting with a 1.5m V-blade, with herbicides applied for additional summer weed control. TAM W-101 and Osage were sampled at Chickasha and TAM W-101 was sampled at Stillwater. A total of six location-tillage-cultivar (LTC) treatment combinations were sampled. Within each of the six LTC units, plants were collected from four 1m samples. Each 1m sample was divided into ten 100mm subsamples. Within each 100mm subsample, each plant was evaluated as a sample. For MSL stage and %TF, analysis of variance was run on each of the LTC units separately to determine the variance components (VC) of each sampling level. In five of the six LTC units, 49 - 65% of the total variance within the LTC unit occurred among the plants within a 100mm subsample. The sampling level VC were incorporated in a computer program that calculated possible combinations of replications and sampling levels that would provide a 90% probability of detecting specified levels of treatment differences. For MSL stage, the number of plant samples required from each LTC unit ranged from 96 - 4,848 plants, depending on sampling procedure. For %TF of T1, sampling to detect an approximate treatment difference as small as 14% was feasible. However, sampling for %TF of T0 or T2 required exorbitant amounts of plant material.

Additional index words: Phyllochron, Phenology, Wheat morphology, Model, Haun scale, *Triticum aestivum* L., Growing degree-days, Variance components.

INTRODUCTION

Plant measurements have been developed that can be used to evaluate the quality of the germination and plant growth environments provided to winter wheat, Triticum aestivum L. (Klepper et al., 1982; Wilkins et al., 1982, Rickman et al., 1983). Mainstem leaf (MSL) stage is used as a measure of the preemergent seedbed environment. Percent tiller formation (%TF) is used to measured the amount of stress experienced by plants during early development. These plant measurements are based on the labeling system developed by Haun (1973); mainstem leaves are numbered according to their order of appearance (illustrated in Klepper et al., 1982). The MSL that is in the process of emergence is measured as a decimal fraction of the antecedent fully emerged leaf. Tillers are labeled according to the leaf base from which they arise. The first tiller (T1) appears from an axillary bud at the base of leaf 1, and so forth. The tiller that develops from the coleoptile node is called the coleoptile tiller (T0).

Klepper et al. (1982) determined that the MSL stage of winter wheat plants could be used to measure the quality of the plant's preemergent seedbed environment. This finding was based on their observation that MSL appear in a linear response to accumulated heat. Heat was measured in growing degree-days (GDD):

$$GDD = \sum_{i=1}^{n} [(T_i max + T_i min)/2 - T_b]$$

Where $T_i$max is the maximum daily temperature, $T_i$min is the daily minimum temperature and T_b is a minimum base temperature, below which growth does not occur. If $T_i$min is less than T_b, then T_b is utilized.

After the plant emerges from the soil, environmental stress does not influence the rate at which new leaves appear, except when leaf appearance ceases altogether under severe stress (Klepper et al., 1982; Wilkins et al., 1982). The relative size and health of the leaves may be affected by adverse environmental conditions, such as dehydration stress, but the rate of mainstem leaf appearance will respond only to the accumulation of heat. Within a uniform planting, a plant that reached a higher MSL leaf stage would have emerged earlier than other, since leaf appearance proceeds at the same rate after emergence. The plants that emerged first would have had the better seedbed environment.

In contrast to MSL appearance patterns, Klepper et al. (1982) observed that environmental stress during the time that tillers are forming may delay their appearance, a sufficient delay will even prevent their formation altogether. The greater the stress during the time period of their formation, the lower the percent of plants that will develop a tiller. The percent of plants with a specific tiller can therefore be used as a measure of the presence or absence of environmental stress during particular time periods in the plant's development (Peterson et al., 1982; Rickman et al., 1983).

Wilkins et al. (1982) applied both of these measurements, MSL stage and %TF, in a study evaluating tillage and planting system effects on winter wheat development. For the planting treatments, %TO and MSL stage per plant showed an observed significance level (OSL) of 8.7% and 8.4%, respectively. Tillage environments were differentiated with an OSL of 8.2% for MSL stage per plant. The study was conducted with only 2 replications.

For these two plant measurements, there was little information available to determine how many plants need to be sampled, or how they need to be sampled, to provide a high probability of detecting treatment differences. The objective of this study was to determine the minimum number of plant samples that would have to be collected to provide a high probability of detecting treatment effects on MSL stage and %TF, if such treatment effects occur. It was decided that available resources would allow for four to eight replications at each of two locations. The amount of time available to process the plants was roughly estimated. The number of plants that could be processed in that time was also estimated, allowing 1 minute per plant for plant evaluation. Within these rough boundaries, the intent of this study was to determine a sampling strategy within plots that would provide enough measurement data to detect cultivar and tillage treatments, at a probability of 90% or greater.

MATERIALS AND METHODS

Winter wheat plant samples were taken out of an ongoing study during the 1983 - 1984 growing season, conducted at two locations in Oklahoma: the South Central Research Station at Chickasha and the Oklahoma State University North Stillwater Research Farm. The soil type at Chickasha was a McLain silt loam (Pachic Argiustoll, fine, mixed, thermic); the annual rainfall in 1983 was 946mm. The soil type at Stillwater was a Pulaski sandy loam (Typic Ustifluvent, fine, mixed, thermic); the annual rainfall in 1983 was 818mm. The ongoing study consisted of a genotype x environment experiment. Utilizing a randomized complete block design with a split-plot arrangement of treatments, ten hard red winter wheat cultivars were grown under lo-till (LT) and conventional tillage (CT). There were four replications, at each of the two locations.

For our sampling study, time and resources did not allow extensive sampling of all cultivars. Rather than collect a small amount of material from each location-tillage-cultivar experimental unit, a large number of samples were collected for two cultivars, TAM W-101 and Osage, at Chickasha and one cultivar, TAM W-101, at Stillwater. Cultivar samples were taken from both the LT and CT plots. A total of six location-tillage-cultivar (LTC) treatment combinations were sampled, with four replications each.

Conventional tillage was performed with a moldboard plow. Additional tillages with a disk were performed as required for weed control. Lo-till consisted of undercutting at a depth of 120mm with a 1.5m V-blade. Additional summer weed control in the LT plots was obtained with a herbicide mixture: cyanazine (2-{[4-chloro-6-(ethylamino)-s-trianzin-2yl]amino}-2-methyl-propioni-trile), at a rate of 2.24 kg/ha of active ingredient (a.i.); and atrazine [2-chloro-4-(ethlyamino)-6-(isopropylamino)-s-triazine], at a rate of 0.5 kg/ha a.i. Glyphosate [N-(phosphonomethyl) glycine] was used to kill volunteer wheat and any weeds present at planting, applied at a rate of 0.5 l glyphosate (a.i.)/50 l H_2O/ha.

Based on soil test results from the Oklahoma State University Soil and Water Service Laboratory, fertilizers were added so as to prevent fertility from limiting growth and yields. Nitrogen was added as anhydrous ammonia with the V-blade on all plots after harvest of the preceding crop at a rate of 112 kg/ha. Ammonium polyphosphate (10-34-0) was applied at the rate of 94 l/ha in the seed furrow at planting.

Plots consisted of 10 drill rows of a cultivar; drill rows were 0.25m apart and 7.5m long. The plots were seeded at a rate of 55 kg/ha using a Crustbuster double disk opener No-Till drill. The Chickasha plots were seeded November 11th; the Stillwater plots were seeded November 8th.

Samples were collected in the spring of 1984, when plants had reached a Haun stage of 3.5 or greater. Within each of the six LTC experimental units, four 1m samples were collected. Within a plot, samples were taken three rows in from the plot edge, the third and seventh drill rows, to minimize border effects. Two 1m samples were taken from each of the two drill rows. The meter stick was randomly tossed within the first half of the row's length, then again within the second half of the row's length. Each 1m stick was marked with

100mm subdivisions; plants within each of the ten 100mm subsamples were were collected and placed in labelled plastic bags. The number of plants within a 100mm sample ranged from 0 - 13. The bagged plants were stored at 2 C for several months until all of the plants could be evaluated. A total of 4,346 plants were examined: 2,889 from Chickasha and 1,457 from Stillwater. Each wheat plant was evaluated for its MSL stage and the presence of the coleoptile (T0), first (T1) and second (T2) tiller.

The data was analyzed using SAS 5.0, utilizing an IBM 3081D, and PC SAS 6.0. Within each LTC combination, there were three levels of sampling: (i) four 1m samples, (ii) ten 100mm subsamples within each 1m sample, and (iii) plants within each 100mm subsample. For each of the plant measurements, analysis of variance was run separately on each of the LTC combinations units to determine the variance components of each sampling level within the experimental unit. The variance components were then incorporated in a computer program that calculated the probability (power) of rejecting the hypothesis of equal treatment means, when δ = "difference in true means divided by their average" is specified. Using MSL stage as an example, if two treatment population means are 5.0 and 4.5 respectively, then δ will be approximately 0.1 [δ = (5.0 - 4.5)/5]. Solving for a δ equal to 0.1 would be solving to detect a true population difference of about half a MSL stage. The computer program solved for possible numbers of replications, 1m samples, 100mm subsamples and plants per subsample that would provide a 90% probability or better of detecting δ equal to 0.1 and 0.5.

