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Effect of Residue and Tillage on Hard Red Spring Wheat Cultivars

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EFFECT OF RESIDUE AND TILLAGE
ON HARD RED SPRING WHEAT CULTIVARS

BY
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This thesis is approved as a credible and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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I. INTRODUCTION

Notill seeding leaves crop residue on the soil surface which reduces wind and/or water soil erosion. The residue modifies the seedbed environment compared to the black soil surface associated with conventional tillage. Seeding into residue has resulted in enhanced, similar, and reduced grain yields of hard red spring wheat (*Triticum aestivum* L.).

Three studies were conducted to evaluate the growth and grain yield of hard red spring wheat cultivars with different residue rates and tillage systems. Greenhouse and field studies were conducted to determine if three rates of wheat residues (0, 2, and 4 Mg ha^{-1}) affect the growth and yield of spring wheat. Six cultivars of wheat were evaluated in the greenhouse and two cultivars in the field. Field studies comparing eighteen commercially available wheat cultivars seeded notill in wheat stubble and black tillage were conducted to evaluate yield differences due to tillage. Also, growth variables were measured which could be used to explain cultivar interactions and make plant selections for notill specific cultivars.

The residue study in the greenhouse evaluated growth variables ten days after emergence and at physiological maturity. In the field emergence, tillering and plant dry weights were evaluated at various growth stages as well as grain yield and yield components. The greenhouse studies indicated the number of plants that emerged, and their root weights ten days after emergence were reduced when residue was present. At physiological maturity, plant dry weight was lower in the 4 Mg ha^{-1} treatment in one study. Tillering was reduced in both residue treatments, compared to no residue. In the 1986 field study, residues reduced emergence and tillering at all growth stages compared to no residue. Plant dry weights were also decreased at these growth stages when residues were present. However, grain yield was unaffected. In general, the presence of residue appears to be more important than the rate of residue in the early plant development of spring wheat. Also, cultivars appear to respond differently to heavy residues.

The field studies compareng wheat cultivars in tillage systems, evaluated emergence and tillering at various plant growth stages and grain yield. A stratified split plot design was used which places statistical emphasis on cultivar x tillage interactions. The cultivars exhibited a range of increase to decrease grain yield in notill compared to black tillage. Stand establishment was superior at all locations in notill. Tillering at the various growth stages did not explain grain yield differences. Seed weight was the only variable where cultivars responded similarly to cultivar x tillage yield differences. Cultivars of spring wheat grown in the north central region do yield differently as a result of tillage methods indicating that plant selection under notill should be considered to optimize yields obtained under notill production systems.

II. CULTIVAR X TILLAGE INTERACTION OF HARD RED SPRING WHEAT

LITERATURE REVIEW

When spring wheat (*Triticum aestivum* L.) is planted notill into wheat stubble compared to a tilled seedbed grain yield has been enhanced, reduced, or not affected (2,3,4). Generally plant growth and grain yield responses to differential seedbed preparation are the result of such factors as soil moisture, soil temperature, pests, and/or the allelopathic effect of residue. Notill seedbeds tend to have lower spring soil temperature; higher soil moisture; and harbor more insect and disease pests which overwinter on residue at or near the soil surface. In addition, the residue associated with notill seedbeds has shown an allelopathic effect on the newly seeded crop (6).

Similar or reduced yields in notill have been noted in other crops. Hallauer and Calvin compared 14 single-cross corn hybrids and Newhouse and Crosbie compared 60 corn hybrids and found reduced yields with no-tillage. Oplinger, et al. reported that there was a yield reduction in notill compared to conventional tillage when soybeans followed corn in rotation. These studies reported delayed early growth with no-tillage.

Elmore evaluated six soybean cultivars following sorghum and found cultivar yields were similar in all tillage systems when averaged over three years. Hwu and Allan compared 18 winter wheat populations where selections were made in tilled and notill cultures over a five year period. They noted tillage had no affect on phenotypic population structure. These researchers concluded that superior cultivars performed the best regardless of the tillage treatment. The above studies, except one, reported there was no need for separate breeding programs for notill specific cultivars. Elmore found a cultivar x tillage interaction in one year and suggested further research was needed.

Chevalier and Chia reported that stress incurred by spring wheat under no-tillage affected early growth. The length of the second leaf on the main stem was reduced in no-tillage compared to conventional tillage. Also the number of days required to produce 12 leaves on the plant increased in no-tillage. Apparently the plants never recovered and yield was reduced. One spring wheat cultivar did not exhibit a reduction in early growth or grain yield. This was attributed to cultivar tolerance to early stress associated with the notill seedbed environment. They suggest that cultivars to be grown under no-tillage should be selected under no-tillage.

Plant selection in most breeding programs is made in conventionally tilled seedbeds. Therefore, factors not associated with conventional tillage which can retard germination and slow plant growth and development are not considered. These factors associated with notill include stress from cooler soil temperature, higher soil moisture, and the chemical and microbial metabolites from surface residue breakdown. Plant selections made in conventionally tilled seedbeds has increased spring wheat yields, however, can the rate of gain be increased by making selections in notill culture. Previous studies with spring wheat have used four or less cultivars to compare tillage and plant response. The intent of this study was to evaluate the growth and grain yield of 18 hard red spring wheat cultivars under continuous wheat notill and black environments for cultivar x tillage interactions.

MATERIAL AND METHODS

Eighteen hard red spring wheat cultivars adapted to South Dakota were selected. These cultivars represented the range of genotypes and phenotypes presently grown in the northern plains region. Listed by maturity, early to late, they were 'Apex-83', 'Butte', 'Centa', 'Challenger', 'Guard', 'Oslo', '711', 'Angus', 'Len', 'Olaf',' 2369', 'Alex', 'A99AR', 'Buckshot', 'Wheaton', 'Marshall', 'Era', and 'Success'.

