



Influence of paired rows on growth, yield, and fertility requirements of no-till spring wheat  
by Arnold Norman Benson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils  
Montana State University

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Abstract:

Paired-row planting is a new method of planting small grains that may possibly improve weed control and increase fertilizer efficiency; however, studies to date with wheat (*Triticum aestivum* L.) have shown mixed results.

Field experiments were conducted in 1987 in three environments in north central Montana to evaluate the effect of paired rows (PR) on growth and yield of no-till spring wheat (cv. 'Rambo'). Secondary objectives were to evaluate fertilizer requirements of spring wheat in a PR system, and to determine optimum placement of P fertilizer. The experimental design was a randomized split-plot with three row configurations as main plot treatments, and various fertilizer rates and P placements as subplot treatments.

Grain yields were significantly reduced in the 15 x 35-cm PR at both dryland sites; yields at an irrigated site were similar across all three row configurations. The 20 x 30-cm PR and 25-cm equidistant row (ER) configurations responded similarly in terms of yield and yield components at all three sites.

Data from tissue samples taken at three growth stages revealed that although early growth differences due to row configuration were slight, and generally favored the PR, the 25-cm ER showed an increasing growth advantage with time compared to the 15 x 35-cm PR. In the combined analysis of variance across sites, this resulted in a significant ( $P < 0.02$ ) row configuration x growth stage interaction for dry matter production. Plant shading within the PR and/or differences in water use efficiency were postulated as causal factors for these responses.

Grain yields were significantly increased by N at the two dryland sites. Considering both yield and grain protein, an N rate of 40 kg N Mg<sup>-1</sup> grain was optimum for PR spring wheat. Since all three sites were high in P and K, few responses to P or K fertilizer were evidenced. Three P placements produced similar yields, except at the irrigated location.

Results of this study indicate that under no-till conditions there is no advantage to planting spring wheat in PR. Paired rows appeared to have little influence on fertilizer requirements of no-till spring wheat.

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OF NO-TILL SPRING WHEAT**

**by**

**Arnold Norman Benson**

**A thesis submitted in partial fulfillment  
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APPROVAL

of a thesis submitted by

Arnold Norman Benson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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## TABLE OF CONTENTS

	Page
APPROVAL.....	ii
STATEMENT OF PERMISSION TO USE.....	iii
VITA.....	iv
ACKNOWLEDGEMENTS.....	v
TABLE OF CONTENTS.....	vi
LIST OF TABLES.....	viii
LIST OF FIGURES.....	xiv
ABSTRACT.....	xv
CHAPTER	
1. INTRODUCTION.....	1
2. LITERATURE REVIEW.....	5
Row Configuration Effects on Crop Growth, Yield, and Weed Control.....	5
Nitrogen Fertilizer Requirement of No-Till Wheat.....	10
Wheat Response to Phosphorus Fertilizer Rate and Placement.....	13
Wheat Response to Potassium Fertilizer.....	19
3. MATERIALS AND METHODS.....	22
Statistical Methods.....	29
4. RESULTS AND DISCUSSION.....	30
Effect of Paired Rows.....	30
Effect of Nitrogen Fertilizer Rate.....	68
Effect on Grain Yield, Yield Components, and Growth.....	68

TABLE OF CONTENTS--Continued

	Page
Effect on Dry Matter Production, Nutrient Concentration, and Nutrient Uptake.....	74
N x P Interaction.....	79
Effect of Phosphorus Fertilizer.....	79
Effect of P Fertilizer Rate.....	79
Effect of P Fertilizer Placement.....	87
Row Configuration x P Placement Interaction.....	95
Effect of K Fertilizer Rate.....	95
5. SUMMARY AND CONCLUSIONS.....	103
LITERATURE CITED.....	107
APPENDICES	
A. Figure 13.....	117
B. Table 50.....	119
C. Table 51.....	121
D. Tables 52-56.....	125
E. Tables 57-61.....	131