The first step in this process was to identify the variance components for each sampling level. The variance components and expected mean squares for a LTC combination is shown in Table 1. There were a variable number of plants within each 100mm subsample, ranging from 0 - 16 plants. To run analysis of variance, the overall harmonic mean of the number of plants within 100mm subsamples was calculated. In the few cases where there were no plants present within a 100mm subsample, the subsample was dropped and the degrees of freedom were adjusted accordingly; this was done so that an absence of plants in the 100mm subsample would not introduce incorrect measurement values of zero into the calculations. The mean square (MS) for plants within a 100mm subsample (Plants) was divided by the harmonic mean, n, of the number of plants per 100mm subsample, as is done in an unweighted means analysis of variance. The SS for the other sources of variation were calculated from the means of the 100mm subplots. The variance components were generated from a nested analysis of variance, with the sampling levels nested.

Sampling level variance components were then averaged across LTC experimental units, since the variance components proved sufficiently uniform across experimental units. The averaged variance components were used to estimate the following ratios:

$$G1 = (\sigma^2 \text{ 100mm subplots})/(\sigma^2 \text{ plant})$$

$$G2 = (\sigma^2 \text{ 1m plots})/(\sigma^2 \text{ plant})$$

And;

$$G3 = (\sigma^2 \text{ experimental unit})/(\sigma^2 \text{plant})$$

The standard error of the difference in means can then be calculated as:

$$SE = CV * \left[\frac{2\ (1 + nG1 + nsG2)}{nspr} + \frac{G3}{r} \right]^{0.5} * \mu$$

Where:

n = number of plants per 100mm subsample
s = number of 100mm subsamples per 1m sample
p = number of 1m samples per replication
r = number of replications
= true overall population mean
CV = the plant standard deviation divided by μ

The population mean of each measurement was estimated by the mean of the plant measurement across LTC combinations. Since μ will cancel out in the following equations, it is dropped. If $DS = SE / \mu$, then to establish the boundaries for 90% confidence:

$$C1 = -1.96 - (\delta /DS)$$
$$C2 = C1 + 3.92$$

Then,

Power = normal probability of (C1) + 1 - normal probability of (C2),

The PROBNORM function of SAS was applied to C1 and C2 to determine the power of detecting the specified values of delta. The computer program was run to try all combinations of the following: r = 4, 6, and 8; p = 4, 6, and 8; s = 2, 4, and 6; and, n = 1 to 100. The program output all possible combinations of these sampling components that provided a 90% probability or greater of detecting the identified delta values of 0.1 and 0.5.

RESULTS AND DISCUSSION

The means for MSL stage and %TF are shown in Table 2 for each LTC combinations. The choice of δ equal to 0.1 is seen to be appropriate for detecting a MSL stage difference between tillage treatments of about half a leaf stage, given the mean MSL stage values.

The variance components for MSL stage, for each LTC, are shown in Table 3. If the variance components are tested for homogeneity using a simple F test, as described by Gomez and Gomez (1984), then tillage, cultivar and location differences for each possible comparison within a sampling level were not significant. In each LTC combination, most of the variation occurred among plants within a 100mm subsample. In general, the higher the sampling level, the lower the relative contribution of the sampling level to the total variance within the experimental unit. The only exception to this trend occurred at Stillwater under LT; for this LTC combination there was a relatively large variation introduced by replication differences. The variance component values at Stillwater were lower than at Chickasha, which might be explained in part by the smaller MSL stage values at Chickasha.

Out of the specified combinations of r, p, s, and n, a number of sampling combinations that would provide a 90% probability of detecting a treatment difference of about half a leaf stage ($\delta = 0.1$) were identified. Combinations providing a 90% probability of detecting the smaller δ of 0.05 were not found; the discussion will therefore be limited to δ equal to 0.1. Six possible sampling strategies are shown in Table 4. In Strategy 1, four replications, four 1m samples per replication, and three 100mm subsamples per sample would require the presence of 100 plants within each 100mm subsample to provide an 86.99% probability of detecting δ equal to 0.1. Obviously, the expectation of 100 plants per 100mm subsample is unreasonable, but this strategy is included to point out the dramatic improvement obtained by simply increasing the number of 1m samples to six, shown in Strategy 2. Even with two 100mm subsamples per sample, only 12 plants are required per 100mm subsample to provide a 90.05% level of probability.

Looking through the other strategies, it is clear that the probability of detection improves as the higher sampling levels increase in number. To improve detection, the first step would be to increase replications, However, if increased replication is not possible due to limited space, then acceptably high probability of detection can be obtained by varying the other sampling levels.

The total number of plants that would have to be collected within an LTC unit for each strategy is shown in Table 4. Also shown is the total number of plants that would have to be collected if each strategy were applied to the ongoing study, with samples taken from each of the two tillage treatments and ten cultivars, at each of the two locations. Applied to the ongoing study, Strategy 1 would require 193,920 plants to provide only a 86.99% level of probability of detection, compared to the 3,840 plants required in Strategy 6 to provide a 91.38% probability. Plants were evaluated in this study at a rate of approximately one plant a minute. At this rate, assuming an 8 hr work day, 404 working days would be required to evaluate the plants collected under Strategy 1! Strategy 6 provides a higher level of probability and would require only eight working days. The amount of plant material and processing time required to obtain a 90% level of probability of detecting a MSL stage treatment difference of half a leaf stage can be reduced by a factor of 50 by determining an optimum sampling strategy before beginning.

The described calculations were also performed for the %TF of T0, T1 and T2. None of the sampling combinations were able to come near a 90% probability of detection for δ equal to 0.05 or 0.1. Therefore the analysis was also run for δ equal to 0.2, 0.3,0.4, 0.5, 0.6, 0.7, 0.8, and 0.9. In this study, a very low percent of T0 formed (3.6%), suggesting that it will be difficult to detect treatment differences with this measurement. For %T0, 90% probability of detection of delta was not possible until delta was equal to 0.7. Since the mean %T0 was 3.6%, this corresponds to a treatment population mean difference of about 2.5%, which is greater than the differences observed in this study. The minimum number of plant samples required to detect this difference was 4,320 plants per LTC combination, 45 times as many plants as required by the optimum sampling strategy for MSL stage (Strategy 6). Sampling specifically for a high probability of detecting treatment differences in %T0 may simply require more plant material than is feasible.

Sampling for %T1 and %T2 might be more reasonable, a 90% probability of detecting delta of 0.2 was possible for both of these tillers. For %T1, with a mean of 70.39% across LTC combinations, a δ of 0.2 corresponds with a treatment mean difference of about 14%, which is less than the observed tillage treatment difference of

15.23% for TAW W-101 at Chickasha. The minimum plant number required for this δ of 0.2 would require 288 plants per LTC combination, 3 times as many required under Strategy 6 for MSL stage. However, at δ equal to 0.3, sampling strategies were available that would require no more plant material than Strategy 6 for MSL stage. A δ of 0.3 would correspond with a treatment difference of 21%. The prospects of sampling specifically for %T1 are not excellent, but the possibility exists.

As with %T1, sampling for a 90% probability of detecting δ of 0.2 was possible for %T2. The minimum amount of plant material for detecting a δ of 0.2 was 180 plants per LTC combination, nearly two times as much plant material as Strategy 6 for MSL stage. While the additional amount of plant material to sample for %T2 may be low enough to be acceptable, a δ value of 0.2 with the mean value of 80.51% indicates a treatment difference of 16%, which is much higher than observed in this study.

Among the tillers, T1 was the most plausible for development of a sampling strategy that would yield a 90% probability of detecting a possible treatment difference. It is likely that investigators will wish to sample plants for both MSL stage and %TF at the same time. Sampling for %T1 may require larger treatment differences than sampling for MSL stage, but some sampling options may be close enough to consider both measurements when choosing a sampling strategy. While detection of treatment differences based on %T0 and %T2 is certainly possible, the probabilities do not appear sufficient to design the sampling strategy specifically for these measurements. In any case, experimenters may greatly improve the probability of detecting treatment differences with these measurements, while minimizing invested time and effort, by performing preliminary analyses of sampling level variance components within their experimental units.

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Table 1. Variance components and estimated mean squares for one location-tillage-cultivar combination, for winter wheat plants.

Source	df	Estimated mean squares
Replications	r-1	1/n+ σ^2plant + σ^2subsample + s σ^2sample + sp σ^2LTC unit
samples	(s-1)r	1/n+ σ^2plant + σ^2subsample + s σ^2sample
subsamples	(sub-1)rs	1/n+ σ^2plant + σ^2subsample
Plants	t-rs(sub)	1/n+ σ^2plant

\+ Overall harmonic mean for the number of plants within a 100mm subsample.

Table 2. Mainstem leaf (MSL) stage and percent of plants that formed the coleoptile tiller (%T0), first tiller (%T1) and second tiller (%T2), for winter wheat cultivars at six location-tillage-cultivar (LTC) combinations.