Cultivars were grown on a Beotia silt loam soil (fine-silty, mixed Pachicudic Haploboroll) at the James Valley Research Center in central Spink County South Dakota and on an Aberdeen silty clay loam (fine montmorillonitic, glossic Udic Natriboroll) in Brown County near Aberdeen, South Dakota. Experiments were conducted at the Spink County site in 1985 and 1986 and in Brown County in 1986. For statistical analysis and discussion site years will be called locations. The average annual rainfall for Spink and Brown County is 47 cm and 45 cm, respectively.

The experimental design was a stratified split plot with cultivars seeded across tillage strips. Two tillage systems which consisted of spring disking until black and notill (direct seeded into standing stubble) were imposed at each location. The previous crop at each location was spring wheat.

Sub-plots consisted of 9 rows 23 cm apart and 7.62m long. The plots were seeded with a modified Noble deep-furrow hoe drill. Cultivars were seeded at the rate of 100 kg ha^{-1} on April 11, 1985 Spink County; April 12, 1986 Brown County and May 3, 1986 Spink County. The first two dates are considered normal and the last is considered late.

A starter application of diammonium phosphate (18-46-0) at the rate of 48 kg ha^{-1} was banded with the seed at planting. Urea ammonium nitrate (28-0-0) was applied at Spink County and ammonium nitrate (34-0-0) was applied at Brown County according to soil test for a yield goal of 4 Mg ha^{-1}. Landmaster (glyphosate + 2,4-D) was applied post harvest at the rate of 1.1 kg ha^{-1} a.i. at Spink County in 1984 and 1985. Roundup (glyphosate) at the rate of 0.32 kg ha^{-1} a.i. was applied preplant in the spring at this location. Ramrod 4L (propachlor) at an 5.6 kg ha^{-1} a.i. was applied pre-emergence to control grassy weeds and Bronate (bromoxynil + MCPA) at a 0.56 kg ha^{-1}

a.i. was applied post-emergence to control broadleaf weeds at all locations.

The following variables were measured: emergence, number of tillers at boot, maturity and productive tillers, grain yield, 1000 seed weight, test weight, and height. Emergence and tillers m^{-2} were determined by identifying a randomly selected meter row in the plot where counts were made at each growth stage. Yield was determined by harvesting a 1.47m wide strip from the center of the plot 4.57m long with a Hege combine. Test weight and 1000 seed weight were determined from a random sample of the grain yield sample.

Analysis of variance was calculated using Statistical Analysis Systems (SAS) software for single locations and combined over locations. Least significant difference (LSD) test was used to test for significant differences between tillage treatments within a cultivar.

RESULTS

The cultivar x tillage study was designed to determine if tillage affected growth and yield of 18 spring wheat cultivars. A significant cultivar x tillage x locations interaction occurred in one variable, the number of tillers at boot. Therefore, all variables except this will be discussed with data combined over three locations. Analysis of variance is shown in Table 1.

Table 1. Combined analysis of variance of 18 spring wheat cultivars tested on two methods of tillage for 3 locations.

		----- Tillers -----				- Weight -		
Source	Emerge	Boot	Mature	Prod.	Yield	Seed	Test	Height
Cultivar (C)	**	**	**	**	**	**	**	**
Tillage (T)	**	**	NS	NS	NS	NS	NS	NS
Location (L)	**	**	**	**	**	**	NS	**
C X T	NS	**	NS	NS	*	NS	NS	NS
C X L	**	NS	NS	NS	**	**	**	**
T X L	*	NS	NS	NS	NS	NS	NS	NS
C X T X L	NS	**	NS	NS	NS	NS	NS	NS

*,**Significance at the 0.05 and 0.01 probability levels, respectively.

Cultivars were significant (P>.01) for all variables measured. The cultivars were chosen to represent a wide range of genetic diversity; from early to late maturity, high to low tillering, tall to semi-dwarf and high to low yield potential. Therefore, a cultivar differences were expected.

Locations were significantly different for all variables except test weight. The environments were different between 1985 and 1986. In 1985, early spring was relatively dry and late June and July were cool and unusually wet producing higher than normal spring wheat yields. In 1986, the spring was extremely wet which delayed the planting date in Spink County 21 days after the Brown County location. July was fairly dry during seed fill lowering yield and seed weight compared to 1985.

There was a significant cultivar x location interaction for the following variables; emergence, yield, seed weight, test weight, and height. These differences were genotypic cultivar responses to the environment.

There were no main effect differences due to tillage except for emergence. In notill a seedling density of 217 plants M^{-2} compared to 185 plants M^{-2} in black was obtained. The tillage x location interaction was significant only for the number of plants emerged as shown in Table 2.

Table 2. Plants emerged in two tillage treatments at three locations averaged over cultivars.

Tillage	1985 Redfield	1986 Redfield	1986 Aberdeen	Tillage Mean
	no. plants			
Black	219	170	168	185
Notill	246	179	226	217
Mean	232	174	197	

At all locations there was a higher seedling density in notill than black. Heavy rain caused a crusting in the black treatment which was at least partially prevented by residue in notill at Brown County. The difference at Spink County 1985 was due to the loss of soil moisture following tillage and lack of April precipitation. Stands were reduced in both tillage treatments at this location in 1986 due to crusting caused by excess soil moisture at planting.