## LIST OF TABLES

Table		Page
1.	Soil characteristics for 1987 no-till spring wheat experiments.....	23
2.	Treatments used for no-till spring wheat experiments at Brady, Conrad, and Agawam, Montana, 1987.....	24
3.	Effect of three row configurations on grain yield and yield components of no-till spring wheat, 1987.....	32
4.	Climatic data for no-till spring wheat experiments, 1987.....	33
5.	Soil water data from Brady site, 1987.....	34
6.	Soil water data from Conrad site, 1987.....	35
7.	Soil water data from Agawam site, 1987.....	36
8.	Main effects of row configuration and P fertilizer placement on grain yield of no-till spring wheat, 1987.....	40
9.	Main effects of row configuration and P fertilizer placement on tiller density of no-till spring wheat, 1987.....	41
10.	Main effects of row configuration and P fertilizer placement on kernels per spike of no-till spring wheat, 1987.....	43
11.	Main effects of row configuration and P fertilizer placement on kernel weight of no-till spring wheat, 1987.....	44
12.	Effect of three row configurations on grain test weight and grain protein of no-till spring wheat, 1987.....	45
13.	Main effects of row configuration and P fertilizer placement on grain test weight of no-till spring wheat, 1987.....	46

LIST OF TABLES--Continued

Table		Page
14.	Main effects of row configuration and P fertilizer placement on grain protein of no-till spring wheat, 1987.....	47
15.	Main effects of row configuration and P fertilizer placement on heading date of no-till spring wheat, 1987.....	48
16.	Effect of three row configurations on heading date, plant height at heading, and plant height at harvest of no-till spring wheat, 1987.....	49
17.	Main effects of row configuration and P fertilizer placement on height at heading and harvest of no-till spring wheat, 1987.....	50
18.	Main effects of row configuration and P fertilizer placement on harvest index of no-till spring wheat, 1987.....	51
19.	Main effects of row configuration and P fertilizer placement on dry matter production at three growth stages of no-till spring wheat, 1987.....	52
20.	Main effects of row configuration and P fertilizer placement on tissue N concentration at three growth stages of no-till spring wheat, 1987.....	53
21.	Main effects of row configuration and P fertilizer placement on N uptake at three growth stages of no-till spring wheat, 1987.....	54
22.	Main effects of row configuration and P fertilizer placement on tissue P concentration at three growth stages of no-till spring wheat, 1987.....	55
23.	Main effects of row configuration and P fertilizer placement on P uptake at three growth stages of no-till spring wheat, 1987.....	56

LIST OF TABLES--Continued

Table		Page
24.	Analysis of variance over all sites and growth stages (GS) for effects of row configuration (RC) and P fertilizer placement (PPL) on tissue N and P concentration, N and P uptake, and dry matter production of no-till spring wheat, 1987.....	60
25.	Main effects of site, row configuration, P fertilizer placement, and growth stage on tissue N and P concentration, N and P uptake, and dry matter production of no-till spring wheat, 1987.....	62
26.	Main effect of row position at two row configurations on grain yield, yield components, and grain test weight of no-till spring wheat at Agawam site, 1987.....	66
27.	Effect of N fertilizer rate on grain yield, tiller density, and kernels per spike of no-till spring wheat, 1987.....	70
28.	Effect of N fertilizer rate on kernel weight, grain test weight, and grain protein of no-till spring wheat, 1987.....	71
29.	Effect of N fertilizer rate on heading date, plant height at heading, and plant height at harvest of no-till spring wheat, 1987.....	75
30.	Main effects of N fertilizer rate and growth stage on dry matter production of no-till spring wheat, 1987.....	76
31.	Main effects of N fertilizer rate and growth stage on tissue N concentration and N uptake of no-till spring wheat, 1987.....	77
32.	Main effects of N fertilizer rate and growth stage on tissue P concentration and P uptake of no-till spring wheat, 1987.....	78
33.	Effect of P fertilizer rate on grain yield, tiller density, and kernels per spike of no-till spring wheat, 1987.....	80