Location	Tillage	Cultivar	MSL	%TO	%T1	%T2
Chickasha	LT+	TAM W-101	5.06++	2.84	57.52	85.21
Chickasha	CT	TAM W-101	5.44	3.75	72.75	88.74
Chickasha	LT	Osage	5.46	1.71	63.21	86.08
Chickasha	CT	Osage	5.89	3.71	69.46	87.07
Stillwater	LT	TAM W-101	4.56	4.37	77.47	80.70
Stillwater	CT	TAM W-101	4.86	5.22	81.93	85.27
Mean			5.2	3.6	70.4	80.5

\+ LT refers to lo-till, CT refers to conventional tillage.

++ Means are averaged across sampling levels and replications of each LTC combination.

Table 3. Mainstem leaf stage variance components for six location-tillage-cultivar combinations.

	Chickasha-TAM W-101				Chickasha-Osage				Stillwater-TAM W-101			
	LT+		CT		LT		CT		LT		CT	
	vc++	%	vc	%	vc	%	vc	%	vc	%	vc	%
Total	0.82	100.00	0.88	100.00	1.21	100.00	1.07	100.00	0.59	100.00	0.39	100.00
Replications	0.11	13.44	0.02	1.65	0.00	0.00	0.02	1.56	0.21	35.14	0.03	8.07
1m samples	0.06	6.93	0.10	11.72	0.05	4.47	0.10	9.70	0.07	11.51	0.03	7.19
100mm subsamples	0.16	19.30	0.29	32.80	0.56	46.13	0.29	26.82	0.14	23.92	0.08	20.25
Plants	0.49	60.33	0.48	53.83	0.60	49.40	0.66	61.92	0.17	29.44	0.25	64.50

\+ LT refers to lo-till, CT refers to conventional tillage.

++ vc refers to the calculated variance component, the percent is the fraction of the total variance within the location-cultivar-tillage combination.

Table 4. Sampling strategies for detecting treatment differences of one-half a mainstem leaf stage in young winter wheat plants.

	Sampling level							
Sampling Strategy	Reps	1m Samples	100mm Subsamples	Plants/ Subsample	Power+	Plants/ LTC	Total no. plants	Working days required
1	4	4	3	100	86.99	4,848	193,920	404
2	4	6	2	12	90.05	576	23,040	48
3	6	4	3	3	91.46	216	8,640	18
4	6	6	2	2	91.69	144	5,760	12
5	8	4	3	2	95.35	192	7,680	16
6	8	6	2	1	91.38	96	3,840	8

+ Power refers to the probability of detecting a treatment difference of half a mainstem leaf stage, given the combination of sampling levels in the sampling strategy. "Plants/LTC" refers to the total number of plants that would have to be sampled from an experimental unit, across all replications. The "Total no. Plants" is the number of plants that would have to be sampled from the desired study. "Working days required" is the number of days required to process the plant samples, assuming an eight hour work day.

PART IV

MAINSTEM LEAF DEVELOPMENT AND TILLER FORMATION OF WINTER WHEAT CULTIVARS GROWN UNDER LO-TILL AND CONVENTIONAL TILLAGE

MAINSTEM LEAF DEVELOPMENT AND TILLER FORMATION OF WINTER WHEAT CULTIVARS GROWN UNDER LO-TILL AND CONVENTIONAL TILLAGE[1]

By T.L. Nipp and E.G. Krenzer,Jr.[2]

ABSTRACT

Mainstem leaf (MSL) stage and percent tiller formation (%TF) are measurements that have been used to evaluate the development of wheat (*Triticum aestivum* L.). The relative quality of the early growth environments provided to ten hard red winter wheat cultivars grown under conventional tillage (CT) and lo-till (LT) was evaluated using MSL stage and %TF for the coleoptile (T0), first (T1) and second (T2) tillers. Field plot studies were conducted at two locations during the 1985 and 1986 growing seasons: the Oklahoma South Central Research Station at Chickasha, on a McLain silt loam (Pachic Argiustoll, fine, mixed, thermic); and, the Oklahoma North Central Research Station at Lahoma, on a Pond Creek silt loam (Pachic

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Argiustoll, fine-silty, mixed, thermic). Conventional tillage (CT) was performed with a moldboard plow, with additional disking performed as required for weed control. Lo-till (LT) consisted of undercutting with a 1.5m V-blade, with herbicides applied for additional summer weed control. Interactions required that analyses be run for each location-year-tillage combination to determine cultivar differences and for each location-year-cultivar to evaluate tillage differences. When analyses were run for each location-year, significant tillage x cultivar interactions were observed for two of the four location-years. Some significant cultivar and tillage differences were observed for each of the measurements. However, generally small differences in MSL stage and %TF indicated that the early growth environments provided by the two tillage systems were of comparable quality for most cultivars. None of the cultivars showed consistently high or low performance under a tillage practice across location-years.

Additional index words: Phyllochron, Phenology, Wheat morphology, Haun scale, *Triticum aestivum* L., Growing degree-days.

INTRODUCTION

In winter wheat (Triticum aestivum L.) production, the choice between lo-till (LT) or conventional tillage (CT) may significantly affect the quality of the plants' early growth environment. The straw residue left on the soil surface in LT can increase soil moisture retention, but it can also reduce soil temperature, reduce seed contact with the soil, reduce incipient light to the emerging plants and harbor insects and disease. To date, cultivars have been selected under CT management. Traits that would enable cultivars to perform more vigorously under LT conditions may not have been selected for, such traits may even have been selected against. Measurements developed by Klepper et al. (1982) have been used to evaluate the effect of tillage on germination and plant development; mainstem leaf (MSL) stage is used as a measure of the quality of the preemergent seedbed environment and percent tiller formation (%TF) is used as a measure of the amount of stress experienced during early plant development (Klepper et al. 1982; Wilkins et al., 1982). The presence of cultivar x tillage interactions for these measurements would indicate cultivars better able to perform under one tillage system than the other.

These two plant measurements, MSL stage and %TF, are based on the labelling system suggested by Haun (1973), in which mainstem leaves are numbered according to their order of appearance (illustrated in Klepper et al., 1982). The mainstem leaf (MSL) that is in the process of emergence is measured as a decimal fraction of the antecedent fully emerged leaf. Tillers are labelled according to the leaf base from which they arise. The first tiller (T1) appears from an axillary bud at the base of leaf 1, and so forth. The tiller that develops from the coleoptile node is called the coleoptile tiller (T0).

The use of MSL stage to evaluate the quality of the preemergent seedbed environment has been based on the observation that mainstem leaves appear in a linear response to accumulated heat (Klepper et al., 1982). After plants emerge from the soil, environmental stress does not influence the linear response of mainstem leaves to accumulated GDD, except when appearance ceases altogether under severe stress (Klepper et al., 1982; Wilkins et al., 1982). Mainstem leaf stage, therefore, may be utilized to measure the quality of the preemergent seedbed environment; since, in a uniform planting, a plant that reached a higher MSL stage would have emerged earlier than others. Assuming a uniform planting depth, the plants that emerged first would have had the better seedbed environment.

The assumption that environmental stresses will not affect the linear response of MSL appearance to GDD may not be valid under all conditions. The rate of incident photosynthetically active radiation (PAR) does affect wheat MSL appearance rates (Rickman et al., 1985). J.T. Baker et al. (1986) observed that reduced moisture availability stress increased the rate at which wheat mainstem leaves appear. They suggest that drought stress may have induced higher canopy temperatures in the stressed plants, resulting in their higher rate of growth. In contrast, Leong and Ong (1983) observed a faster rate of leaf appearance in irrigated groundnut (*Arachis hypogaea* L.) plants, compared with nonirrigated plants. Nipp and Krenzer (1987c) observed that moisture treatment significantly affected early winter wheat MSL appearance, but that reduced water availability reduced the rate of MSL appearance, opposite to the secondary temperature effect in latter development suggested by Baker et al. (1986). Caution should therefore be exercised before assuming MSL stage reflects only differences in the preemergent seedbed environment. However, MSL stage may still be used as a measure of the quality of the total growth environment up to the time of measurement.

In addition to using MSL stage, Klepper et al. (1982) proposed that the percentage of plants that develop a specific tiller can be used to indicate whether there was environmental stress at the time the tiller was forming. Stress may delay a tiller's appearance. If the stress is sufficient, the tiller will not form at all. The percent of plants with a specific tiller can be used as a measure of the presence or absence of environmental stress during the appropriate time period in the plants' development (Peterson et al., 1982; Rickman et al. 1983). Reduced levels of incident PAR have been shown to reduce tiller formation (Rickman et al., 1985). Similarly, tiller formation has been reduced by lower temperatures (Smika and Ellis, 1971) and dehydration stress (Stark and Longley, 1986).

