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Grain Yield and Yield Components of Doublecropped Winter Wheat as Affected by Wheat and Previous Soybean Production Practices

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ABSTRACT

Development and grain yield of doublecropped winter wheat (*Triticum aestivum* L.) are influenced by the production practices used to produce the wheat crop and potentially by those used to produce the previous crop. This 2-yr field study was conducted on a Goldsboro loamy sand (fine-loamy, siliceous, thermic Aquic Kandiudult) to determine whether production practices used in the spring to produce the previous soybean [*Glycine max* (L.) Merr.] crop affect wheat grain yield and yield component responses to fall production practices. Treatments were deep tillage the previous spring prior to planting soybean using row widths of 19 or 76 cm, deep tillage in the fall prior to wheat planting, deep tillage in both the spring and fall, and no deep tillage for wheat planted with and without surface tillage. Fall deep tillage was the only treatment that consistently increased grain yield and all of the yield components; increasing grain yield, fertile head number per square meter, kernel number per head, and individual kernel weight by an average of 27, 11, 10, and 3%, respectively, over all other treatments. Grain yield and kernel number per square meter responses to fall deep tillage were greatest with no spring deep tillage, with no surface tillage, or when the previous soybean was grown using 76-cm-row widths. Grain yield, fertile head number per square meter, and kernel weight were all higher without surface tillage than with surface tillage. Results from this study show that production practices used to produce the previous soybean crop, such as row width and spring deep tillage, can have a significant effect on the grain yield and yield component responses of wheat to fall production practices.

WINTER WHEAT can be an important source of plant residues in no-surface-tillage systems on the southeastern Coastal Plain, especially when doublecropped with soybean, a crop that leaves few residues after seed harvest. Few studies have identified the optimum set of production practices needed to produce winter wheat in this region with no surface tillage. With conventional practices centered on disking, annual deep tillage is recommended for Coastal Plain soils that contain a tillage pan, a naturally occurring hardpan layer (E soil horizon), or both (Busscher et al., 1986; NeSmith et al., 1987, Martin et al., 1979). Fracturing these compacted layers promotes faster and deeper root growth into the subsoil where leached nutrients and additional water can be found. Drought stress generally develops slowly during the wheat growing season, with the most severe drought stress occurring during the grain-filling period (Frederick and Camberato, 1994, 1995a, 1995b). Therefore, deep tillage effects should last well into the grain-filling period of winter wheat.

Although deep tilling is usually necessary, little is known about the optimum time to deep till for winter wheat produced on the Coastal Plain, especially for wheat grown with no surface tillage. If controlled traffic is used during the growing season, deep tilling once prior to wheat planting is usually sufficient for optimum soybean yields when soybean is interseeded into winter wheat (Khalilian et al., 1991). However, the optimum time to deep till may depend on the specific management practices used to produce the crop. For example, Frederick et al. (1998) found deep tillage done prior to planting both wheat and soybean resulted in the highest doublecropped soybean yield when the soybean was planted with no surface tillage and 19-cm-row widths. In contrast, they found the timing of deep tillage had little effect when the soil was disked and the soybean was planted with 76-cm-row widths. Surface residues increase water infiltration and soil water availability (Langdale et al., 1992) and, therefore, may reduce the need for deep tillage for most crops. However, for winter wheat, deep tillage appears to be more important when no surface tillage is used, compared with disking (Frederick and Bauer, 1996). Additional factors that could affect wheat yield and yield component responses to deep tillage include whether the previous summer crop was deep tilled and the amount of soil fracturing by the deep tillage implement used.

How wheat is produced affects grain yield by increasing or decreasing the number of fertile heads per square meter, the number of kernels per head, and/or individual kernel weight. The number of fertile heads per square meter and number of kernels per head determine the number of kernels per square meter, a parameter that is often closely associated with grain yield (Frederick and Bauer, 1999). With respect to responses to management practices, an increase in one wheat yield component is often compensated for by a reduction in a subsequently formed yield component (Frederick and Marshall, 1985; Frederick and Camberato, 1995a). Therefore, examining the components of wheat grain yield can determine whether a treatment had no effect at all on the crop or whether a positive increase in one component was compensated for by a reduction in another component. If compensation occurs, researchers may be able to devise improved production strategies that will prevent the reduction in the compensatory yield component.