LIST OF TABLES--Continued

Table		Page
34.	Effect of P fertilizer rate on kernel weight, grain test weight, and grain protein of no-till spring wheat, 1987.....	82
35.	Effect of P fertilizer rate on heading date, plant height at heading, and plant height at harvest of no-till spring wheat, 1987.....	83
36.	Main effects of P fertilizer rate and growth stage on dry matter production of no-till spring wheat, 1987.....	84
37.	Main effects of P fertilizer rate and growth stage on tissue N concentration and N uptake of no-till spring wheat, 1987.....	85
38.	Main effects of P fertilizer rate and growth stage on tissue P concentration and P uptake of no-till spring wheat, 1987.....	86
39.	Effect of P fertilizer placement on grain yield and yield components of no-till spring wheat, 1987.....	88
40.	Effect of P fertilizer placement on grain test weight and grain protein of no-till spring wheat, 1987.....	89
41.	Effect of P fertilizer placement on heading date, plant height at heading, and plant height at harvest of no-till spring wheat, 1987.....	90
42.	Main effects of P fertilizer placement and growth stage on dry matter production of no-till spring wheat, 1987.....	91
43.	Main effects of P fertilizer placement and growth stage on tissue N concentration and N uptake of no-till spring wheat, 1987.....	92
44.	Main effects of P fertilizer placement and growth stage on tissue P concentration and P uptake of no-till spring wheat, 1987.....	93

LIST OF TABLES--Continued

Table		Page
45.	Effect of K fertilizer on grain yield and yield components of no-till spring wheat, 1987.....	96
46.	Effect of K fertilizer on grain test weight and grain protein of no-till spring wheat, 1987.....	97
47.	Effect of K fertilizer on heading date, plant height at heading, and plant height at harvest of no-till spring wheat, 1987.....	99
48.	Mean effect of K fertilizer averaged over three growth stages (GS) on tissue K concentration, K uptake, and dry matter production of no-till spring wheat, 1987.....	101
49.	Mean effect of K fertilizer averaged over three growth stages (GS) on tissue N and P concentration and N and P uptake of no-till spring wheat, 1987.....	102
50.	Analysis of variance over all sites for effects of row configuration (RC) and P fertilizer placement (PPL) on grain yield, yield components, grain test weight, protein, heading date, and plant height of no-till spring wheat, 1987.....	120
51.	Treatment means for treatments 17, 21, 25, and 26 of no-till spring wheat experiments, 1987.....	122
52.	Analysis of variance over two row configurations (RC) for effects of P fertilizer placement (PPL) and row position (POS) on grain yield, yield components, and grain test weight of no-till spring wheat at Agawam site, 1987.....	126
53.	Main effect of row position at two row configurations on grain yield, yield components, and grain test weight of no-till spring wheat at Brady site, 1987.....	127
54.	Analysis of variance over two row configurations (RC) for effects of P fertilizer placement (PPL) and row position (POS) on grain yield, yield components, and grain test weight of no-till spring wheat at Brady site, 1987.....	128

LIST OF TABLES--Continued

Table		Page
55.	Main effect of row position at two row configurations on grain yield, yield components, and grain test weight of no-till spring wheat at Conrad site, 1987.....	129
56.	Analysis of variance over two row configurations (RC) for effects of P fertilizer placement (PPL) and row position (POS) on grain yield, yield components, and grain test weight of no-till spring wheat at Conrad site, 1987.....	130
57.	Effect of N and P fertilizer rate on grain yield and tiller density of no-till spring wheat, 1987.....	132
58.	Effect of N and P fertilizer rate on kernels per spike and kernel weight of no-till spring wheat, 1987.....	133
59.	Effect of N and P fertilizer rate on grain test weight and grain protein of no-till spring wheat, 1987.....	134
60.	Effect of N and P fertilizer rate on heading date of no-till spring wheat, 1987.....	135
61.	Effect of N and P fertilizer rate on plant height at heading and plant height at harvest of no-till spring wheat, 1987.....	136

## LIST OF FIGURES

Figure		Page
1.	Diagram of equidistant and paired-row configurations.....	2
2.	Diagram showing location of rows sampled to determine main effects of row position.....	28
3.	Effect of three row configurations on grain yield of spring wheat, 1987.....	31
4.	Effect of three row configurations on kernel number of spring wheat, 1987.....	37
5.	Main effect of two row configurations on grain yield of spring wheat, 1987.....	39
6.	Main effect of two row configurations on dry matter production at Conrad, 1987.....	58
7.	Main effect of two row configurations on dry matter of spring wheat, 1987.....	59
8.	Main effect of two row configurations on P uptake of spring wheat, 1987.....	61
9.	Main effect of two row configurations on dry matter production at Agawam, 1987.....	64
10.	Effect of N fertilizer rate on grain yield of spring wheat, 1987.....	69
11.	Effect of N fertilizer rate on grain protein of spring wheat, 1987.....	73
12.	Effect of K fertilizer rate on heading date of spring wheat, 1987.....	98
13.	Soil temperatures at Brady, Conrad, and Agawam sites, 1987 (50 cm depth).....	118

## ABSTRACT

Paired-row planting is a new method of planting small grains that may possibly improve weed control and increase fertilizer efficiency; however, studies to date with wheat (*Triticum aestivum* L.) have shown mixed results.