Both of these plant measurements, MSL and %TF, have potential as tools for evaluating the relative quality of the early growth environments provided by different tillage systems (Wilkins, 1982; Wilkins et al., 1984). In growth chamber studies, Nipp and Krenzer (1987a) found significant cultivar differences in MSL stage, using a range of hard red winter wheat cultivars. If cultivar x tillage interactions can be identified for these measurements, it may be possible to identify cultivars that are better adapted to LT environments.

In this study, 10 hard red winter wheat cultivars common to the Southern Great Plains were grown under LT and CT regimes. The objectives were: (i) to identify tillage effects on the early growth environment of winter wheat cultivars, using MSL stage and %TF, (ii) identify cultivar differences for these measurements under field conditions, and (iii) identify whether tillage x cultivar interactions occurred for these measurements.

MATERIALS AND METHODS

Field plot studies were conducted at two locations: the Oklahoma South Central Research Station at Chickasha and the Oklahoma North Central Research Station at Lahoma, during the 1985 and 1986 growing seasons. The soil type at Chickasha was a McLain silt loam (Pachic Argiustoll, fine, mixed, thermic); the annual rainfall was 1.11m in 1985 and 1.19m in 1986, with a long term average of 0.81m . The soil type at Lahoma was a Pond Creek silt loam (Pachic Argiustoll, fine-silty, mixed, thermic); the annual rainfall was 0.98m in 1985 and 1.20m in 1986, with a long term average of 0.71m.

Ten hard red winter wheat cultivars were grown under LT and CT. A randomized complete block design was employed, with split-plot subunits in strips; there were 8 replications at each location. Tillage made up the main plots and subplots of cultivars were seeded across the tillage strips. The ten hard red winter wheat cultivars used are adapted to the Southern Great Plains: Chisholm, Mustang, Newton, Osage, Payne, Probrand 835, TAM 105, TAM W-101, Triumph 64 and Vona.

Conventional tillage was performed with a moldboard plow. Additional tillages with a disk were performed as required for weed control. Lo-till consisted of undercutting with a 1.5 m V-blade to a depth of 120mm. Additional weed control in the LT plots was obtained by spraying immediately following the V-blade with a tank mixture of terbutryn (2-[tert-butylamino-4-(ethylamino)-6-(methylthio)-s-triazine]), at 1.79 kg/ha of active ingredient (a.i.); atrazine [2-chloro-4-(ethlyamino)-6-(isopropylamino)-s-triazine], at 0.50 kg/ha (a.i.); chlorsulfuron (2-chloro-N-{[(4-methoxy-6-6-methyl-1,3,5-triazine-2-yl)amino]carbonyl}benzenesulfonamide), at 16.5 g/ha (a.i.); 2,4-D [(2,4-dichlorophenoxy)acetic acid, butoxyethanol ester] was included at 1.5 l/ha (a.i.) if broadleaves were already present. Glyphosate [N-(phosphonomethyl) glycine] was used to kill volunteer wheat and any weeds present at planting, at 0.5 l glyphosate (a.i.)/50 l H_2O/ha.

Based on soil test results from the Oklahoma State University Soil and Water Service Laboratory, fertilizers were added so as to prevent fertility from limiting growth and yields. Anhydrous ammonia was applied with the V-blade on all plots immediately after harvest of the preceding crop, at 100 kg N/ha, before other tillage or spray operations. Diammonium phosphate (18-46-0) was banded at 100 kg/ha at planting.

Plots consisted of 10 drill rows of a cultivar; rows were 0.25m apart and 7.5m long. The plots were seeded with a Crustbuster No-Till drill with double disk openers at 55 kg/ha; the Chickasha 1985 plots were seeded October 2nd, the Lahoma 1985 plots were seeded November 5th. In 1986, seeding was delayed because of wet field conditions: the Chickasha plots were seeded Nov. 25th, the Lahoma plots were seeded Dec. 1st. Soil moisture at planting was determined as percent moisture on a weight basis, using gravimetric soil samples taken from 0 to 50mm and 50mm to 150mm depths. Straw residue cover at seeding was evaluated using the modified step-point system described by Owensby (1973).

Plant samples were collected when all plants appeared to have reached a Haun stage of 3.5 or greater, to insure adequate time for tiller formation. From each tillage-cultivar experimental unit, 12 plants were sampled, based on an optimum sampling strategy for MSL stage described by Nipp and Krenzer (1988b). Whole plants were removed, placed in labelled plastic bags and stored at 2 C until all samples could be examined for MSL stage and %TF.

Analysis of variance was run on MSL stage, %T0, %T1, and %T2, using SAS 5.0 on an IBM 3081K mainframe and PC SAS 6.0. Duncan's Multiple Range Test was used to test for significant differences among treatment levels.

RESULTS AND DISCUSSION

Percent straw cover ranged from 2 to 5% in the CT plots and from 52 to 61% in the LT plots. Soil moisture at planting in the 0 to 50mm level averaged 12.5% at Chickasha in 1985 and 18.3% in 1986, 9.9% at Lahoma in 1985 and 17.1% in 1986. Differences between the sampling depths was less than 2% at all location-years. Tillage treatments were not significantly different in soil moisture at either depth.

For MSL stage and %TF for each of the tillers studied, the following interactions were significant: location x cultivar, tillage x cultivar, location x year, and cultivar x year. Location x tillage x cultivar was significant for each of the tillers, with an observed significance level (OSL) of 7% for MSL stage. Tillage x cultivar x year was significant for all measurements but %T0. Location x tillage x cultivar x year was significant for %T1 and %T2. There was no attempt to collect plant samples after equivalent accumulation of GDD at each location-year, so it would not be reasonable to make comparisons across location-years for MSL stage. Accordingly, and because of the significant interactions for each measurement, analysis was run separately for each location-year-tillage (LYT) combination to compare cultivars, and for each location-year-cultivar (LYC) to compare tillage treatments.

Analysis of variance was run separately for each location-year combination to determine the significance of the tillage x cultivar interactions. Tillage x cultivar interaction was not significant for MSL stage or %TF in 1985 for either Chickasha or Lahoma, though %T0 had an observed significance level of 6.35% at Lahoma-1985. Tillage x cultivar interaction was significant for all measurements at Chickasha-1986 and for all of the measurements except %T2 at Lahoma-1986. In 1986, the developing plants were occasionaly subjected to excessively wet conditions, which might have induced differences between the tillage systems, to which some cultivars showed a differential response. This confirms that these measurements can be used to detect cultivars better able to perform under a specific cultivation practice, especially where substantial environmental differences between the tillage systems have been demonstrated.

Three cultivars showed a significant tillage difference at Chickasha in 1985: LT MSL stage was lower for Mustang and TAM 105 and higher for Probrand 835. At Chickasha-1986, LT MSL stage was lower for Mustang and higher for TAM W-101. Only one cultivar showed a significant tillage difference at Lahoma-1985, LT MSL stage was lower for Osage. At Lahoma-1986, the location-year with the highest number of cultivars showing a significant tillage effect, LT MSL stage means were higher for Chisholm, TAM W-101 and Osage and lower for TAM 105 and Triumph 64.

Mainstem leaf stage means for each location-year-treatment are compared in Table 1. Tillage treatment differences were small, but significant in some cases. Looking across location-years, four of the cultivars were significantly affected by tillage practice at two location-years. Three of these cultivars consistently performed better under one tillage practice: LT MSL stage was higher for TAM W-101 and lower for Mustang and TAM 105. Osage had a significantly higher LT MSL stage at Lahoma-1986 and a significantly lower LT MSL stage at Lahoma-1985. Three cultivars showed a significant tillage difference at only one location-year: Chisholm, Probrand 835 and Triumph 64. Three of the cultivars failed to show a significant tillage difference at any of the location-years: Newton, Payne and Vona.

Cultivars were significantly different in MSL stage within tillage treatments at six of the eight LYT combinations. Chickasha-1985-LT and Lahoma-1985-CT did not show significant cultivar differences. The cultivars did not show a consistent ranking across LYT combinations.

The generally small differences in MSL stage between the two tillage systems indicates that the early growth environments provided by the two tillage systems were of comparable quality for most cultivars. Differences were also small among cultivars, none of the cultivars showed consistently high or low performance under a tillage practice across location-years. The relative persistence in tillage effect across location-years for Mustang, TAM 105 and TAM W-101 suggests that these cultivars might have early development traits that favor establishment under particular tillage practices: TAM W-101 was higher under LT, the others were higher under CT. These cultivars may be of special interest if further attempts are made to identify plant traits that assist early wheat establishment.

Percent tiller formation for T0 is shown in Table 2. Looking across location-years, four cultivars showed a significant tillage effect at two location-years: TAM 105 and Vona had consistently lower LT %T0; Vona had higher LT %T0; Mustang's LT %T0 was higher at one location-year but lower at the other. Chisholm, Newton, and Osage showed a significant tillage effect at one location-year only. Payne, Probrand 835 and Triumph 64 did not show a significant tillage effect at any of the location-years. Cultivars were significantly different within tillage treatments at six of the eight LYT combinations; however, none of the cultivars showed a consistent ranking across LYT combinations.