The development and final grain yield of doublecropped winter wheat may depend on both the production practices used to produce the wheat crop and those used to produce the previous soybean crop. Understanding whether these production effects occur or

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not, and the magnitude of their impact on wheat yield, will aid in the development of new wheat cropping systems for the Coastal Plain region. The objectives of this study were (i) to determine how wheat production practices and those practices used to produce the previous soybean crop affect winter wheat grain yield and yield components and (ii) to identify which yield component(s) has the greatest effect on winter wheat grain yield over the different treatments examined.

MATERIALS AND METHODS

Site Description and Cultural Practices

Soft red winter wheat (Northrup King cv. Coker 9134)[1] was grown following doublecropped soybean on a Goldsboro loamy sand (fine-loamy, siliceous, thermic Aquic Kandiudult) soil in 1995 and 1996 at the Pee Dee Research and Education Center located near Florence, SC. Northrup King Coker 9134 was selected for this study because of its high grain yield potential, high straw yield, and good disease and insect resistance (Graham et al., 1999). The experimental site was the same, and the same treatments were applied to each plot in both years. Wheat was also grown on these plots in 1994 using the same surface and deep tillage treatments as described below for the 1995 and 1996 wheat crops. Data from 1994 were not include in this study's analysis since 1994 was the first year of the study and no treatments had been imposed on the previous soybean crop.

Cultural practices used to produce the previous soybean crop in 1994, 1995, and 1996 have been described in detail (Frederick et al., 1998). For the wheat crop, phosphorus and potassium fertilizers and lime were broadcast applied each year to all plots in the fall before planting at rates based upon soil test results. The no-surface-tillage plots were sprayed before planting with glyphosate [*N*-(phosphonomethyl)glycine] at a rate of 1.12 kg a.i. ha^{-1}. Wheat seeds were planted on 20 and 21 November 1994 and 1995, respectively, with a John Deere 750 grain drill. Seventy-three seeds per meter of crop row were planted in rows spaced 0.19 m apart oriented in a north-south direction. Each plot was 16 rows wide and 15.2 m long.

Ammonium nitrate was broadcast onto all plots immediately after wheat planting at a rate of 34 kg N ha^{-1} with a 3-m-wide Gandy fertilizer spreader (Gandy Co., Owatonna, MN). Ammonium nitrate was also applied at a rate of 56 kg N ha^{-1} to all plots at Feekes Growth Stage 5.0 (stem erect growth stage; Large, 1954).

Treatments Applied

Treatments were all combinations of surface tillage (disked or no surface tillage), spring deep tillage (deep tilled or no deep tillage prior to planting the previous soybean crop), row width culture of previous soybean crop (production practices used with row widths of 76 or 19 cm), and fall deep tillage (deep tillage or no deep tillage prior to wheat planting). Each treatment was replicated four times. The same level of surface tillage was used to produce both the soybean and wheat crops. Plots assigned to be disked were disked twice to a depth of 18 cm before planting. After disking in the spring, the soybean plots having the 19-cm-row width assigned to be deep tilled were deep tilled to a depth of 41 cm (top of B soil horizon) with a four-shanked ParaTill (Bigham Brothers, Inc., Lubbock, TX). A four-shanked Kelly (Kelly Mfg. Co., Tifton, GA) in-row subsoiling unit mounted in front of a four-row planter was used to deep till to a depth of 41 cm the appropriate soybean plots having the 76-cm-row width. Shanks were mounted as opposed pairs and spaced 71 cm apart on the ParaTill and spaced 76 cm apart on the Kelly subsoiling unit. Both deep tillage devices were equipped with a serrated cutting coulter mounted in front of each shank. The same ParaTill and depth settings were also used for the fall deep tillage treatment.

Parameters Evaluated

At harvest maturity (kernel hard stage), a 1-m-long section of crop row was hand-harvested from each of the six center rows of each plot to determine wheat grain yield and yield components. In both years, the number of fertile (grain bearing) heads was counted after sample harvest, and the grain from each sample was threshed, cleaned, dried at 75°C for 2 d, and weighed. Individual kernel weight was determined by counting, drying, and weighing 200 kernels from each sample. Kernel number per head and kernel number per square meter were calculated from the head number, grain yield, and individual kernel weight data. Apparent harvest index (harvest index measured at harvest maturity) was calculated by dividing the grain yield of each sample by the biological yield (total aboveground dry weight). Grain yield data were converted to a 130 g kg^{-1} water basis. Yield and yield component responses to fall deep tillage in 1995 have previously been reported (Frederick and Bauer, 1996).

