Tillage System, Crop Rotation and Environmental Stress on Spring Wheat Development and Yield

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Wheat plants develop in an orderly fashion from seed germination to plant maturity. Development can be quantified in the field by visual identification and measurement of leaves and tillers using a method developed by Haun (5). Each new leaf formed represents one unit of development. Haun 4.3 indicates four fully mature leaves, plus a fraction of the fifth leaf has developed.

Klepper et al. (6,7) further expanded identification of leaf and tiller development of the wheat plant. Plants were segregated into main stem (MS), the first culm developed by the plant, coleoptile tiller (TO) which develops on a node near the seed, and the first (T1), second (T2), and third (T3) tillers that develop on nodes at the base of the respective leaves. Each leaf (main stem and tiller) is assigned a Haun rating (according to development) and length measured. Their research indicated this plant development identification method was useful in detecting environmental stresses since various stresses caused tillers to be skipped or delayed.

Plant development is influenced by heat units or energy. Daily heat units are determined by finding the mean air temperatures (maximum minus minimum) and subtracting the base temperature (32 degrees Fahrenheit) at which wheat plants cease to grow. The accumulation of daily heat units is called growing degree days (GDD). If maximum air temperature exceeds 70 F before growth stage 2.0 or 95 F after growth stage 2.0, the high temperatures are replaced with the 70 or 95 F temperatures in GDD calculations, because plant development ceases at high temperaturs. Bauer et al. (1) suggested that GDD may be used as an alternative method to estimate growth stage. As an example, a plant at Haun growth stage 6.0 normally requires or accumulates 800 GDD heat units from emergence.

The environment to which wheat plants are subjected not only affects development but also determines growth rate. We know that amount and distribution of precipitation, soil type or texture, soil fertility level and soil temperature influence plant growth. Tillage system, previous crop or crop rotation, type and amount of residue, time, type and degree of cultivation, seeding depth, seeding rate, row spacing and cultivar planted plus weed, disease or insect pressure may also influence rate of growth. We need to understand how each of these individual variables or their interaction with other variables affect plant development, growth rate and final yield to establish the best management techniques.

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The effects of management techniques, positive or negative, applied to spring wheat production are often masked when growing conditions are ideal. Plants need to be exposed to environmental stress to truly evaluate some management techniques. The drought stress during 1988, although not planned, appeared to be ideal for evaluating plant stress under established management variables. Plant development, growth and yield of spring wheat as influenced by tillage system, crop rotation, previous crop maturity, cultivation, residue type, GDD and soil temperature were evaluated in this study.

PROCEDURE

This field study was conducted on a fine-textured Fargo clay soil where four tillage systems were previously established and planted to an alternating rotation of barley and row crop (soybean or sunflower). The soybean-barley rotation and only two of the four tillage systems were considered in this study.

Tillage systems for the row crop portion included conventional fall plow (barley stubble mold board plowed followed by both fall and spring secondary tillage prior to planting) and no-till (row crop planted directly into barley stubble without tillage). Each tillage system plot was split to include cultivation or no cultivation for weed control. Weed control subplots were further split to include two different maturity soybean cultivars, an early cultivar (McCall) and a medium to late maturity cultivar (Dawson). Barley in the rotation was planted no-till into soybean residue on both tillage systems. Details on the previous tillage system-crop rotation are outlined in papers by Deibert (2,3,4).

In the fall of 1987 the study area contained four blocks, two with soybean residue (3,400 to 3,500 lb/A) and two with barley residue (2,100 to 2,200 lb/A). One half of the previous plow and no-till system plots of each residue type was cultivated while the other half received no cultivation. Cultivation consisted of one chisel plow operation (barley stubble late August and soybean stubble early October) plus two double disk operations in late October. Cultivated plots also received one tillage operation in the spring with a field cultivator prior to planting. No fertilizer was applied to the plots (see Table 1 for soil test values).

The study consisted of two replications set up with a split, split, split plot arrangement in a randomized complete block design. Main plots were residue type, followed by splits of tillage system, cultivation and previous cultivar maturity.

Amidon spring wheat was planted in late April at 90 lb/A in 10-inch spacing (26 seeds per foot row) with a no-till drill.

Table 1. Soil test values for various crop residues and tillage systems on a Fargo clay soil — 1988.