Field experiments were conducted in 1987 in three environments in north central Montana to evaluate the effect of paired rows (PR) on growth and yield of no-till spring wheat (cv. 'Rambo'). Secondary objectives were to evaluate fertilizer requirements of spring wheat in a PR system, and to determine optimum placement of P fertilizer. The experimental design was a randomized split-plot with three row configurations as main plot treatments, and various fertilizer rates and P placements as subplot treatments.

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Data from tissue samples taken at three growth stages revealed that although early growth differences due to row configuration were slight, and generally favored the PR, the 25-cm ER showed an increasing growth advantage with time compared to the 15 x 35-cm PR. In the combined analysis of variance across sites, this resulted in a significant ( $P \leq 0.02$ ) row configuration x growth stage interaction for dry matter production. Plant shading within the PR and/or differences in water use efficiency were postulated as causal factors for these responses.

Grain yields were significantly increased by N at the two dryland sites. Considering both yield and grain protein, an N rate of 40 kg N Mg<sup>-1</sup> grain was optimum for PR spring wheat. Since all three sites were high in P and K, few responses to P or K fertilizer were evidenced. Three P placements produced similar yields, except at the irrigated location.

Results of this study indicate that under no-till conditions there is no advantage to planting spring wheat in PR. Paired rows appeared to have little influence on fertilizer requirements of no-till spring wheat.

## CHAPTER 1

## INTRODUCTION

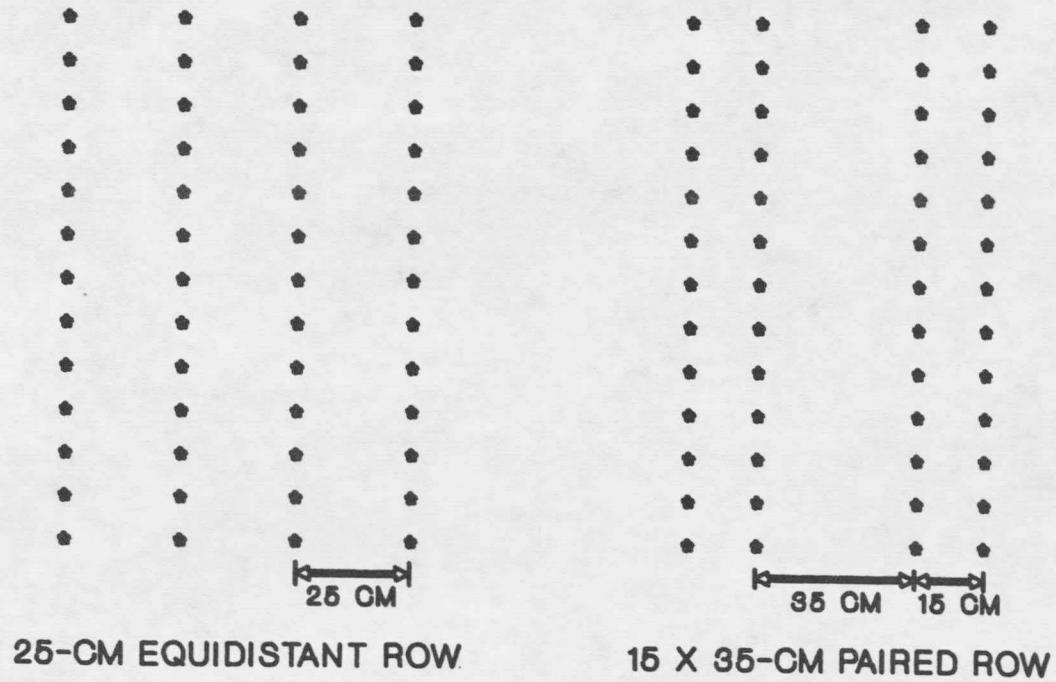
The use of no-till and minimum tillage systems for small grain production is growing rapidly in grain-producing regions of the western United States. These production systems have the potential to effectively control soil erosion and reduce production costs. Advances in fertilizer placement technology and equipment design have further increased the yield potential of these systems.