Rainfall data were collected during the growing season at a weather station located about 200 m from the experimental field. The rate of rainfall accumulation was generally above normal until about day 70 of the year in 1995 and below normal thereafter (Fig. 1). Rate of rainfall accumulation was near to above normal until about day 90 in 1996 and below normal for most of the remainder of the growing season (except for 5.3 cm of rain which occurred on Day 121). Growing degree days were calculated by averaging the daily maximum and minimum air temperatures. A maximum threshold of 30°C was used for the daily high temperature and a minimum threshold of 0°C was used for the daily lows. A base temperature of 0°C was used for degree day calculations. Growing degree day accumulation was less in 1996 than in 1995, especially during the grain filling period (Fig. 1).

Statistical Analyses

All grain yield and yield component data in this 2 by 2 by 2 by 2 factorial experiment were subjected to analysis of variance as a randomized complete block design with four replications. The analyses were conducted over years and data reported as year averages. An LSD (0.05) was calculated for the data to compare interaction means when at least one interaction effect was significant at the 0.05 probability level. Linear regression analysis was used to examine the relationship between grain yield and each grain yield component. Regression analysis was conducted across all treatments within each year using plot values. Significance was set at the 0.05 probability level.

RESULTS AND DISCUSSION

The combined statistical analysis of data over years is shown in Table 1. Only the fall deep tillage and year

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[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by Clemson University and the USDA-ARS or does not imply its approval to the exclusion of other products or vendors that may be also be suitable.

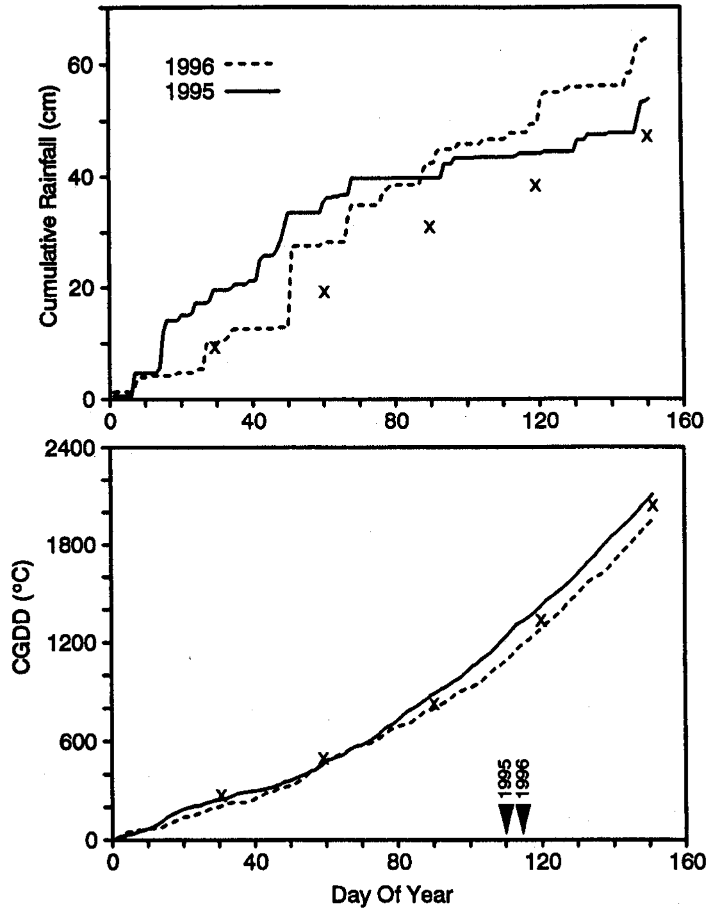

Fig. 1. Cumulative rainfall and cumulative growing degree days (CGDD) for the 1995 and 1996 spring growing seasons. X symbols indicate normal cumulative rainfall and growing degree days, based on monthly 30-yr averages (1951–1980). Arrows indicate average date of 100% inflorescence emergence (Feekes growth stage 10.5; Large, 1954) over all treatments in 1995 and 1996.

effects were consistently significant over all of the variables measured. Averaged over all treatments, grain yield, apparent harvest index, kernel number per head, individual kernel weight, and kernel number per square meter were 36, 62, 56, 27, and 7% higher in 1995 than in 1996, respectively (data not shown). In contrast, average head number per square meter was 32% lower in 1995. There were few year × treatment interaction effects, with the exception of the year × surface tillage interaction that was significant for four of the six variables (Table 1). When significant, each variable was higher with no surface tillage than with disking in 1995, but lower with no surface tillage in 1996 (data not shown).