The cultivar x tillage interaction for grain yield was significant (P>.05) where cultivars responded differently to tillage across locations. Table 3 ranks the cultivars by yield differences when comparing tillage treatments. Differences are calculated by subtracting notill yield from black yield.

Table 3. Means for grain yield and 1000 seed weight combined over three locations.

Cultivar	Tillage Yield Black	Notill	TYD#	1000 Seed Weight Black	Notill
	----- Mg ha^{-1}	-----		----grams	----
Olaf	3.11	2.75	+0.36*	28.2	26.3
A99AR	3.14	2.87	+0.27	30.8	29.9
Butte	3.31	3.07	+0.24	26.7	26.1
Buckshot	3.34	3.11	+0.23	28.2	28.1
2369	3.69	3.53	+0.16	29.0	27.9
711	3.26	3.17	+0.09	27.3	28.0
Challenger	3.28	3.23	+0.05	27.3	26.7
Len	2.74	2.69	+0.05	26.2	25.6
Centa	3.15	3.12	+0.03	26.3	26.0
Wheaton	3.18	3.15	+0.03	28.0	27.1
Success	3.53	3.53	0.00	29.0	29.2
Marshall	3.46	3.56	-0.10	24.8	24.9
Alex	3.17	3.36	-0.19	27.8	28.5
Era	3.18	3.37	-0.19	24.4	26.2
Oslo	2.88	3.08	-0.20	26.1	26.9
Apex83	3.28	3.48	-0.20	25.4	26.8
Guard	3.33	3.63	-0.30	26.2	26.6
Angus	3.31	3.64	-0.33*	28.5	29.2
*$LSD_{.05}$			0.33		

#TYD=Tillage yield difference=black treatment-notill treatment.

Increased yield in black resulted in positive values and increased yield on notill resulted in negative values. Olaf, listed first, yielded significantly more (LSD P>.05) when grown in black tillage and Angus listed at the bottom yielded significantly more when grown in notill. The cultivars evaluated exhibit a range from a positive to negative yield response.

A significant variety x tillage x locations interaction (P>.01) for the number of tillers at boot (Table 4) indicated cultivars tillered differently between tillage treatments and locations.

Table 4. Number of tillers at boot in two tillage treatments at three locations.

Cultivar	1985 Redfield Black	1985 Redfield Notill	1986 Redfield Black	1986 Redfield Notill	1986 Aberdeen Black	1986 Aberdeen Notill	Mean Black	Mean Notill
	Tillers per square meter							
Olaf	835	801	1209	937	722	706	992	814
A99AR	662	590	701	816	561	512	641	639
Butte	728	636	730	875	616	580	691	697
Buckshot	726	768	815	877	536	572	692	739
2369	801	877	1209	1046	675	771	895	898
711	751	672	707	691	455	501	638	711
Challanger	693	639	916	910	555	507	721	685
Len	806	714	1015	1057	685	514	835	762
Centa	640	701	740	997	642	720	674	806
Wheaton	648	688	775	872	572	605	665	722
Success	838	855	820	983	704	756	787	865
Marshall	872	814	922	1248	551	808	782	957
Alex	825	909	1125	1226	574	842	841	992
Era	822	693	1190	1130	664	568	892	797
Oslo	621	439	785	653	540	668	649	587
Apex83	682	693	745	977	348	672	592	781
Guard	790	896	1071	1094	733	700	865	897
Angus	796	855	1135	1107	543	739	825	900
means	752	736	923	987	593	652	756	792

Alex, Apex83, Buckshot, Centa, Success, and Wheaton tillered more in notill at all locations. Challenger, Era and Olaf tillered more in black at all locations and the remaining cultivars were not consistent. All other variables measured did not have a significant cultivar x tillage x location interaction.

DISCUSSION

When locations were combined, the cultivar x tillage interaction for yield was significant. There was no significant cultivar x tillage x location interactions, indicating cultivars were responding differently to tillage independent of environmental differences. Factors causing this interaction were not clear.

The number of tillers at the boot stage (Table 3) was the only variable which had a significant cultivar x tillage x location interaction. The cultivars Angus, A99AR, Butte, Guard, Marshall, Oslo, 2369 and 711 all had one location that tillered more in one tillage treatment, but tillered less at other locations. Although there was a significant three-way interaction for tiller number at the boot stage, this effect did not appear to affect yield. In some cases these cultivars yielded more in black tillage, some yielded similarly in both tillage treatments, and some yielded more in no-tillage. Therefore, tiller number did not appear to account for the cultivar x tillage yield difference.

A significant cultivar x tillage interaction was not detected for seed weight although the probability was 0.07. Table 3 compares the cultivar yield and weed weight differences between the two tillage treatments. Success and 711 were the only cultivars that produced a higher seed weight in the tillage treatment where yield was reduced. Chia reported a significant increase in seed weight in notill. Farber, et al. reported no significant differences in seed weight due to tillage but seed weights were consistently higher in black tillage. Hwu and Allan found no differences in seed weight in winter wheat due to tillage.

The cultivar x tillage interaction for yield may best be explained by variables not measured in this study. Yield increases in notill are most often associated with increased soil moisture. Wilhelm, et al. reported a linear yield increase with increasing residues. Soil moisture was closely associated with the amount of surface residue. Yield reductions in notill are often associated with allelopathic effect of residue and lower spring soil temperatures. In a study by Cochran, et al. early root growth was inhibited by allelopathic effects of residue. Anderson and Russell found lower soil temperatures in notill which delayed plant growth from germination through early heading. Delayed growth in notill compared to conventional tillage has been reported by many researchers, (3,7,9,11,12). Chevalier & Chia found one of four cultivars did not display delayed early growth, indicating a difference in cultivar tolerance to notill culture.