Soil Property	Depth (inches)	Soybean Residue		Barley Residue	
		Plow	No-till	Plow	No-till
pH	0 - 3	7.7	7.5	7.6	7.6
(1:1)	3 - 6	7.6	7.6	7.8	7.8
O.M.	0 - 3	4.0	4.5	4.2	4.3
(%)	3 - 6	4.2	4.1	4.2	3.8
P	0 - 3	16	27	20	26
(lb/A)	3 - 6	12	9	14	13
K	0 - 3	860	1470	920	1240
(lb/A)	3 - 6	830	710	860	650
NO_3-N	0 - 24	55	53	68	53
(lb/A)	24 - 48	12	16	42	20

Table 2. Precipitation, maximum-minimum air temperature, pan evaporation and Growing Degree Days at Fargo, N.D.

Climatic Parameter	Year[1]	April	May	June	July	Aug
Precipitation	Normal	1.90	2.24	3.06	3.34	2.67
(in.)	1988	0.00	2.72	1.41	0.63	0.41
Avg. Maximum	Normal	52	68	77	83	81
Air Temperature (°F)	1988	60	77	87	89	85
Avg. Minimum	Normal	32	43	54	58	56
Air Temperature (°F)	1988	29	49	61	60	59
Pan Evaporation	Normal	—	8.2	8.0	8.9	7.8
(in.)	1988	—	11.1	12.6	13.2	11.3
Growing Degree	Normal	352	606	999	1161	—
Days (GDD)	1988	455	914	1260	1294	—

[1]Normal refers to the long term average 1951-1980 for all parameters except pan evaporation which is based on the 10 year average 1978-1987.

Continuous recording soil thermometers were installed at a 4-inch depth to monitor soil temperature on the different residue, tillage system and cultivation treatments. Plots were sprayed with recommended rates of bromoxynil and diclofop for postemergence weed control. Whole plants (roots and tops) were collected from 20 inches of row at seven weeks after planting and counted for stand determination. Ten plants were randomly selected and seed depth, crown depth, Haun ratings and leaf length determined. The above ground portion of the wheat plant was sampled from 10 feet of row at soft dough stage (12 weeks after planting) to determine total dry matter and head count numbers. At maturity, a 104 foot square area was harvested with a small plot combine for yield determination. Straw dry matter was determined by subtracting grain dry matter from total dry matter.

RESULTS AND DISCUSSION

Weather

Growing conditions were not ideal for spring wheat production in 1988 as a result of the extreme drought conditions, as indicated in the climatic conditions presented in Table 2. No precipitation was received in April. Severe wind erosion occurred the first week of May on fields with little residue cover. Although precipitation received in May during early plant development was above normal, June and July amounts were below normal. A total of 4.7 inches of precipitation was received from planting to harvest, which was 4.0 inches below amounts normally received during this period. Precipitation events that exceeded 0.50 inches occurred on only May 18 (0.50 inches), May 31 (0.62 inches) and July 14 (0.86 inches). Average maximum and minimum air temperatures were above normal in May, June and July. Air temperatures exceeded 90 F during the growing season on 20 days. Pan evaporation ranged from 2.9 to 4.6 inches above normal.

Soil Temperature

Soil temperatures at the 4-inch depth were below 50 F the first week after planting but increased rapidly as average maximum air temperatures exceeded 75 F the second week. Some variation in emergence was observed within plot but was consistant irrespective of tillage system, cultivation or residue type. Row sections that emerged at the same time were marked for later plant sampling.

Both maximum and minimum soil temperatures (Table 3) were normally cooler with no cultivation than when cultivated. It is interesting that maximum soil temperatures were much warmer under soybean residue with the plow system when no cultivation was performed whereas with barley residue the opposite was true, having lower maximum temperatures without cultivation. Soil temperatures with the no-till system were affected less by cultivation and residue type. This difference in soil temperature is related to heat retention of moist versus dry soils in conjunction with residue cover.

Growing Degree Days

The warm air temperatures provided for a large number of GDD units, with 284 units received from planting to emergence. Normally during this time period, 237 units can be expected. The number of GDD accumulated from emergence to plant sample time (6 leaf or main stem Haun 6.0) in 1988 was 1,182 while the normal is 946. According to Bauer et al. (1), only 803 GDD units are required to reach Haun stage 6.0. Thus the excessive temperatures caused high evapotranspiration rates or plant stress, which slowed plant development. The accumulated number of GDD units from planting to harvest time was 3,168, or 341 units above what is normally expected for this growing season period.

Crop Emergence

The surface 0 to 3 inches of soil was extremely dry. Cultivated soils dried to a greater depth than soils not cultivated. Seeds were planted to moisture to ensure uniform emergency, which required a greater seeding depth than normal. The average measured seeding depth was 2.3 and 2.0 inches for the respective cultivated and noncultivated soils with little difference between soybean or barley residue. Crowns were located, on the average, 1.3 and 1.2 inches below the soil surface for cultivated and noncultivated soils. Plants did not emerge until 14 days after planting and received no precipitation during this time (see Table 3).