Grain Yield and Apparent Harvest Index

Average grain yield was 6% higher for wheat that followed soybean planted with the 19-cm-row width

Table 1. Results from statistical analysis of winter wheat grain yield, apparent harvest index, and yield component data collected in 1995 and 1996.

Treatment effects:†	Grain yield	Harvest index	Head number per m^2	Kernel number per head	Individual kernel weight	Kernel number per m^2
Row Width (RW)	**	**	NS	NS	NS	*
Surface Tillage (ST)	**	NS	*	NS	NS	*
Spring Deep Tillage (SDT)	**	NS	**	NS	NS	**
Fall Deep Tillage (FDT)	**	**	**	**	**	**
ST × SDT	NS	*	NS	NS	NS	NS
ST × FDT	*	NS	NS	NS	*	NS
SDT × FDT	*	NS	NS	NS	**	NS
ST × SDT × FDT	NS	NS	*	NS	NS	NS
RW × STD × FDT	*	NS	*	NS	NS	**
Year (Yr)	**	**	**	**	**	**
Yr × ST	**	NS	**	NS	**	**
Yr × FDT	**	NS	NS	NS	*	*
Yr × ST × SDT	NS	*	NS	NS	NS	NS
Yr × ST × SDT × FDT	NS	NS	**	NS	NS	NS
Yr × RW × SDT × FDT	NS	NS	**	NS	NS	*

† Only treatment effects significant at the 0.05 (*) or 0.01 (**) probability levels for at least one variable are listed. NS = not significant at 0.05 probability level.

Table 2. Winter wheat grain yield and apparent harvest index as affected by row-width culture of previous soybean crop, surface tillage, previous spring deep tillage, and fall deep tillage treatments. Values are averages over years (1995 and 1996).

Soybean row width	Surface tillage	Spring deep tillage	Grain yield		Harvest index	
			Fall deep tillage		Fall deep tillage	
			No	Yes	No	Yes
cm			— kg ha^{-1} —		— kg kg^{-1} —	
76	Disked	Yes	2466	3189	0.348	0.367
76	Disked	No	2329	3013	0.366	0.359
76	None	Yes	2635	3371	0.357	0.369
76	None	No	2277	3084	0.358	0.358
19	Disked	Yes	2952	3141	0.358	0.361
19	Disked	No	2341	2960	0.370	0.380
19	None	Yes	2951	3438	0.366	0.391
19	None	No	2253	3563	0.365	0.379
LSD†			78		0.012	
LSD‡			110		NS	

† LSD(0.05) for comparison of two-way interaction means.

‡ LSD(0.05) for comparison of three-way interaction means. NS = no three-way interactions significant at the 0.05 probability level.

than for wheat that followed soybean planted with the 76-cm-row width (Table 2). This response is of importance to Coastal Plain grain crop producers, since a majority of the doublecropped soybean produced in South Carolina is now planted in row widths of 38 cm or less (J. Palmer, 1999, personal communication). Planting wheat with no surface tillage also increased wheat grain yields by 6%, compared with disking.

Surface tillage had an effect on the grain-yield response of wheat to fall deep tillage. Grain yields were increased an average of 34% by fall deep tillage when the wheat was planted with no surface tillage, but only increased an average of 22% when the wheat was planted in the plots that were disked. This response supports previous research on soybean showing deep tillage to be more important with no surface tillage than with disking on Coastal Plain soils (Frederick et al., 1998). Fall deep tillage resulted in higher grain yields in both years of the study (data for each year not shown), but the increase in grain yield due to fall deep tillage was greater in 1995 (29%) than in 1996 (24%).