Wheat cultivars grown in wheat stubble in South Dakota yield differently as a result of tillage as indicated by the significant cultivar by tillage interaction. It should be noted that three of the top four cultivars exibited a high yield regardless of tillage imposed. The variables used to evaluate this study failed to identify phenotypic traits a plant breeder could use for selecting notill specific cultivars. However, it does indicate that selection under notill culture should be considered to optimize yield response for notill production systems.

III. EFFECTS OF WHEAT RESIDUE ON THE GROWTH AND GRAIN YIELD OF HARD RED SPRING WHEAT

LITERATURE REVIEW

Yield reductions were observed in a tillage study in South Dakota when spring and winter wheat were seeded directly into standing stubble in a continuous monocropping system (7). Notill yields were reduced by 23% in winter wheat and by 25% in spring wheat compared to conventional tillage in a year when the spring was cooler and wetter than normal.

Under conditions of high moisture and cool temperatures, other researchers have reported crop yield reductions when the crop was seeded into residue. Lynch (1980) reported crop grain yield reduction of 20% when winter wheat was direct seeded into stubble in a wet autumn. In Washington, Cochran (1977) reported direct seeding of winter wheat into stubble reduced grain yield by 25% compared to clean cultivation. In addition they noted reduced tiller numbers when the wheat was direct seeded into stubble. They attributed the yield reduction and decreased tillering in part to allelopathic inhibition caused by decomposing residue.

Allelopathy as defined by Rice (1974) is any direct or indirect harmful effect of one plant (including microorganisms) on another plant via the production of chemical compounds that escape into the environment. The harmful effects from allelopathy are often first observed as one or more plant symptoms. These symptoms include reduced tillering, shortened internodes, spindly stems, leaves corkscrewing, leaf yellowing, shrunken grain, small heads, overwinter stand loss, and reduced yields especially with large amounts of residue (Elliott, et al. 1978).

To separate the effects of residue from tillage, causal agents have been investigated mainly in the laboratory and greenhouse. An extensive list of chemical compounds identified as allelopathic agents have been isolated from many crop residues (Rice, 1984). They have been identified as inherent toxins in the residue before and during breakdown and as by-products produced by microbial decomposition in either aerobic or anaerobic conditions.

Extracted or direct leachate of plant residue have retarded root and shoot development. Yakle and Cruse (1984) observed significant reductions in corn root and shoot weights with corn residue and corn residue plus soil extracts compared to tap water or soil extracts alone.

Chapman & Lynch (1983) found a significant reduction of barley root lengths when barley seed was in contact with anaerobically decomposed wheat straw filtrate compared to a distilled water check. Lovett and Jessop (1982) noted that seminal root length and coleoptile height decreased when wheat residue was placed in contact with wheat seed compared to no residue. Kimber (1967) observed a significant reduction in wheat root and shoot lengths in an aseptic environment when seed was grown with leachate of wheat straw compared to a distilled water check.

Kimber (1973) also observed a significant reduction in wheat seedling emergence when a 7.5 cm deep layer of wheat residue was placed on the surface of pots in the greenhouse. There was no differences in emergence between a residue layer of 1.5 cm and the no residue check.

In the field the effects of residue are seldom separated from other factors which are known to affect growth and yield of plants in notill. Lovett and Jessop (1982) spread wheat residue at the rate of 3 t ha^{-1} on plots planted with wheat and observed a significant reduction in emergence compared to no residue. However, after 18 days they found no differences in root and shoot lengths. Cochran et al (1977) in a combination field and laboratory study spread a 5-8 cm layer of wheat residue on plots in the field and sampled residue plus 1 cm of soil on a weekly basis. They leached the sample in the laboratory and used the leachate for seedling germination. They found wheat seedlings grown in contact with the sample leachate taken one week after the first rain had significantly reduced root but not shoot length. Anderson and Russell (1964) using eight rates of wheat residue on plowed plots found that 4.5 t ha^{-1} of straw per acre on spring wheat and 5.6 t ha^{-1} of straw per acre on winter wheat was required before mean yields were depressed significantly compared to bare plots.

The purpose of this study was to evaluate the effects of three rates of residue on six hard red spring wheat cultivars in the greenhouse and two cultivars in the field while limiting the effects of notill.

MATERIAL AND METHODS

Greenhouse:

Six hard red spring wheat cultivars adapted to the growing conditions in South Dakota were selected. These culivars represent the range of genotypes and phenotypes presently grown in the northern plains region. Listed by maturity, early to late, they are 'Butte', 'Guard', 'Len', 'Olaf', 'Wheaton', and 'Marshall'.

Three residue rates (0, 2, and 4 Mg ha^{-1}) were selected as treatments. Len straw was cut, baled, and stored after harvest in 1984.

Experiments were conducted in the greenhouse at Brookings, South Dakota, initiated on January 3, 1985 (study 1), and repeated on November 22, 1985 (study 2) and October 22, 1986 (study 3). The two 1985 crops were harvested at physiological maturity and the 1986 crop was terminated 10 days after germination.

The experimental design was a randomized complete block arrangement of six cultivars and three residue treatments with 9 replications. Three replications were harvested 10 days after germination and 6 replications were harvested at physiological maturity. Plants were considered physiologically mature when the head and peduncle lost their green color.

Plants were grown in a 15 cm plastic pot filled to 2.5 cm below the top with a loam soil. Twelve seeds of a given cultivar were seeded per pot and treated with the appropriate rate of chopped straw in study 1. However, in study 2 and study 3 the residue treatments were applied and watered for 10 days before the seeds were planted. This eliminated the problem of volunteer plants from the residue. Pots were thinned to 6 plants ten days after germination. Approximate 21^{o}C day 16^{o}C night temperature was maintained with supplemental lighting equal to 14 hour daylight. Ozomocote (14-14-14) was applied to insure nitrogen was not a limiting factor for growth and development.