Table 3. Precipitation, air temperature and growing degree days plus 4-inch soil temperature under different residue, tillage system and cultivation conditions — 1988.

Climatic Parameter	Tillage System	Cultivation System		Days After Planting 1-7	8-14	15-21	22-28	29-35	36-42	43-49
Precipitation (in.)				0.00	0.00	0.69	1.00	0.41	0.62	0.00
Air Temperature (°F)			Max	62	77	75	72	76	90	90
(Average)			Min	31	46	45	46	48	64	61
Growing Degree Day			Normal	108	129	141	176	198	201	230
(Base 32° F)			1988	102	182	180	167	213	319	303
Soil Temperature (°F) Soybean Residue (Average 4-inch)										
	Plow	Cultivation	Max	48	58	59	60	66	75	79
			Min	38	51	51	53	57	66	69
		No Cultivation	Max	47	59	60	61	67	77	84
			Min	36	50	50	52	56	66	69
	No-till	Cultivation	Max	46	57	58	59	65	76	81
			Min	37	49	50	53	56	66	69
		No Cultivation	Max	46	56	58	58	65	75	79
			Min	35	48	49	51	54	65	67
Soil Temperature (°F) Barley Residue (Average 4-inch)										
	Plow	Cultivation	Max	[1]	—	—	61	68	75	81
			Min	—	—	—	53	56	66	68
		No Cultivation	Max	—	—	—	57	63	72	77
			Min	—	—	—	52	55	65	68
	No-till	Cultivation	Max	47	56	59	59	66	74	78
			Min	39	51	52	54	57	66	69
		No Cultivation	Max	46	55	57	58	64	72	77
			Min	38	49	50	52	56	66	68

[1]Incomplete data due to continuous recording thermometer malfunction.

Seed germination and emergence was excellent, as average stand counts taken 49 days after planting ranged from 39 to 49 plants per 20 inches of row (Tables 4, 5, 6). Stand counts averaged four plants higher on the soybean residue than barley residue and four to seven plants lower on the cultivated compared to no cultivation. The small difference in stand related to cultivation is associated with drier soil conditions with cultivation while the difference in stand with respect to residue type is possibly disease or alleopathic related with the planting of one crop species into residue of similar nature.

Main Stem Development

Main stem Haun leaf rating ranged from 5.8 to 6.1 at 12 weeks with plants on the no-till system and no cultivation less developed on both residue types. However, main stem leaves on the no-till system and no cultivation plots were longer than systems with tillage. The observance of taller plants with no-till was reported earlier by Deibert (4). A visual observation indicated that plants on tilled plots produced wider and shorter leaves whereas untilled plots produced longer, narrower leaves. Although some differences in single plant weights were observed, the higher weights in general appear to be more closely related to plant stand than tillage system, cultivation or residue type.

Tiller Development

Plants in this study exhibited no development of the ceoloptile tiller (TO). This may have been related to the plant stress but is probably due to the higher stand, since Peterson et al. (8) indicated that TO development was more pronounced with thin stands. Development of TO in the field may be one management indicator of a thin stand. Early season moisture stress also affected T1 tiller development. Plants on the soybean residue had a higher percentage of plants (20.0 percent) with T1 tillers than with barley residue (11.9 percent). Cultivated soybean residue had fewer plants with T1 tillers than without cultivation, but with barley residue the opposite was true. Plots where an early maturity row crop was previously grown also exhibited a higher percentage of plants with T1 tillers than when following a late maturity row crop. Plants grown on the plow system also had less T1 tillers than those planted on no-till. Leaf development was further along and leaf length was greatest on the T1 tiller with barley residue, no cultivation, and no-till system when compared to their counter parts of soybean residue, cultivation and plow system.

These results indicate cultivation of soybean residue had a negative effect on T1 development, probably due to moisture stress. Cultivation of the no-till system had a greater negative effect on T1 development than further cultivation of the plow system. Early plant stress, indicative of T1 development, was controlled by those management practices that dried out the soil early or retained less soil water, namely (1) growing a later maturity crop the previous year, (2) cultivating the soybean residue and (3) cultivating a system previously in no-till.

Table 4. Drought stress, previous residue type and cultivation influence on spring wheat growth parameters — 1988.