Klepper et al. (1982) report %T0 ranging from 0 to 75% in different growth environments. Wilkins et al. (1982) observed %T0 values ranging from 4.5 to 20.6% under different planting and tillage systems, with OSL of 8.7% and 33.6% respectively. Each of the cultivars included in this study were grown under favorable conditions in growth chamber studies (Nipp and Krenzer, 1988a). The %T0 values obtained are consistent with previous studies (Klepper et al., 1982; Wilkins et al., 1982; Nipp and Krenzer, 1988a). The large CV's in this study prevented declaring a number of the observed treatment differences to be significant. This high variability may greatly limit the utility of this measurement in detecting differences in the quality of the early growth environments provided by tillage practices, as suggested by Nipp and Krenzer (1988a).

Formation of the first tiller was much less variable than %T0, as indicated by the dramatically lower CV's (Table 3). However, the reduced variability might be associated with a decreased sensitivity to environmental variations. Tillage x cultivar interactions for %T1 were significant for Chickasha-1986 and Lahoma-1986. Cultivars were significantly different within tillage treatments at four of the LYT combinations, but ranking was not consistent across location-year-tillages. A significant tillage treatment difference was observed at two of the location-years. Mustang's %T1 was consistently lower under LT at both Lahoma-1986 and Chickasha-1986, while Osage's %T1 was consistently higher under LT. Percent formation of T1 was lower at Chickasha-1986, compared to the other location-years (Table 3), possibly due to the wet condition of the early growth environment.

Five cultivars showed a significant tillage difference in percent formation of T2 at Chickasha-1986 (Table 4). Lo-till %T2 was higher for Osage and TAM 105 and lower for Newton, Probrand 835 and Vona. No other location-year had more than one cultivar with a significant tillage difference. Only Newton showed a significant tillage effect at more than one location-year, but the tillage effect was opposite at each. Substantial cultivar differences for %T2 within tillage treatment only occurred at Chickasha-1986. As with %T1, the percent formation of T2 was lower at Chickasha-1986 compared to the other location-years. The observed %T1 and %T2 was consistent with other growth chamber studies (Klepper et al., 1982; Wilkins et al., 1982).

Among the %TF measurements, %T1 appears the most usable measurement for detecting tillage environment differences, less variable than %T0, but more sensitive that %T2. The relative insensitivity of %T2 in most location-years of this study is consistent with the earlier reports by Klepper et al. (1982).

It is difficult to demonstrate a correlation among %T0, %T1 or %T2 when significant tillage differences occurred; since, for most cultivars, significant tillage effect occurred at different location-years for each measurement. Response to tillage varied across location-years for most of these cultivars. Since %TF was not consistent across tillers for most cultivars, the treatment differences that existed in the early growth environments may not have persisted. For example, an environmental difference that induced a significant reduction in %T0 might not have been present, or not sufficiently, to induce a similar reduction in %T1 or %T2, for most cultivars. A significant treatment effect for one of the tillers should therefore be interpreted only as an indication of stress when that particular tiller was forming, rather than an indicator of the overall quality of the early growth environment during plant development.

Among the studied measurements, MSL stage and %T1 appeared the most sensitive for detection of treatment differences. High variation with T0 was a problem. Percent formation of T2 was relatively insensitive to environmental differences for most location-years. Given the significant tillage x cultivar interactions for these measurements at two location-years, and the fact that tillage and cultivar differences were observed, MSL stage and %T1 might be of use in selecting cultivars better able to become established under LT conditions. However, the measurements are more likely to be of value where there are larger differences between tillage environments than were observed in this study.

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Table 1. Mainstem leaf stage of winter wheat cultivars grown under lo-till (LT) and conventional tillage (CT), at each of two locations and two years.

	Chickasha				Lahoma			
	1985		1986		1985		1986	
Cultivar	CT	LT	CT	LT	CT	LT	CT	LT
	- - - - - - - - - - - - - - - -			Mainstem leaf stage	- - - - - - - - - - - - - -			
Chisholm	6.1 ab+	6.1 a	5.9 bc	5.7 e	5.4 a	5.4 a	6.1 c	6.5 abc **
Mustang	6.3 a	6.1 a **	6.0 abc	5.8 de *	5.3 a	5.3 ab	6.4 ab	6.2 d
Newton	6.2 a	6.1 a	6.0 abc	6.0 b	5.2 a	5.2 ab	6.2 c	6.3 cd
Osage	6.2 a	6.2 a	5.8 c	5.9 bcd	5.2 a	5.0 b **	6.4 ab	6.7 a **
Payne	5.9 ab	5.9 a	5.9 bc	5.9 bcd	5.3 a	5.1 ab	6.4 ab	6.3 cd
Probrand 835	5.8 b	6.1 a *	5.9 bc	5.7 e	5.2 a	5.3 ab	6.5 ab	6.4 bcd
TAM 105	6.1 ab	5.9 a *	5.5 bc	5.4 f	5.2 a	5.3 ab	6.4 ab	5.9 e **
TAM W-101	6.1 ab	6.1 a	5.9 bc	6.3 a **	5.3 a	5.2 ab	6.3 b	6.6 ab **
Triumph 64	6.1 ab	6.0 a	6.1 ab	5.9 bcd	5.4 a	5.2 ab	6.6 a	6.3 bcd *
Vona	6.1 ab	6.1 a	6.2 a	6.1 b	5.1 a	5.3 ab	6.5 ab	6.4 bc
CV, %	7.6	7.5	11.8	13.4	10.5	9.6	9.9	9.2

\+ Means within a column followed by the same letter do not differ significantly at the 0.05 level of probability, according to Duncan's Multiple Range Test.

*,** Tillage effect, within a year and location, is significant at the 0.05 and 0.01 levels of probability, respectively.

Table 2. Percent of plants containing the coleoptile tiller (%TO) in winter wheat cultivars grown under lo-till (LT) and conventional tillage (CT), at each of two locations and two years.

	Chickasha				Lahoma			
	1985		1986		1985		1986	
Cultivar	CT	LT	CT	LT	CT	LT	CT	LT
	%TO							
Chisholm	28 a+	28 a	4 c	0 d *	46 ab	45 ab	33 abcd	21 b
Mustang	23 a	22 a	17 a	13 bc	33 bc	52 a **	50 a	29 ab **
Newton	11 a	16 a	13 ab	25 a *	7 d	8 e	33 abcd	25 ab
Osage	21 a	18 a	7 bc	4 cd	18 cd	6 e **	38 abc	33 a
Payne	20 a	24 a	8 bc	17 ab	14 cd	14 de	29 bcd	33 a
Probrand 835	18 a	23 a	17 a	8 bcd	24 cd	20 cde	21 bcd	25 ab
TAM 105	26 a	25 a	8 bc	0 d **	19 cd	9 e	29 bcd	13 c **
TAM W-101	20 a	31 a	13 ab	8 bcd	26 bcd	40 abc *	17 d	29 ab *
Triumph 64	28 a	24 a	17 a	9 ab	21 cd	26 bcde	33 abcd	33 a
Vona	27 a	30 a	8 bc	17 ab	59 a	34 abcd *	46 ab	33 a *
CV, %	174.2	171.1	291.6	288.1	143.3	146.1	139.1	162.7

\+ Means within a column followed by the same letter do not differ significantly at the 0.05 level of probability, according to Duncan's Multiple Range Test.

*,** Tillage effect, within a year and location, is significant at the 0.05 and 0.01 levels of probability, respectively.

Table 3. Percent of plants containing the first tiller (%T1) in wheat cultivars grown under lo-till (LT) and conventional tillage (CT), at each of two locations and two years.

	Chickasha				Lahoma			
	1985		1986		1985		1986	
Cultivar	CT	LT	CT	LT	CT	LT	CT	LT
	- - - - - - - - - - - - - - - - - - - -			%T1	- - - - - - - - - - - - - - - - - - - -			
Chisholm	100 a+	100 a	92 a	75 d **	100 a	100 a	83 d	96 b *
Mustang	100 a	98 a	96 a	83 c **	99 a	100 a	100 a	96 b *
Newton	99 a	98 a	92 a	83 c	85 b	93 b	88 c	83 c
Osage	99 a	100 a	73 cd	92 b **	97 a	99 a	96 b	100 a *
Payne	100 a	100 a	75 bcd	83 c	97 a	99 a	100 a	100 a
Probrand 835	100 a	100 a	89 ab	75 d	100 a	100 a	100 a	100 a
TAM 105	100 a	100 a	67 d	96 ab**	99 a	100 a	96 b	96 b
TAM W-101	100 a	100 a	100 a	100 a	99 a	100 a	96 b	100 a *
Triumph 64	100 a	100 a	96 a	91 b	100 a	99 a	100 a	100 a
Vona	98 a	100 a	84 abc	83 c	100 a	100 a	100 a	100 a
CV, %	6.3	9.0	35.6	39.1	13.4	9.7	18.9	14.9

\+ Means within a column followed by the same letter do not differ significantly at the 0.05 level of probability, according to Duncan's Multiple Range Test.