Averaged over the other treatments, wheat grain yields were increased 28% by fall deep tillage but increased only 11% by spring deep tillage, compared with no deep tillage. Grain yields averaged 3220 kg ha^{-1} with fall deep tillage and 3018 kg ha^{-1} with spring deep tillage. The greater response and higher average yield with fall deep tillage suggest that some soil recompaction occurred during the summer months, even though controlled traffic was used. The magnitude of the response to fall deep tillage depended on whether or not the plots were deep tilled in the spring. For example, fall deep tillage increased grain yields an average of 20% when the plots were also deep tilled in the spring, but were increased an average of 34% when the plots were not spring deep tilled. The plots receiving no deep tillage in the fall nor spring had the lowest average yield (2300 kg ha^{-1}), whereas the plots deep tilled in both the fall and spring had the highest average yield (3300 kg ha^{-1}). However, the additional 145 kg ha^{-1} obtained by deep tilling in both the fall and spring, compared with deep tilling in the fall alone, probably would not pay for the cost of the spring deep tillage operation.

The row width used to plant the previous soybean crop also had an effect on the wheat yield response to fall deep tillage. When the 76-cm-row width was used to produce the previous soybean crop, the response to fall deep tillage was relatively large (29%) even if the soil was deep tilled the previous spring (Table 2). In contrast, for the 19-cm-row width system, fall deep tillage increased average wheat yield by only 13% when the plots were deep tilled the previous spring. When deep tilled in the spring but not the fall, grain yields averaged 2550 and 2951 kg ha^{-1} for the wheat grown following soybean planted with the 76- and 19-cm-row widths, respectively. These row-width differences were probably due to the type of devices used to deep till the soil prior to soybean planting in the spring. With the 76-cm soybean row width system, the soil was in-row subsoiled for the plots receiving deep tillage. These devices generally fracture only a small portion of the soil profile, primarily near the subsoiler shanks (Busscher et al., 1999). Therefore, much of the soil probably was not fractured when the 76-cm-row width was used to plant the previous soybean crop, thus accounting for the relatively large wheat yield increase that resulted from fall deep tillage. In contrast, with the 19-cm soybean row width system, the soil was deep tilled with a Paratill which loosens almost all the soil located between the tillage shanks (Busscher et al., 1999). If minimal soil compaction occurred during the summer months, there would have been less response to fall deep tillage with the 19-cm soybean row width system (deep tillage with Paratill) than with the 76-cm soybean row width system (in-row subsoiled), as was found.

There were few treatment effects on apparent harvest index (Table 2). Apparent harvest indices were usually higher with fall deep tillage than with no fall deep tillage. Surface tillage influenced the apparent harvest index response to spring deep tillage. Average apparent harvest indices were 10% higher with spring deep tillage than with no deep tillage when the soil was disked, but 5% less with deep tillage when the wheat was planted with no surface tillage.

Components of Grain Yield

Average fertile head number per square meter was 4% higher with no surface tillage than with disking (Table 3). This response was unexpected because plant densities are usually less with no surface tillage than with disking (Frederick and Bauer, 1996), which may result in fewer heads per square meter at maturity. Average increases in fertile head number due to deep tillage were about 10% for both the fall only and spring only deep tillage treatments. Higher head numbers per square meter were generally found when the plots were deep tilled both in the fall and spring (504 heads), compared with either time alone (about 470 heads). The most benefit from deep tilling both times occurred for the wheat grown with no surface tillage and the wheat following soybean grown with the 76-cm-row width.

Table 3. Winter wheat fertile head number per m^2, kernel number per head, individual kernel weight, and kernel number per m^2 as affected by row-width culture of previous soybean crop, surface tillage, previous spring deep tillage, and fall deep tillage treatments. Values are averages over years (1995 and 1996).

			Head number		Kernel number		Individual kernel weight		Kernel no.	
			Fall Deep Tillage							
Soybean row width	Surface tillage	Spring deep tillage	No	Yes	No	Yes	No	Yes	No	Yes
cm			m^{-2}		head^{-1}		mg		m^{-2}	
76	Disked	Yes	435	506	21.9	24.5	23.9	23.5	9 015	11 824
76	Disked	No	421	456	22.8	24.4	22.9	24.7	8 974	10 552
76	None	Yes	476	516	21.5	24.3	23.4	23.9	9 747	12 193
76	None	No	426	481	21.0	23.2	23.2	24.8	8 479	10 672
19	Disked	Yes	473	504	23.6	23.2	24.4	24.6	10 514	11 060
19	Disked	No	394	449	23.1	24.8	23.5	24.0	8 688	10 730
19	None	Yes	495	515	23.1	24.4	23.4	24.4	10 945	12 155
19	None	No	399	529	21.9	25.1	22.6	24.2	8 528	12 722
LSD†			NS		NS		0.5		NS	
LSD‡			31		NS		NS		921	

† LSD(0.05) for comparison of two-way interaction means. NS = no two-way interactions significant at the 0.05 probability level.