Variables measured include: emergence, root dry weight, shoot dry weight, and shoot length 10 days after emergence; and tillers, height and plant dry weight at physioligical maturity. Root and shoot dry weight was determined by submerging pots in water and carefully removing the plants. All soil and residues were then washed from the plants. The roots were then exisized from the crown and oven dried at 60^{o} C. Analysis of variance was calculated using Statistical Analysis Systems (SAS) software for single study and combined over studies. Waller/Duncan separations were used to test for significant differences between residue treatments and cultivars.

Field:

Two hard red spring wheat cultivars, Butte and Wheaton, were selected. Butte is early maturing, standard height and medium tillering while Wheaton is a late semi-dwarf and medium tillering. Three residue rates (0, 2 and 4 Mg ha^{-1}) were selected as treatments. Len straw was cut, baled, and stored under cover after harvest in 1984 and Guard straw was cut and baled after harvest in 1985. A line source irrigation was applied as a treatment in 1985 during stand establishment to insure a moisture gradient but was eliminated in 1986 because of excessive rain after planting.

Plants were grown on a Beotia silt loam soil (fine-silty, mixed Pachicudic Haploboroll) at the James Valley Research Center in central Spink County South Dakota. The previous crop in 1985 was soybeans and in 1986 was flax. In 1985 the site was chisel plowed in the fall and disked in the spring just prior to residue application and planting. In 1986 the site was disked in the fall and seeded with flax. After a killing freeze, the residue was applied to the plots using the flax stubble to hold the residue in place. Fall application of residue was used to eliminate the volunteer wheat problem experienced in 1985.

The experimental design was a split plot with cultivars seeded across residue treatments. Main plots were 2.9 x 18.3 m with 15.2 cm row spacings and subplots were 2.9 m with half used for yield and tiller counts and half used as plant sample area in 1985. Subplots were 5.8 m in 1986 since the line source irrigation was not used.

Plots were seeded with a John Deere double disk drill. Cultivars were seeded at the rate of 100 kg ha^{-1} on April 10, 1985 and May 20, 1986. The first date is considered normal and the last is considered late.

A starter application of diammonium phosphate (18-46-0) at the rate of 48 kg ha^{-1} was banded with the seed at planting. Urea ammonium nitrate (28-0-0) was applied pre-emergence in both years (according to soil test) for a yield goal of 4 Mg ha^{-1}. Roundup (glyphosate) at the rate of 0.32 kg ha^{-1} a.i. was applied preplant in 1986 to control volunteer wheat from the residue treatment. Hoelon (dicoflop) at the rate of 1.12 kg ha^{-1} a.i. was applied post-emergence to control grassy weeds in 1985. Bronate (bromoxynil + MCPA) at a 0.56 kg ha^{-1} a.i. was applied post-emergence to control broadleaf weeds both years.

Variables measured include: number of plants emerged; plant weight 10 days after emergence; number of tillers and plant weight at 3-leaf, boot, heading, and maturity; productive tillers; grain yield; height; test weight; 1000 seed weight; spikelets per spike; seeds per spike. Emergence and tillers m^{-2} were determined by identifing a randomly selected meter row in the plot where counts were made at each growth stage. Plant weights at emergence and each growth stage was determined by the mean dry weight of ten plants. Yield was determined by harvesting a 1.47 x 2.9 m strip from the subplot with a Hege combine. Test weight and 1000 seed weight were determined or a random sample from the grain yield sample. Spikelets per spike and seed per spike were determined from a random sample of 25 spikes.

Analysis of covariance in 1985 and analysis of variance in 1986 was calculated using Statistical Analysis Systems (SAS) software. The covariate was the water applied by the line source irrigation. Waller/Duncan separations were used to test for significant differences between residue treatments and cultivars.

RESULTS

Greenhouse:

Table 1 indicates a highly significant difference (P>.01) in plant emergence when combined over the three studies due to cultivar, residue, study and residue x study interaction.

Table 1. Analysis of variance combined over three studies in the greenhouse.

	Ten Days After Germination				Physiological Maturity		
Source	Emerge	Root Weight	Shoot Weight	Shoot Length	Dry Weight	Height	Tillers
Cultivars (C)	**	NS	NS	**	**	**	NS
Residues (R)	**	**	**	NS	NS	NS	**
C X R	*	*	NS	NS	NS	NS	NS
Study (S)	**	**	**	**	**	**	**
C X S	NS	**	**	NS	**	**	NS
R X S	**	NS	**	**	*	NS	NS
C X R X S	NS	NS	NS	**	NS	NS	NS

*,** indicates probability greater .05, .01, respectively.

There was also a significant cultivar x residue interaction (P>.05).

The residue x study interaction is presented in Table 2.

Table 2. Effects of three residue rates on plant emergence over cultivars in three studies.

Residue Rate	Study 1	Study 2	Study 3	Residue Mean
	Plants/Pot			
Mg ha^{-1}				
0	11.1b	10.4a	10.9	10.7a
2	11.0b	7.7b	10.5	9.7b
4	11.5a	7.4b	10.5	9.7b
Study Mean	11.3x	8.5z	10.7y	

Means within a column or row followed by the same letter are not significantly different (P>.05) according to Waller/Duncan test.