*,** Tillage effect, within a year and location, is significant at the 0.05 and 0.01 levels of probability, respectively.

Table 4. Percent of plants containing the second tiller (%T2) in winter wheat cultivars grown under lo-till (LT) and conventional tillage (CT), at each of two locations and two years.

	Chickasha				Lahoma			
	1985		1986		1985		1986	
Cultivar	CT	LT	CT	LT	CT	LT	CT	LT
	- -				%T2 -			
Chisholm	100 a+	100 a	96 ab	96 ab	98 a	100 a	92 b	100 a **
Mustang	100 a	100 a	96 ab	92 bc	98 a	100 a	100 a	100 a
Newton	100 a	99 a	100 a	96 ab *	84 b	94 a *	100 a	100 a
Osage	100 a	100 a	87 c	96 ab **	96 a	97 a	100 a	100 a
Payne	100 a	100 a	88 bc	92 bc	97 a	97 a	100 a	100 a
Probrand 835	100 a	100 a	100 a	88 c **	100 a	100 a	100 a	100 a
TAM 105	100 a	100 a	79 c	96 ab **	98 a	100 a	100 a	100 a
TAM W-101	100 a	100 a	96 ab	100 a	99 a	100 a	100 a	100 a
Triumph 64	100 a	100 a	100 a	100 a	100 a	99 a	100 a	100 a
Vona	100 a	100 a	100 a	92 bc **	98 a	100 a	100 a	100 a
CV, %	0	3.2	24.2	24.3	15.9	10.9	6.7	0

\+ Means within a column followed by the same letter do not differ significantly at the 0.05 level of probability, according to Duncan's Multiple Range Test.

*,** Tillage effect, within a year and location, is significant at the 0.05 and 0.01 levels of probability, respectively.

PART V

YIELD AND YIELD COMPONENTS OF WINTER WHEAT CULTIVARS GROWN UNDER LO-TILL AND CONVENTIONAL TILLAGE

YIELD AND YIELD COMPONENTS OF WINTER WHEAT CULTIVARS GROWN UNDER LO-TILL AND CONVENTIONAL TILLAGE[1]

By T.L. Nipp and E.G. Krenzer,Jr.[2]

ABSTRACT

Yields obtained for winter wheat (Triticum aestivum L.) under lo-till (LT) cultivation have not been consistently different than yields obtained under conventional tillage (CT). This may be due to cultivar performance differences across tillages. Lo-till may favor some cultivars while conventional tillage practices favor a different group of cultivars. In this study, ten hard red winter wheat cultivars were grown under LT and CT in field plot studies conducted at two locations during the 1985 and 1986 growing seasons: the Oklahoma South Central Research Station at Chickasha, on a McLain silt loam (Pachic Argiustoll, fine, mixed, thermic); and, the Oklahoma North Central Research Station at Lahoma, on a Pond Creek silt loam (Pachic Argiustoll, fine-silty, mixed, thermic). The CT was performed with a

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moldboard plow, with additional disking performed as requiredfor weed control. Lo-till consisted of undercutting with a 1.5m V- blade, with herbicides applied for additional summer weed control. Location, tillage, cultivar and year interactions were statistically significant for yield and yield components. Accordingly, analyses were run separately for each location-year-tillage combination to determine cultivar differences, and for each location-year-cultivar to detect tillage differences. Significant tillage and cultivar effects were observed for yield (YIELD), spikelets per head (SPK/HD), seeds per head (SEEDS/HD) and 1000 kernel weight (1000KWT). The greatest tillage effect was observed at Chickasha-1985: wet conditions delayed planting and harvest, YIELD and 1000KWT showed significantly lower values under LT. At the remaining three location-years, LT performed better that CT for 25 of the 28 instances in which a significant tillage effect was observed for a measurement. Tillage x cultivar interactions were not significant for any of the yield components; tillage x cultivar interactions were significant for YIELD only at Lahoma-1986. We conclude, for these environmental conditions, that there does not appear to be any need to develop a separate breeding program for hard red winter wheat cultivars to be grown under LT cultivation.

Additional index words: Genotype x Tillage Environment, Conservation tillage, Minimum tillage, Triticum aestivum L.

INTRODUCTION

The use of lo-till (LT) cultivation in winter wheat (Triticum aestivum L.) production may provide important advantages to farmers. Lo-till requires fewer energy consuming tillage operations, saving the farmer time and reducing his cultivation energy costs. Surface residues left by LT reduce wind and water erosion of topsoil and increase water storage in the soil profile. However, wheat yields obtained under LT cultivation have not been consistent compared to CT. Yields for LT are sometimes lower than yields obtained under conventional tillage (CT) (Knisel et al., 1961; Bond et al., 1971; Tucker et al., 1971; Bauer and Kucera, 1978), and sometimes the same or higher (Gates et al., 1981; Allan, 1982; Ciha, 1982).

The amount of environmental stress and its timing can influence wheat development and interact with the tillage system being used. Because of higher moisture retention under LT cultivation (Greb et al., 1967; Smika and Wicks, 1968), LT should tend to provide for better germination and early root development (Finney and Knight, 1973; Ellis and Barnes, 1978; R.E. Phillips, 1981; Richard and Passioura, 1981). Increased soil moisture retention may allow earlier planting in such areas or allow for better stand establishment. The amount and distribution of straw residue left on the surface will also affect soil temperature, thereby affecting plant development and potential yields (Black, 1970; Van Doren and Allmaras, 1978; Gauer et al., 1982)..

Lo-till cultivation, however, may create new problems, especially in the control of weeds, diseases and insects. As well, straw cover may prevent adequate seed contact with the soil (Lynch et al., 1981; Izaurralde et al., 1986). The straw cover may also reduce light available to the emerging plants, reducing the chances of successful plant establishment (Rickman et al., 1985). Tillage systems also effect soil compaction and aeration (Power, et al., 1984).

Yield components can reflect differences in the quality of the growth environment provided by different tillage systems. Ciha (1982) found, for spring wheat, that tillage environment did not significantly affect heads per unit area, or seeds per head, but that tillage did influence the number of spikelets per head and 100-seed weight. Allan (1982) found that wheat kernel weight decreased under CT.

In this study, 10 hard red winter wheat cultivars common to the Southern Great Plains were grown under LT and CT management. The objectives were: (i) identify tillage effects on yield and yield components (ii) identify cultivar differences for these measurements and (iii) identify tillage x cultivar interactions for these measurements.

MATERIALS AND METHODS

Field plot studies were conducted at two locations: the Oklahoma South Central Research Station at Chickasha and the Oklahoma North Central Research Station at Lahoma, during the 1985 and 1986 growing seasons. The soil type at Chickasha was a McLain silt loam (Pachic Argiustoll, fine, mixed, thermic); the annual rainfall was 1.11m in 1985 and 1.19m in 1986, with a long term average of 0.81m. The soil type at Lahoma was a Pond Creek silt loam (Pachic Argiustoll, fine-silty, mixed, thermic); the annual rainfall was 0.98m in 1985 and 1.20m in 1986, with a long term average of 0.71m.

Ten hard red winter wheat cultivars were grown under LT and CT. A randomized complete block design was employed, with split-plot subunits in strips; there were 8 replications at each location. Tillage made up the main plots and subplots of cultivars were seeded across the tillage strips. The ten hard red winter wheat cultivars used are adapted to the Southern Great Plains: Chisholm, Mustang, Newton, Osage, Payne, Probrand 835, TAM 105, TAM W-101, Triumph 64 and Vona. They were selected to try to represent as broad a genetic diversity as possible for adapted cultivars.

Conventional tillage was performed with a moldboard plow. Additional tillages with a disk were performed as required for weed control. LT consisted of undercutting with a 1.5 m V-blade to a depth of 120mm. Additional weed control in the LT plots was obtained by spraying immediately following the V-blade with a herbicide tank mixture of terbutryn (2-[tert-butylamino-4-(ethylamino)-6-(methylthio)-s-triazine]), at 1.79 kg/ha of active ingredient (a.i.); atrazine [2-

chloro-4-(ethlyamino)-6-(isopropylamino)-s-triazine], at 0.50 kg/ha (a.i.); chlorsulfuron (2-chloro-N-{[(4-methoxy-6-6-methyl-1,3,5-triazine-2-yl) amino] carbonyl} benzenesulfonamide), at 16.5 g/ha (a.i.); 2,4-D [(2,4-dichloro-phenoxy) acetic acid, butoxyethanol ester] was included at 1.5 l/ha (a.i.) if broadleaves were already present. Glyphosate [N-(phosphonomethyl) glycine] was used to kill volunteer wheat and any weeds present at planting, at a rate of 0.5 l glyphosate (a.i.)/50 l H_2O/ha.

Based on soil test results from the Oklahoma State University Soil and Water Service Laboratory, fertilizers were added so as to prevent fertility from limiting growth and yields. Anhydrous ammonia was applied with the V-blade on all plots immediately after harvest of the preceding crop, at a rate of 100 kg N/ha, before other tillage or spray operations. Diammonium phosphate (18-46-0) was banded at the rate of 100 kg/ha at planting.