Despite these advantages, there is the frequent problem of grassy weeds, resulting in increasing dependence on herbicides for weed control (Papendick and Miller, 1977). Crop residues left on the soil surface also make planting more difficult, and can result in immobilization of applied fertilizer (Tomar and Soper, 1981).

Paired-row planting is a new method of planting small grains that originated in the Pacific northwestern United States in the early 1980's. In this method, two rows of seeds are planted 10 to 18 cm apart with an untilled zone of 33 to 40 cm between each set of rows (Fig. 1). Paired-row planting makes it possible to supply all of the crop's fertilizer needs at the time of seeding by placing a deep band (>10 cm deep) of fertilizer midway between the paired rows; the nutrients are thus equally accessible to each seed row. This represents a possible advantage over the practice of banding fertilizer prior to planting. Leikam et al.

Figure 1

### DIAGRAM OF EQUIDISTANT AND PAIRED-ROW CONFIGURATIONS



(1983) found that winter wheat growth was best immediately atop pre-plant fertilizer bands and poor midway between bands.

Fertilizer deep-banded between paired rows may also improve weed control in no-till systems by making nutrients less accessible to weeds. Easier field access for application of herbicides or soil fumigants has been suggested as another possible advantage of paired-row planting (Papendick et al., 1984).

Several studies have shown that deep-banded nitrogen fertilizer is more effective than unincorporated broadcast applications, especially in no-till systems (Parsons and Koehler, 1984; Carter and Rennie, 1984). The strategy of deep banding fertilizer is usually adopted along with a paired-row planting system. For this reason, when paired rows show an apparent yield advantage over equidistant rows, it is difficult to determine if the response is due to banded fertilizer or due to row configuration. Furthermore, direct comparison of row configuration is difficult because most drills do not allow for major adjustments in row spacing or configuration.

For these reasons, little information is available for comparing crop response to equidistant and paired-row planting systems. Studies to date with wheat have shown mixed results. The fertilizer requirements of wheat under paired-row cropping have not been fully evaluated.

Field experiments were conducted in 1987 at two dryland sites and one irrigated site in north central Montana with the following objectives:

- (1) to determine the effect of paired rows on growth and yield of no-till spring wheat (*Triticum aestivum* L.) and investigate possible causes of differential response;
- (2) to determine optimum nitrogen (N), phosphorus (P), and potassium (K) fertilizer rates for spring wheat in a paired-row system; and
- (3) to determine the optimum placement of P fertilizer for spring wheat.

## CHAPTER 2

## LITERATURE REVIEW

Row Configuration Effects on Crop  
Growth, Yield, and Weed Control

Wheat is normally planted in equidistant row (ER) spacings ranging from 10 to 15 cm in regions where seeding rates are high to 35 cm where seeding rates are low (Paulsen, 1987). At constant seeding rate, narrowing the row spacing results in a more equidistant plant spacing. In high yield environments where moisture is not limiting, narrow row spacings are usually most advantageous (Roth et al., 1984). This is probably due to a more complete exploitation of existing resources (Marshall and Ohm, 1987), as well as earlier canopy closure leading to reduced evaporation losses from the soil surface (Doyle and Fischer, 1979).

In arid or semiarid environments, substantial differences in row spacing may not affect grain yield (Ketata et al., 1976; Vander Vorst et al., 1983). In contrast, some studies have indicated that even in semiarid regions narrow row spacings can provide yield advantages (Doyle, 1980; Reinertsen et al., 1984). Wheat response to row spacing is also dependent upon cultivar characteristics (Marshall and Ohm, 1987).

Holliday (1963) described the "ratio of rectangularity" as the ratio of the distance between rows to the average distance between plants within a row. This ratio approaches unity, or a square planting pattern,

when row spacing is decreased at constant seeding rate. When environmental resources available to a plant are limited and seeding rates are low, a square rather than a rectangular planting pattern should result in a more efficient use of these resources by delaying the time of leaf and root zone overlap from neighboring plants (Auld et al., 1983).