In study 1 more plants emerged in the 4 Mg ha^{-1} residue treatment as a result of volunteer seedlings from the residue. However, in study 2 volunteer plants were eliminated and the zero residue had significantly more plants emerge than the residue treatments. There was no difference in emergence in study 3 due to residue. Therefore, this interaction was the result of an experimental design error.

The cultivar x residue interaction is presented in Table 3. In all cultivars more plants emerged in the zero residue pots compared to residue treated pots. The interaction occurred between the 2 and 4 Mg ha^{-1} residue treatments. Guard, Len, Marshall and Olaf had more plants emerge in the 4 Mg ha^{-1} residue treatment while Butte and Wheaton had more plants emerge in the 2 Mg ha^{-1} residue treatment. Waller/Duncan separations for differences due to residue indicates 2 and 4 Mg ha^{-1} residue rates were similar for emergence.

Table 3. Emerged plants per pot cultivar x residue interaction over three studies.

Residue	Butte	Guard	Len	Marshall	Olaf	Wheaton	Residue Mean
			Cultivars				
Mg ha^{-1}			Plants/Pot				
0	10.7	11.1	10.7	11.1	10.4	10.3	10.7a
2	10.5	10.4	9.3	9.6	9.3	8.8	9.7b
4	10.0	10.5	9.4	10.3	9.6	8.1	9.7b
Cultivar Mean	10.4mn	10.7m	9.9no	10.33mn	9.8o	9.07p	

Means within a column followed by the same letter are not significantly different (P>.05) according to Waller/Duncan test.

Root dry weights were significantly different (P>.01) for residue, study, and cultivar x study interaction. The cultivar x residue interaction was significant (P>.05) as presented in Table 4.

Table 4. Root dry weights for cultivar x residue interaction of six cultivars of spring wheat with three residue rates over three studies.

Residue Rate	Butte	Guard	Len	Marshall	Olaf	Wheaton
	Cultivars Root Dry Weight					
Mg ha^{-1}	grams/plant					
0	0.0124	0.0116	0.0129	0.0117	0.0111	0.0142
2	0.0086	0.0081	0.0095	0.0098	0.0103	0.0091
4	0.0085	0.0096	0.0107	0.0094	0.0101	0.0077

Roots always weighed more with zero residue regardless of cultivar. The interaction occured between the two residue treatments with Guard and Len roots weighing more under 4 Mg ha^{-1} residue than 2 Mg ha^{-1} residue. Root dry weights decreased with increasing residue rates for Butte, Marshall, Olaf and Wheaton.

Root dry weights were different for cultivar x study interaction over residue rates. Cultivar ranking changed between studies but cultivar root weights were not significantly different within a study.

Root dry weights were different (P>.01) among residue rates when averaged over the three studies as shown in Table 5. Roots weighed more in the zero residue compared to roots under 2 and 4 Mg ha^{-1} residue. This was consistent for each study except in Study 1 when 2 Mg ha^{-1} residue was not significantly different from zero residue or 4 Mg ha^{-1} residue.

Table 5. Root dry weights of plants at three residue rates combined over three individual studies.

Residue Rate	Root Dry Weight: Study 1	Study 2	Study 3	Residue Mean
$Mg\ ha^{-1}$	grams/plant			
0	0.0115a	0.0169a	0.0081a	0.012a
2	0.0104ab	0.0123b	0.0064b	0.009b
4	0.0096b	0.0119b	0.0057b	0.009b
Study Mean	0.0105y	0.0137x	0.0067z	

Means within a column followed by the same letter are not significantly different (P>.05) according to Waller/Duncan test.

Residue X study and cultivar x residue x study interactions were not significantly different for root weight.

Shoot dry weights were significantly different (P>.01) for residues, study and cultivar x study and residue x study interactions. Table 6 shows the dry weights of shoots ten days after germination.

Table 6. Shoot dry weights at three residue rates for three individual studies.

Residue Rate	Study 1	Study 2	Study 3	Residue Means
$Mg\ ha^{-1}$	grams/plant			
0	0.027	0.036a	0.022	0.028a
2	0.029	0.028b	0.019	0.025b
4	0.027	0.031b	0.022	0.027b
Study Means	0.028y	0.031x	0.021z	

Means within a column and row followed by the same letter are not significantly different (P>.05) according to Waller/Duncan test.

Plant shoots weighed significantly more (P>.01) when plants were grown without residue compared to 2 and 4 Mg ha^{-1} residue. Among studies this variable was only significantly different (P>.05) in study 2. However, in studies 1 and 3 there was no differences in shoot weights nor no clear trend which is reflected in the significant residue x study interaction.

The cultivar x study interaction is shown in Table 7.

Table 7. Shoot dry weights of six cultivars of spring wheat ten days after emergence for 3 individual studies.

Cultivar	Study 1	Study 2	Study 3	Cultivar Mean
	---------grams/plant--------------			
Butte	0.032a	0.034a	0.018	0.029
Guard	0.026ab	0.027b	0.024	0.026
Len	0.025c	0.029b	0.022	0.027
Marshall	0.038ab	0.034a	0.019	0.026
Olaf	0.025c	0.033a	0.022	0.027
Wheaton	*	0.032a	0.021	0.027
Study mean	0.028y	0.031x	0.021z	

Means within a column or row followed by the same letter are not significantly different (P>.05) according to Waller/Duncan test.
*Due to poor germination Wheaton was not included in study 1.

Cultivar shoot weights were significantly different in studies 1 and 2 but not in study 3. Cultivar rankings changed among individual studies which accounts for the cultivar x study interaction. When averaged across studies, cultivars were not significantly different for shoot dry weight; however when averaged across cultivars, shoot dry weights were different between studies.