Plots consisted of 10 drill rows of a cultivar; drill rows were 0.25m apart and 7.5m long. The plots were seeded with a Crustbuster No-Till drill, with double disk openers at 55 kg/ha; the Chickasha 1985 plots were seeded October 2nd, the Lahoma 1985 plots were seeded November 5th. In 1986, seeding was delayed because of wet field conditions: the Chickasha plots were seeded Nov. 25th, Lahoma plots were seeded Dec. 1st. Soil moisture at planting was determined as percent moisture on a weight basis, using gravimetric soil samples taken from 0 to 50mm and 50mm to 150mm depths. Straw residue cover at seeding was evaluated using the modified step-point system described by Owensby (1973).

At maturity, 10 wheat heads were randomly collected; two or three heads were pulled from either side of a 1m stick tossed into the plots two times. The collected heads were evaluated to determine spikelets per head (SPK/HEAD) and seeds per head (SEED/HD). Total plots were harvested with a Gleaner A combine with a 3m header. Because of lodging, it was not possible to obtain a count of heads per unit area at Chickasha in both years, therefore heads per square meter (HD/SQM) was calculated from the yield and the remaining yield components: kernel weight and seeds per head. Grain yields were adjusted to 13.5% moisture and 27.2 kg test weight. Samples were collected from the harvested grain from each plot to determine 1000 kernel weight (1000KWT).

Analysis of variance was run using SAS 5.0 on an IBM 3081K mainframe and PC SAS 6.0. Analysis was run for YIELD, SPK/HD, SEED/HD, 1000KWT and HD/SQM. Duncan's Multiple Range Test was used to test for significant difference among treatment levels.

RESULTS AND DISCUSSION

Percent straw cover ranged from 2 to 5% in the CT plots and from 52% to 61% in the LT plots. Soil moisture at seeding in the 0 to 50mm depth averaged 12.5% at Chickasha in 1985 and 18.3% in 1986, 9.9% at Lahoma in 1985 and 17.1% in 1986, there were no significant tillage differences (Nipp and Krenzer, 1988).

Many of the two and three way interactions were statistically significant (P = 0.05) for all parameters evaluated. Therefore, analyses were run separately for each measurement for each location-year-tillage (LYT) combination to compare cultivars, and for each location-year-cultivar (LYC) to compare tillage treatments. Analyses were run for each location-year to evaluate tillage x cultivar interactions.

There were no significant YIELD differences between tillage treatments at Chickasha-1985 (Table 1). The most dramatic tillage difference for YIELD occurred at Chickasha-1986, where LT was significantly lower for every cultivar. Repeated rains delayed harvest for several weeks at this location-year and YIELD was relatively low for both tillages. The delay reduced grain quality and allowed weeds to become established. The LT plots showed greater weed infestation at harvest than the CT plots. Three cultivars showed a significant difference in YIELD at Lahoma-1985; LT was higher for Chisholm, Payne and Probrand 835. At Lahoma-1986, LT YIELD was higher for Mustang and Vona and lower for TAM W-101. Looking across location-years, only TAM W-101 LT YIELD was consistent over two location-years, LT YIELD was lower than CT. Five other cultivars were significantly effected by tillage practice at two location-years, but the tillage effects were reversed at each. Except for the unique conditions at Chickasha-1986, LT and CT provided comparable YIELD for most of the studied cultivars; where there were significant tillage effects at the other location-years, LT YIELD was significantly higher than CT for five of the six LTC combinations.

Cultivars had significantly different YIELD for four of the LYT combinations. Cultivar ranking was not consistent across LYT combinations. Chisholm, Mustang and TAM 105 tended to perform relatively well. Probrand 835 showed the most difference between location-years, having the highest YIELD in Chickasha-1985 and one of the lower values at Lahoma-1986. For each of the yield components, cultivars were significantly different at each LYT combination, but relative rankings were not consistent across location-years.

Two cultivars had significantly higher LT SPK/HD at Chickasha-1985: Payne and TAM 105 (Table 2). The highly significant tillage difference for YIELD at Chickasha-1986 is not present for SPK/HD. SPK/HD values tend to be relatively large for both tillages at Chickasha-1986, compared to the other location-years. The developing plants at Chickasha-1986 were subjected to wet field conditions, and the plants showed relatively poor early development (Nipp and Krenzer, 1988). Given a poor beginning, the relatively high SPK/HD suggests some attempt to compensate, or at least a better environment during floral initiation development. Three cultivars had significantly higher LT SPK/HD at Lahoma-1985: Osage, Payne and TAM W-101. At Lahoma-1986: LT SPK/HD was lower for Vona, but higher for Probrand 835. Except for Vona, LT SPK/HD was higher for all LTC combinations showing a significant tillage effect. Only Payne showed at consistent tillage difference at more than one location-year: Chickasha-1985 and Lahoma-1985.

In Table 3, the means for SEED/HD are shown. Chisholm and Payne showed significantly higher SEED/HD under LT at Chickasha-1985. At Chickasha-1986, as with SPK/HD, there were no significant tillage effects. Unlike SPK/HD, SEED/HD at Chickasha-1986 was not noticeably higher that the other location-years. Given the higher SPK/HD and the normal SEED/HD, the number of seeds per spikelet was relatively low at Chickasha-1986; suggesting possible stress during flowering at this location-year. At Lahoma-1985: three cultivars had significantly higher SEEDS/HD under LT: TAM W-101, Triumph 64 and Vona. At Lahoma-1986: LT SEEDS/HD were significantly higher for Osage and significantly lower for Triumph 64. Except for Triumph 64, LT was higher for all LTC combinations showing a significant tillage effect. Only Triumph 64 showed a significant tillage effect at more than one location-year; LT was higher at Lahoma-1985 and lower at Lahoma-1986.

The means for 1000KWT are shown in Table 4. There were no significant tillage differences at Chickasha-1985. At Chickasha-1986, LT 1000KWT was higher for one cultivar, TAM W-101, and lower for five cultivars: Chisholm, Mustang, TAM 105, Triumph 64 and Vona. The lower LT 1000KWT for the five cultivars supports the observation that the delayed harvest at Chickasha-1986, combined with weed problems in the LT plots, reduced grain quality in most of the LT plots. At Lahoma-1985, the tillage trend reversed, with six cultivars showing a higher LT 1000KWT: Chisholm, Mustang, Osage, Payne, TAM 105 and Triumph 64. At Lahoma-1986, only TAM W-101 showed a significant tillage effect.

TAM W-101 showed a consistent tillage effect at two location-years. Four cultivars showed significant but opposite tillage effects at two location-years: Chisholm, Mustang, TAM 105 and Triumph 64. Osage and Vona showed a significant tillage effect at only one location-year. Newton and Probrand 835 did not show a significant tillage effect at any location-year. For most of the cultivars, LT and CT provided comparable results for each measurement. If Chickasha-1986 is not included, due to its exceptional conditions, LT performed better than CT for 25 of the 28 instances in which a significant tillage effect was observed for a measurement. The relative value and the problems of LT production appear dependent on the specific locale and environmental conditions. Lo-till did as well or better than CT at three out of four location-years, but did very poorly at one location-year.

Tillage x cultivar interaction was not significant at any of the location-years for SEEDS/HD, SPK/HD or 1000KWT. Nonetheless, tillage x cultivar interaction for YIELD was significant for one location-year, Lahoma-1986. Mustang and Vona had higher YIELD under LT, TAM W-101 had higher YIELD under CT. There may therefore be grounds to select for LT cultivars, but it may be more relevant in environments where more dramatic differences in the growth environments provided by the two tillage practices are known to be consistently present, as in areas prone to severe drought stress.

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Table 1. Yield of winter wheat cultivars grown under lo-till (LT) and conventional tillage (CT), at each of two locations and two years.

	Chickasha				Lahoma			
	1985		1986		1985		1986	
Cultivar	CT	LT	CT	LT	CT	LT	CT	LT
	kilograms/ha							
Chisholm	2713 a+	2898 a	1304 a	678 a **	1480 a	1644 a *	2186 bc	2362 ab
Mustang	2688 a	2797 ab	1499 a	899 a **	1768 a	2025 a	1980 d	2214 bc *
Newton	2269 cd	2432 cd	1478 a	986 a **	1483 a	1534 a	1459 g	1409 f
Osage	1930 ef	1670 e	1362 a	782 a **	1470 a	1717 a	1932 de	1909 d
Payne	2450 bc	2570 bc	1005 a	596 a **	1499 a	1779 a *	2478 a	2484 a
Probrand 835	2581 ab	2794 ab	1185 a	710 a **	1514 a	1702 a *	1709 f	1802 de
TAM 105	2067 de	2321 cd	1675 a	1057 a **	1886 a	1864 a	1774 ef	1670 e
TAM W-101	2191 d	2270 cd	1090 a	568 a **	1450 a	1542 a	2292 b	2138 c **
Triumph 64	1805 f	1801 e	1415 a	742 a **	1619 a	1805 a	2100 cd	2187 bc
Vona	2128 de	2238 d	1282 a	851 a **	1604 a	1785 a	2075 cd	2226 bc *

\+ Means within a column followed by the same letter do not differ significantly at the 0.05 level of probability, according to Duncan's Multiple Range Test.