‡ LSD(0.05) for comparison of three-way interaction means. NS = no three-way interactions significant at the 0.05 probability level.

Fall deep tillage was the only treatment having an effect on kernel number per head (Tables 1 and 3). Deep tilling at this time resulted in a 10% average increase in kernel number per head, compared with no fall deep tillage. Little rainfall occurred during the 3-wk period prior to inflorescence emergence in both years (Fig. 1). Drought stress during this time on the Coastal Plain reduces the number of kernels per head (Frederick and Camberato, 1995a). Since deep tillage increases the volume of soil water available to crop plants, it should

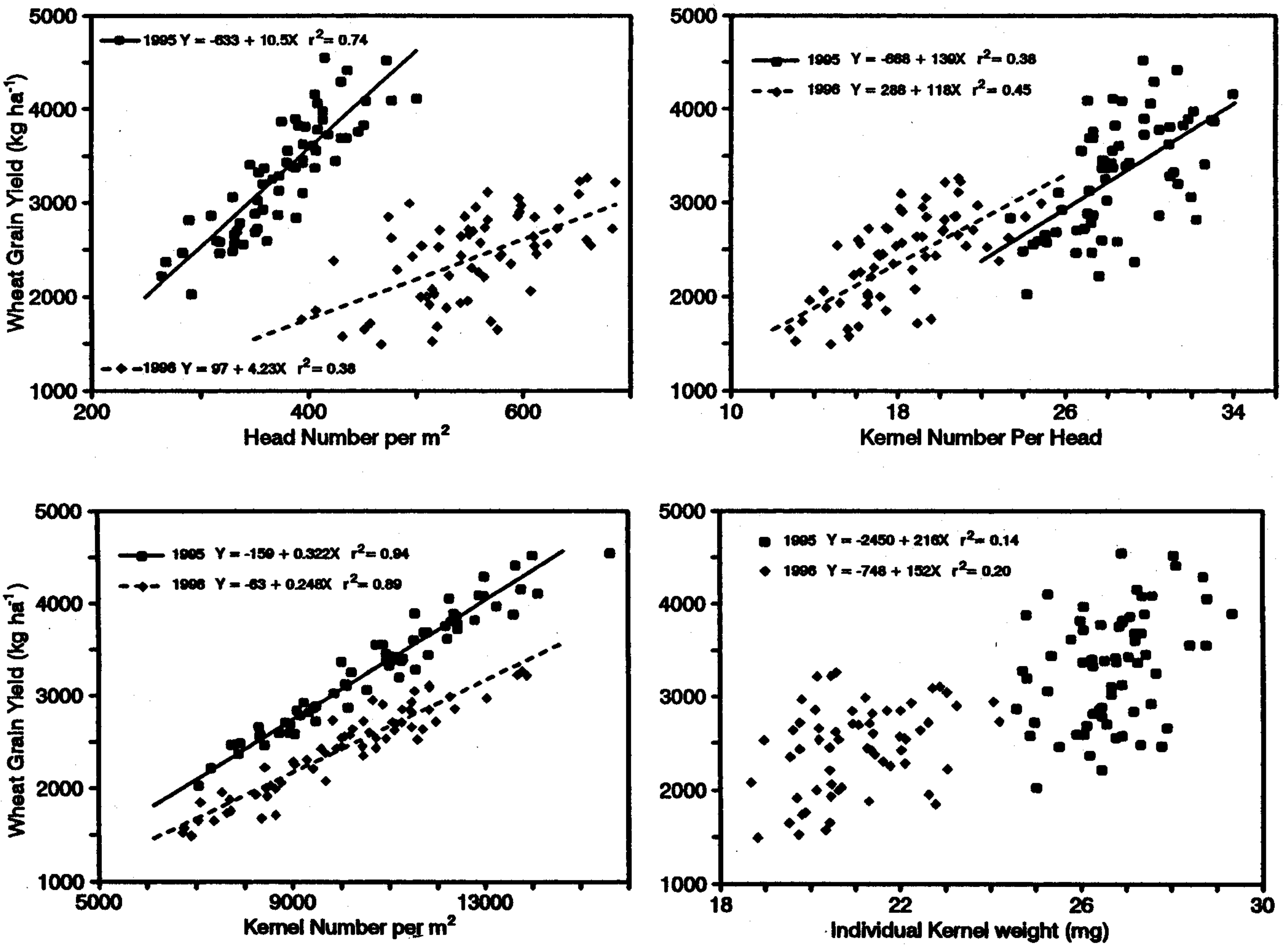

Fig. 2. Winter wheat grain yield as a function of fertile head number per square meter, kernel number per head, kernel number per square meter, and individual kernel weight in 1995 and 1996. Regression equations shown are those derived by linear regression analysis. Each value is a plot mean.

result in higher kernel numbers per head if stress occurs for a period of time prior to inflorescence emergence, as was found.