	Barley Residue			Soybean Residue		
Plant Growth Parameter	Cultivation	No Cultivation	Avg.	Cultivation	No Cultivation	Avg.
Plant Stand (no./20 in. row)	39	46	43	45	49	47
Main Stem Haun Leaves (no.)	6.1	5.9	6.0	6.0	5.8	5.9
Leaf Length (in.)	11.4	11.8	11.6	9.8	11.4	10.6
Tiller #1 Plants Showing (%)	15.0	8.8	11.9	16.2	23.8	20.0
Haun Leaves (no.)	1.9	2.1	2.0	1.7	1.7	1.7
Leaf Length (in.)	4.8	6.8	5.8	4.0	5.0	4.5
Tiller #2 Plants Showing (%)	17.4	30.0	23.7	11.2	20.0	15.6
Haun Leaves (no.)	2.0	2,0	2.0	1.2	1.6	1.4
Leaf Length (in.)	6.2	5.4	5.8	3.4	4.2	3.8
Tiller #3 Plants Showing (%)	26.2	26.2	26.2	10.0	17.6	13.8
Haun Leaves (no.)	1.5	1.7	1.6	0.6	1.2	0.9
Leaf Length (in.)	3.3	5.3	4.3	2.3	2.9	2.6
Single Plant Weight (grams)	.24	.24	.24	.19	.21	.20
Head Produced (no./20 in. row)	43	49	46	41	45	43
Total Dry Matter (lb/A)	2560	2980	2770	1610	2070	1840
Straw Dry Matter (lb/A)	1140	1640	1390	860	1200	1030
Grain Yield (bu/A)	26.8	25.6	26.2	14.3	16.5	15.4

Table 5. Drought stress, previous tillage system and cultivation influence on spring wheat growth parameters — 1988.

	Conventional Plow System			No-till System		
Plant Growth Parameter	Cultivation	No Cultivation	Avg.	Cultivation	No Cultivation	Avg.
Plant Stand (no./20 in. row)	43	47	45	42	48	45
Main Stem Haun Leaves (no.)	6.0	6.0	6.0	6.0	5.8	5.9
Leaf Length (in.)	10.2	11.0	10.6	11.1	12.1	11.6
Tiller #1 Plants Showing (%)	15.0	12.6	13.8	16.2	20.0	18.1
Haun Leaves (no.)	2.7	2.0	2.1	1.4	1.8	1.6
Leaf Length (in.)	5.5	5.7	5.6	3.4	5.2	4.3
Tiller #2 Plants Showing (%)	17.5	27.5	22.5	11.3	22.5	16.9
Haun Leaves (no.)	1.4	2.0	1.7	2.2	1.6	1.9
Leaf Length (in.)	4.0	5.8	4.9	6.5	3.9	5.2
Tiller #3 Plants Showing (%)	13.8	21.2	17.5	22.5	22.5	22.5
Haun Leaves (no.)	1.2	1.6	1.4	1.3	1.3	1.3
Leaf Length (in.)	2.7	4.3	3.5	3.3	4.3	3.8
Single Plant Weight (grams)	.23	.23	.23	.22	.22	.22
Heads Produced (no./20 in. row)	36	44	40	48	50	49
Total Dry Matter (lb/A)	1720	2240	1980	2440	2820	2630
Straw Dry Matter (lb/A)	780	1220	1000	1230	1630	1430
Grain Yield (bu/A)	18.0	19.6	18.8	23.0	22.4	22.7

Table 6. Drought stress, previous rotation crop maturity and crop residue type influence on spring wheat growth parameters — 1988.

Plant Growth Parameter	Rotation: Early Maturity Crop — Barley Residue	Soybean Residue	Avg.	Rotation: Late Maturity Crop — Barley Residue	Soybean Residue	Avg.
Plant Stand (no./20 in. row)	39	49	44	46	44	45
Main Stem Haun Leaves (no.)	5.9	5.9	5.9	6.0	6.0	6.0
Leaf Length (in.)	11.6	10.6	11.1	11.7	10.5	11.1
Tiller #1 Plants Showing (%)	15.0	22.6	18.8	8.7	17.5	13.1
Haun Leaves (no.)	2.0	1.6	1.8	1.9	1.7	1.8
Leaf Length (in.)	5.6	4.2	4.9	5.3	4.9	5.1
Tiller #2 Plants Showing (%)	25.0	17.4	21.2	22.5	13.7	18.1
Haun Leaves (no.)	2.3	1.5	1.9	1.7	1.3	1.5
Leaf Length (in.)	6.4	3.6	5.0	4.9	4.3	4.6
Tiller #3 Plants Showing (%)	27.5	13.7	20.6	25.0	13.8	19.4
Haun Leaves (no.)	1.8	1.0	1.4	1.2	1.0	1.1
Leaf Length (in.)	5.1	3.1	4.1	3.4	2.4	2.9
Single Plant Weight (grams)	.26	.20	.23	.23	.19	.21
Heads Produced (no./20 in. row)	46	46	46	46	40	43
Total Dry Matter (lb/A)	2770	2130	2450	2760	1540	2150
Straw Dry Matter (lb/A)	1420	1100	1260	1360	940	1150
Grain Yield (bu/A)	25.7	19.6	22.7	26.6	11.2	18.9