Shoot length was significantly different (P>.01) for the cultivar x residue x study interaction. Therefore, shoot length will be reported by individual study only. Cultivars were significantly different in all three studies which was expected as they are phenotypically different. Differences due to residue were significantly different (P>.05) in study 2. The shoot length of cultivars grown without residue were longer than cultivars grown in 2 Mg ha^{-1} residue rate but not longer than cultivars grown in 4 Mg ha^{-1} residue. There were no differences in shoot length due to residue treatment in studies 1 and 3.

At physiological maturity cultivars, study, and cultivar x study interaction was highly significant (P>.01). There was a significant residue x study interaction (P>.05) for plant dry weights as shown in Table 8.

Table 8. Dry weight of physiologically mature spring wheat at three residue rates in greenhouse in study 1 and study 2.

Residue Rate	Study 1	Study 2
Mg ha^{-1}	--grams per plant--	
0	1.62a	2.87
2	1.59a	3.15
4	1.49b	3.16
Study mean	1.56y	3.06z

In study 1 the plants weighed significantly more (P>.01) from the zero and 2 Mg ha^{-1} residue rate compared to 4 Mg ha^{-1}. In study 2 there was no significant difference in plant dry weights due to residue treatments. However, plants grown without residue weighed less than plants grown in the 2 and 4 Mg ha^{-1} residue treatments resulting in the residue x study interaction. The cultivars had significantly different (P>.01) weights at maturity. These cultivars have different height and yield potentials, therefore cultivar differences were expected. The cultivar rankings changed between the two studies causing the cultivar x study interaction. There was no cultivar x residue interaction indicating all cultivars responded similarly to residue rates.

The number of tillers was greater (P>.01) when grown without residue (1.94) than when grown with 2 (1.80) or 4

Mg ha^{-1} (1.77) residue. Cultivar heights were significantly different (P>.01) which indicated phenotypic differences among cultivars. Residue rates did not affect plant height.

Field:

This study could not be combined over years as a line source irrigation was imposed on the study in 1985 but not in 1986. Therefore, each year will be considered separately. Analysis of variance is shown in Table 9.

Table 9. Analysis of variance of field studies for 1985 and 1986.

	1985 Source			1986 Source		
Variables	Cultivar	Residue	C X R	Cultivar	Residue	C X R
Emergence	NS	NS	NS	**	**	NS
Emergence weight	NS	NS	NS	NS	**	NS
3-leaf tillers	*	NS	NS	**	**	NS
3-leaf weight	NS	NS	NS	*	**	NS
Boot tillers	NS	NS	NS	NS	**	NS
Boot weight	--	--	--	NS	*	NS
Heading tillers	--	--	--	*	*	NS
Heading weight	**	NS	NS	NS	**	NS
Mature tillers	NS	NS	NS	*	**	NS
Mature weight	**	*	NS	**	**	NS
Prod.tillers	NS	NS	NS	NS	*	NS
Yield	NS	NS	NS	**	NS	NS
Test weight	**	NS	NS	**	NS	NS
Height	NS	NS	NS	**	NS	NS
Seed weight	NS	NS	NS	*	NS	NS
Spikelets $head^{-1}$	NS	NS	NS	NS	NS	**
Seed $head^{-1}$	*	NS	NS	NS	NS	*

*,** indicates probability greater .05, .01, respectively.

In 1985 cultivar was significantly different (P>.05) for tillers at 3-leaf, and for number of seeds per head. Plant weight at heading and maturity and seed test weights were also significantly different (P>.01). Butte had 585 tillers at 3-leaf stage and Wheaton had 508. Butte produced 22.0 seeds with Wheaton producing 24.2 seeds per head. Wheaton plants were heavier at both heading and maturity than Butte. Butte had a heavier seed test weight than Wheaton. No differences between cultivars were detected for any other variable.

Plant weight at heading was significantly different (P>.05) due to residue. Zero, 2, and 4 Mg ha^{-1} residue treatments resulted in plant weights of 9.51, 4.89 and 5.42 grams per plant respectively. No other variable was significantly different due to residue and there was no cultivar x residue interactions.

In 1986 cultivars were highly significant (P>.01) for germination, number of tillers at 3-leaf, plant weight at maturity, yield, height, and test weight; and significant (P>.05) for plant weight at 3-leaf, number of tillers at maturity, and seeds per spike.

The cultivar Butte established 283 while Wheaton established 212 plants per square meter across residue treatments. At the 3-leaf stage Butte still had more tillers compared to Wheaton. At maturity Butte attained 456 tillers while Wheaton attained 368 tillers per square meter.

Wheaton weighed more at 3-leaf stage and at maturity than Butte. Butte yielded 1.17 Mg ha^{-1} and Wheaton yielded 0.96 Mg ha^{-1} across treatments. Butte also had a heavier test weight and increased plant height compared to Wheaton. Wheaton, however, did have more seeds per spike compared to Butte.

The effect of the residue treatments on the variables measured at five growth stages is presented in Table 10. There was a significant difference (P>.01) due to residue rates in number of plants that emerged and the number of tillers and plant weight at each growth stage through maturity. The number of productive tillers were significantly different (P>.05).

Table 10. Plant weight and tiller number at five growth stages on three residue rates in 1986.

Variable	Residue Rate -----Mg ha^{-1} ----- 0	2	4
	--- no. per M^2 ---		
Plants emerged	298a	237b	217b
Tillers:			
3-leaf	1175a	913b	831b
boot	1319a	1100b	1007c
heading	634a	557ab	536b
mature	467a	391b	378b
productive	335a	276b	272b
Plant weight:	-- grams plant^{-1} --		
10 days after emergence	.053a	.040b	.036b
3-leaf	.627a	.532b	.486b
boot	1.13a	1.02ab	0.89b
heading	3.04a	2.52b	2.43b
maturity	5.00a	3.64b	3.63b

Means within a row followed by the same letter are not significantly different (P>.05) according to Waller/Duncan test.