Fall deep tillage also had the greatest effect on individual kernel weight (Tables 1 and 3). Fall deep tillage increased wheat kernel weight an average of 3%, with surface tillage and spring deep tillage affecting the magnitude of the response. When disked, individual kernel weight was increased an average of 2% by fall deep tillage but increased an average of 6% with no surface tillage. When the soil was deep tilled the previous spring, there was little change in kernel weight with fall deep tillage. However, when the soil was not deep tilled in the spring, fall deep tillage increased individual kernel weight an average of 6%. This response indicates spring deep tillage can have an effect well into the growing season of the subsequent wheat crop.

Fertile head number per square meter and kernel number per head determine the number of kernels per square meter, which is usually closely associated with wheat grain yield (Frederick and Bauer, 1999). Treatment main effects on kernel number per square meter (Tables 1 and 3) were similar to those found for grain yield. Wheat kernel number per square meter was 5% higher when the 19-cm soybean row width was used than when the 76-cm soybean row width was used. As for grain yield, kernel number per square meter was 5% higher for no surface tillage than for disking. Spring deep tillage increased kernel number per square meter an average of 11%, whereas fall deep tillage increased kernel number an average of 23%. Kernel number per square meter averaged 11 470 with fall deep tillage and 10 930 with spring deep tillage. These results support the grain-yield responses showing the benefits from fall deep tillage are greater than those from deep tillage the previous spring. Unlike grain yield, there was no treatment interaction effects on kernel number per square meter (Table 1).

Over all treatments, the number of fertile heads per square meter had a greater effect on wheat grain yield than the number of kernels per head in 1995, but these two yield components had about the same effect in 1996 (Fig. 2). The close association between head number per square meter and grain yield suggest that a good plant stand and managing for a high fertile tiller number per plant are important for obtaining high winter wheat yields on the Coastal Plain. Grain yield was most closely associated with the number of kernels per square meter (Fig. 2). In contrast, there was little association between wheat grain yield and individual kernel weight (Fig. 2). Frederick and Bauer (1999) proposed that grain-yield improvement for wheat grown on the Coastal Plain has been the result of breeders selecting for a higher kernel number per square meter, rather than heavier kernels. They concluded that selection for heavier wheat kernels in this region is limited by the warm and dry weather conditions that frequently occur during grain fill and by the desire to avoid extending the duration of grain fill because of the loss in doublecropped soybean yield that would occur due to the delay in soybean planting. The close association we found between kernel number per square meter and grain yield, and lack of association between grain yield and kernel weight, support their hypotheses about yield improvement in winter wheat.

In summary, the grain-yield responses of wheat to deep tillage depended not only on the management practices used to produce the wheat crop, but also the practices used to produce the previous soybean crop. Deep tillage resulted in the greatest carry-over effects of all the treatments examined. Higher yields were found when deep tillage was done both in the spring and fall compared with either time alone, and deep tilling in the spring reduced the magnitude of the wheat yield response to fall deep tillage. These yield differences were primarily due to the effects of these treatments on the number of kernels per square meter. Planting the previous soybean crop with the 19-cm-row width also had a positive effect on wheat grain yield and kernel number per square meter, and resulted in a greater residual spring deep tillage effect than when the soybean was planted with the 76-cm-row width.

Fall deep tillage had the greatest effect of any treatment on the components of yield and was the only treatment that had a positive effect on all of the yield components. Planting with no surface tillage also had a positive effect on the number of fertile heads per square meter and individual kernel weight, but had no effect on kernel number per head. In no case did we find one yield component reduced in response to an increase in a previously determined yield component, as has frequently been reported to occur in wheat (Frederick and Marshall, 1985; Frederick and Camberato, 1995a). This would indicate that higher wheat yields on the Coastal Plain can be obtained by using production practices that result in little to no yield component compensation.

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