Development of T2 and T3 tillers gives an indication of how well plants survive stress later in the season. Soybean residue, both cultivated and noncultivated, had progressively fewer plants develop T2 and T3 tillers than plants that developed T1 tillers. However, cultivation of soybean residue decreased both Haun leaf rating and leaf length of both T2 and T3 tillers. Noncultivated barley residue had a higher percentage of plants that developed T2 tillers than plants with T1 or T3 tillers. Cultivated and noncultivated barley residue had similar numbers of plants with T3 tillers, but Haun rating and leaf length were lower. The plow system, especially when cultivated, contained a higher percentage of plants with T2 tillers but fewer plants with T3 tillers than the no-till system. Leaf ratings and leaf length of T2 and T3 were affected less by tillage systems. Rating and length of leaves of T3 were affected less by tillage system, residue type and maturity of previous crop because plant moisture stress was less as a result of the late precipitation received. The maturity of the previous crop grown appeared to have less effect on development of T2 and T3 than T1 development. There was a trend toward a higher percentage of wheat plants with greater leaf development and leaf length grown on barley residue where the previous crop was early maturity.

Heads Produced

The number of heads counted at plant maturity were three to four heads higher than stand count with barley residue but four heads lower with soybean residue. This indicates that a few of the wheat tillers that developed on barley residue, cultivated or noncultivated, produced mature heads while some wheat plants grown on soybean residue were under such stress than even the main stem did not develop a head. The number of heads produced under the plow system were also lower than the plant stand while some tillers did produce heads under no-till. The negative effect of plant stress on head development also was accentuated by previous crop maturity, especially with soybean residue, since previous crop maturity is more apparent the year after soybeans than after two years (barley planted the previous year).

Plant Dry Matter

Total plant wheat dry matter averaged 930 pounds higher after barley residue than soybean residue. Total plant dry matter decreased 420 pounds per acre when barley residue was cultivated and decreased 460 lb/acre when soybean residue was cultivated. Wheat straw dry matter averaged 360 lb/acre less after planting in soybean residue than after planting in barley residue. Barley and soybean residue cultivation resulted in a straw dry matter decrease of 500 to 340 lb/acre, respectively. Wheat grown after the no-till system produced 650 lb/acre more total dry matter than when planted after a plow system. Cultivation of the no-till system caused an average reduction in total dry matter of 380 lb/acre while cultivation after the plow system decreased total dry matter by 520 lb/acre. Straw production was reduced 400 to 440 lb/acre with cultivation. Total dry matter after barley residue was similar between early and late maturity crop as expected but decreased from 2,130 lb/acre to 1,540 lb/acre when the late maturity soybean crop was previously planted. This definitely points out the drain on soil water when comparing previous crop (barley vs. soybean) and previous crop maturity (early vs. late).

Crop Yield

Wheat yield after soybean residue was 10.8 bu/acre less than following barley residue. Cultivated barley residue and noncultivated soybean residue produced the highest yields within residue type. No-till provided a 3.6 bu/acre yield advantage over the plow system. Wheat yields were similar after barley residue when comparing areas previously planted to early or late maturity crop but where a late maturity soybean crop was grown the previous year, a 8.4 bu/acre or 43 percent reduction in yield was observed when compared to the area where an early maturity row crop was previously planted.

SUMMARY

The yield differences obtained under limited soil water or drought stress conditions indicate that (1) cultivation of soybean residue has a greater effect on soil water loss than cultivation of barley residue, (2) the no-till system conserved more water than the conventional plow system, and (3) wheat yield following a late maturity row crop, which extracts water for a longer period the previous year, will be expected to have lower yields than on an area where an early maturity crop is grown.

These results were obtained from one year's data (1988) when stored soil water was depleted and growing season precipitation was below normal. However, the information does offer some soil water management ideas since these conditions were not unlike those in previous years (1977, 1980, 1984) and that may occur in the future. The data does point out the dramatic effect previous crop, previous tillage and even previous crop maturity have on the development, growth, and eventual yield of the wheat plant. Since water is the most limiting factor in crop production, one needs to be aware of the effect each management practice has on conserving soil water, and those practices which deplete soil water today will have an effect on water supply and growth of succeeding crops.

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