Number of emerged plants and tillers at 3-leaf were significantly higher under zero residue than under 2 and 4 Mg ha^{-1} residue rates. The number of tillers at boot was significantly different among zero, 2, and 4 Mg ha^{-1} residue treatments with tillers decreasing with increased residue. At heading there were more tillers in zero residue compared to 4 Mg ha^{-1} residue treatment but neither residue treatment was different from 2 Mg ha^{-1}. Mature and productive tillers were increased in zero residue compared to the number of tillers in 2 and 4 Mg ha^{-1} residue rates.

The plants weighed more ten days after emergence and at 3-leaf in zero residue compared to 2 and 4 Mg ha^{-1}. However, at boot the plants in zero residue weighed more than plants in 4 Mg ha^{-1} but neither was different from plant weights in 2 Mg ha^{-1}. At heading and maturity plants again weighed more in zero residue than in 2 or 4 Mg ha^{-1}.

Spikelets per spike and seed per spike had a significant cultivar x residue interaction which is shown in Table 11.

Table 11. Spikelets per spike and seeds per spike for two cultivars and three residue treatments.

Residue Rate	Cultivars			
	Butte	Wheaton	Butte	Wheaton
Mg ha^{-1}	Spikelets/Spike		--Seed/Spike--	
0	14.5	15.5	27.1	29.5
2	14.4	15.2	26.9	27.4
4	15.3	15.2	29.0	28.0

Butte had 15.3 spikelets per spike at 4 Mg ha^{-1} residue compared to 14.5 and 14.4 spikelets per spike at zero and 2 Mg ha^{-1} residue. In contrast Wheaton had 15.5 at zero residue with 15.2 spikelets per spike at 2 and 4 Mg ha^{-1} residue. Butte also had 29.0 seeds per spike at 4 Mg ha^{-1} residue with 27.1 and 26.9 seeds per spike at zero and 2 Mg ha^{-1} residue, respectively. In contrast Wheaton had

29.5 seeds per spike at zero residue 27.4 and 28.0 seeds per spike with 2 and 4 Mg ha^{-1} residue, respectively. No other variable had a significant cultivar x residue interaction.

DISCUSSION

Volunteer wheat contained in residue applied at planting increased emergence in the 4 Mg ha^{-1} compared to 0 and 2 Mg ha^{-1} residue rates in greenhouse study 1 and resulted in differences in emergence in the field in 1985. When residue was placed on pots or plots early to allow for volunteer germination, emergence increased in zero compared to 2 and 4 Mg ha^{-1} residue rate in study 2. A similar trend occurred in study 3. Volunteer wheat in study 1 was easily eliminated as pots were thinned to 6 plants per pot and later variables were not affected. In the field however, the volunteer wheat was not eliminated which resulted in a confounded study. Therefore, little emphasis will be placed on the 1985 field study.

Residue did not affect grain yield in the field or plant dry weight at physiological maturity in study 2 in the greenhouse. However, in study 1 the plants weighed more in 0 and 2 Mg ha^{-1} compared to 4 Mg ha^{-1} residue. Kimber (1973) reported a grain yield reduction in wheat with 7.5 cm deep wheat residue compared to zero and 1.5 cm which is similar to the results in study 1. Although mature plant weights were not different due to residue rates in study 2 there was increased emergence, root and shoot weights 10 days after emergence in the zero residue treatment. In tillage studies delayed early growth is often reported in no-tillage. Delayed early growth is usually followed by similar or reduced yields (3,7,8). Growth variables in the field also indicated increased emergence, tillering, and plant weights with zero residue compared to residue treatments. Late planting, leaf rust and lack of moisture during seed fill resulted in extremely low yields in 1986 which decreased the plants ability to reach their yield potential.

Cultivars responded differently to residue in the greenhouse as indicated by the residue x cultivar interactions. All cultivars had increased root weights and emergence when no residue was present. The interaction occurred between 2 and 4 Mg ha^{-1} residue treatments. The cultivars which had increased emergence in 4 Mg ha^{-1} residue compared to 2 Mg ha^{-1} were Guard, Len, Marshall, and Olaf. Of those four cultivars Guard and Len also had increased root weights in 4 Mg ha^{-1} residue while Butte, Marshall, Olaf and Wheaton had reduced root weight with increasing residues. Although root weight differences between residue treatments were not large it may indicate differences in cultivar tolerance to early stress when direct seeded in heavy residue. Chevalier and Chia (1986) reported the growth of one of four cultivars of spring wheat was not delayed in notill. Elmore (1987) also found a cultivar x tillage response in soybeans.

Cultivar response to residue in the field was similar. Butte and Wheaton responded similarly to all variables in the greenhouse. There was a cultivar x residue interaction for the number of spikelets per spike and seeds per spike. These are genetic yield component differences between the cultivars.

In conclusion, residue did not affect yield except in study 1 in the greenhouse. In general residue did reduce growth variables both in the greenhouse and field. Root weights were consistently decreased due to residue in the greenhouse. Emergence both in the greenhouse and field was reduced as well as early plant weights in the field. The presence of residue appears to be more important than the rate of residue in the early growth stages of wheat. Cultivars responded differently to residue rates of 2 and 4 Mg ha^{-1} indicating specific cultivar tolerance to heavy residues.

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