*,** Tillage effect, within a year and location, is significant at the 0.05 and 0.01 levels of probability, respectively.

Table 2. Spikelets per head for winter wheat cultivars grown under lo-till (LT) and conventional tillage (CT), at each of two locations and two years.

	Chickasha				Lahoma			
	1985		1986		1985		1986	
Cultivar	CT	LT	CT	LT	CT	LT	CT	LT
	spikelets / head							
Chisholm	13.9 abc+	14.8 a	18.0 ab	18.1 a	13.5 b	13.2 bcd	12.3 c	12.9 cd
Mustang	14.0 abc	14.3 abc	17.3 bc	17.3 abc	14.5 a	13.9 ab	13.8 b	13.6 abc
Newton	14.8 a	14.3 abc	17.3 bc	17.1 abc	13.4 b	13.4 abcd	13.9 ab	13.2 bcd
Osage	12.6 d	13.4 c	16.0 d	16.7 c	13.0 b	14.3 a **	14.0 ab	14.4 a
Payne	13.4 cd	14.6 ab *	17.1 bcd	16.4 c	12.9 b	14.0 ab *	14.1 ab	14.4 a
Probrand 835	14.0 abc	14.3 abc	17.0 bcd	16.1 c	13.7 ab	13.8 abc	14.0 ab	13.2 bcd
TAM 105	13.4 cd	14.6 ab **	18.0 ab	18.1 a	13.5 b	12.8 d	12.5 c	12.4 d
TAM W-101	13.0 cd	13.7 bc	17.1 bcd	16.4 c	12.8 b	14.0 ab **	14.8 a	14.0 ab
Triumph 64	13.6 bc	14.1 abc	16.8 cd	17.0 bc	12.7 b	13.0 cd	14.5 ab	12.5 d *
Vona	14.6 ab	14.0 abc	18.6 a	17.8 ab	13.1 b	13.5 abcd	14.7 ab	13.5 bc *
CV, %	16.6	16.6	12.7	13.1	14.9	13.2	13.4	13.5

\+ Means within a column followed by the same letter do not differ significantly at the 0.05 level of probability, according to Duncan's Multiple Range Test.

*,** Tillage effect, within a year and location, is significant at the 0.05 and 0.01 levels of probability, respectively.

Table 3. Seeds per head for winter wheat cultivars grown under lo-till (LT) and conventional tillage (CT), at each of two locations and two years.

	Chickasha				Lahoma			
	1985		1986		1985		1986	
Cultivar	CT	LT	CT	LT	CT	LT	CT	LT
	seeds / head							
Chisholm	25.8 b+	40.0 a **	32.5 a	33.2 a	30.6 bc	31.5 abc	24.6 c	25.7 abc
Mustang	29.7 a	26.6 bc	31.1 ab	33.2 a	34.0 a	30.0 bc	25.1 c	25.9 abc
Newton	29.9 a	29.3 abc	32.5 a	29.2 ab	31.6 ab	29.4 c	26.4 abc	27.0 ab
Osage	24.5 b	26.3 c	26.2 c	27.2 b	28.7 bc	32.0 ab	25.3 bc	28.0 a *
Payne	25.1 b	30.2 ab *	31.0 ab	29.2 ab	30.4 bc	32.6 ab	25.0 c	26.5 ab
Probrand 835	26.7 ab	27.8 abc	31.1 ab	29.2 ab	31.4 abc	31.9 abc	28.7 a	27.8 ab
TAM 105	25.6 b	28.5 abc	34.8 a	33.2 a	30.4 bc	29.3 bc	24.9 c	25.1 bc
TAM W-101	24.4 b	27.5 abc	28.2 bc	28.2 b	29.8 bc	33.1 ab *	27.9 ab	28.3 a
Triumph 64	25.8 b	27.5 abc	31.9 ab	31.2 ab	29.2 c	31.9 abc *	26.7 abc	23.7 a **
Vona	27.2 ab	26.4 c	34.9 a	31.2 ab	29.4 bc	33.8 a **	26.8 abc	26.2 abc
CV, %	29.1	27.7	25.7	27.7	20.8	19.6	21.3	19.8

\+ Means within a column followed by the same letter do not differ significantly at the 0.05 level of probability, according to Duncan's Multiple Range Test.

*,** Tillage effect, within a year and location, is significant at the 0.05 and 0.01 levels of probability, respectively.

Table 4. 1000-seed weight of winter wheat cultivars grown under lo-till (LT) and conventional tillage, (CT) at each of two locations and two years.

	Chickasha				Lahoma			
	1985		1986		1985		1986	
Cultivar	CT	LT	CT	LT	CT	LT	CT	LT
	- grams -							
Chisholm	29.4 b+	29.2 bcd	20.4 abc	17.8 ab **	23.6 b	26.2 b *	25.2 bc	25.0 bc
Mustang	31.4 a	31.0 a	21.6 a	19.6 ab **	25.4 b	26.4 b *	23.8 cd	24.0 c
Newton	25.8 de	25.6 e	20.8 ab	20.2 a	21.2 c	21.8 d	23.4 d	23.4 cd
Osage	28.0 e	28.2 cd	21.6 a	19.2 ab	21.8 c	23.0 cd *	25.8 b	26.6 b
Payne	26.6 de	27.2 d	19.6 abc	19.0 ab	21.6 c	23.0 cd *	25.4 b	25.0 bc
Probrand 835	29.8 b	30.4 ab	18.0 c	17.2 b	24.4 b	25.8 b	22.8 d	23.4 cd
TAM 105	25.2 e	25.2 e	20.6 ab	19.2 ab **	20.4 c	22.0 d *	23.0 d	23.4 cd
TAM W-101	30.4 ab	30.8 ab	18.2 c	18.8 ab **	24.4 b	24.8 bc	29.6 a	30.4 a *
Triumph 64	27.6 c	29.2 bcd	19.0 bc	17.2 b **	29.2 a	30.4 a *	26.6 b	26.0 b
Vona	25.8 de	25.0 c	20.8 ab	19.8 a **	21.8 c	22.6 d	21.0 e	22.2 d
CV, %	4.5	5.8	10.9	12.0	7.0	7.6	6.3	5.9

\+ Means within a column followed by the same letter do not differ significantly at the 0.05 level of probability, according to Duncan's Multiple Range Test.

*,** Tillage effect, within a year and location, is significant at the 0.05 and 0.01 levels of probability, respectively.

CONCLUSIONS

Among the measurements proposed by Klepper and her associates, MSL stage and %T1 appear the most usable for detecting treatment differences in the quality of the early growth environment of winter wheat plants. Measuring %T0 did reveal significant treatment differences, but the very high variability of this measurement appears to limit its usefulness. The percent formation of T2 was affected by treatment differences, but the treatment effect was lower that for either %T0 or %T1; %T2 was relatively unaffected by environmental differences.

Significant treatment differences for one or more of these measurements were observed in each of the studies. Significant differences were observed among cultivars grown in a favorable environment for MSL stage, PI and %TF for T1 and T2. Since treatments affected MSL response to accumulated heat units, experimenters should be aware that cultivars may develop a little differently in their environments when compared to the basic developmental model worked out by Klepper. Extrapolation of other plant development stages based on MSL stage is therefore questionable if the basic developmental pattern of a specific cultivar has not been shown to conform to Klepper's model.

Moisture treatments can significantly effect the rates at which mainstem leaves appear in response to accumulated heat, which is in contrast to the proposal of Klepper et al. (1982) that this response rate would not be affected by environmental factors, short of killing the plant. Since reduced moisture did affect the response rate, MSL stage may not reflect only the preemergent seedbed environment, but it may also be indicative of the quality of the overall growth environment until the time of measurement.

Sampling to detect treatment differences using MSL stage required the least amount of plant material; %T1 required three times as much material, at best. The remaining tillers required substantially more plant material to detect treatment differences. Since there were substantial differences in the variability of the studied sampling levels within experimental units, it was possible to devise an optimum sampling strategy that would minimize the number of plants required to detect half a MSL stage difference. A sampling strategy was identified that would provide an 90% probability of detecting the treatment difference of half a leaf stage, with a small number of plants sampled.

Tillage and cultivar differences were observed at some of the location-years in field studies. As in the growth chamber and sampling strategies, MSL stage and %T1 were the most successful in detecting treatment differences. The growth environments provided by LT and CT management were comparable for most cultivars at most location-years. Consistent tillage effects for cultivars across location-years were not observed for yield and yield components. At Chickasha-1986, LT did poorly, but in the remaining year locations LT had a performance advantage over CT in most cases where significant treatment differences were observed. There may therefore be grounds to select for LT cultivars, but it may be more relevant in environments where more dramatic differences in the growth environments provided by the two tillage practices are thought to be present, as in areas prone to severe drought stress.

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