If a paired-row (PR) configuration is adopted instead of an ER spacing, this ratio of rectangularity does not change. However, plants encounter competition from adjacent rows earlier in the growing season (Fig. 1). This early plant competition can reduce tillering (Doyle, 1980; Auld et al., 1983). The wider distance between each set of PR is also likely to affect canopy light and water relations, growth, and perhaps yield.

Results of studies with winter wheat at Washington State University were inconsistent when PR and ER were compared. Paired rows showed yield advantages in some, but not all years. Paired rows appeared to increase early plant vigor (R.I. Papendick, USDA-ARS, Pullman, WA, 1988, personal communication; V.P. Rasmussen, Department of Soil Science and Biometeorology, Utah State University, 1988, personal communication). Rasmussen's results in Utah indicated that PR were advantageous on calcareous, eroded soils when used in conjunction with deep-banded fertilizer. Planting systems with fertilizer banded between PR and banded below ER have resulted in similar wheat yields (Veseth, 1987).

Results after one year of studies with barley (*Hordeum vulgare* L.) in Alaska indicate that grain yield differences due to row configuration (18-cm ER vs. 18 x 36-cm PR) were not statistically significant (B.S. Sharratt, USDA-ARS, Fairbanks, AK, 1988, personal communication). The

PR treatments produced more grain on a per-plant basis than ER treatments, the difference being related to lower reflectance of solar radiation and higher between-row soil temperatures in PR barley.

Wheat response to PR in Montana has been inconsistent. Yields of winter wheat in PR and ER were not significantly different at most sites in 1985, an extremely dry year. Spring wheat yields were increased by PR at one site and decreased at another. Significant cultivar x row configuration interactions were also noted (H.A.R. Houlton, unpublished data, Montana Agricultural Experiment Station, Havre, MT). Research in north central Montana in 1986 showed no significant yield differences due to row configuration for both spring wheat and barley (G.D. Kushnak, unpublished data, Montana Agricultural Experiment Station, Conrad, MT).

In an Australian study, Auld et al. (1983) compared the yields of three wheat cultivars sown in rhomboidal, square, and rectangular patterns with wheat planted in 18-cm ER and broadcasted wheat. Square sowing resulted in significant ( $P < 0.05$ ) yield increases over rectangular arrangements in one experiment at sowing densities of 75, 150, and 200 plants  $m^{-2}$ . Over all four experiments during the three year period there was a consistent significant trend of decreasing yield with increasing rectangularity at low seeding rates. Decreased tiller numbers in rectangular as compared to square planting patterns were largely responsible for reduced yields of the rectangular planting pattern. The researchers concluded that there would be no advantage in changing from the traditional 18-cm ER spacing to any precise geometric pattern. However, when plant densities are less than 200 plants  $m^{-2}$ , rectangular planting patterns will likely result in lower yields than square planting

patterns. It was postulated that this is due to reduced ability of the plants to utilize available space.

Studies with wheat planting geometry in other countries have been focused mainly on the feasibility of planting other crops in the space between multi-row strips of wheat. In a study in Pakistan, wheat was planted in single rows 40 cm apart, PR 60 cm apart, triple rows 80 cm apart, and quadruple rows 100 cm apart (Nazir et al., 1984). The distance between wheat rows within each multi-row strip was 20 cm in all the planting systems. Although yield differences between the various planting patterns were not statistically significant, the equidistant 40-cm single rows produced the most tillers and the highest yields.

Improved weed control in no-till systems has been suggested as another possible advantage of PR. Since fertilizer is usually deep-banded midway between the PR, this may reduce the ability of weeds to compete with the crop. On the other hand, the wider space between each set of PR may encourage growth of certain weed species.

Manipulation of crop planting patterns to reduce weed interference has been studied with many crops in conventional tillage systems (Zimdahl, 1980). The majority of the literature shows that crop density influences wild oat (*Avena fatua* L.) infestations more than crop row spacing (Chancellor and Peters, 1976). In no-till systems, narrow row spacings have improved weed control in a winter wheat-corn-fallow rotation (Vander Vorst et al., 1983). Reinertsen et al. (1984) found that in a no-till system, spring wheat sown in 20-cm row spacings resulted in significant increases in dry matter yield, N uptake, and grain yield compared to 30-cm and 40-cm row spacings. Increased grain

yields in the narrow rows were not associated with reduced wild oat infestations, however, because wild oat dry weight and N uptake were not affected by row spacing.

Another study was conducted in Washington to evaluate the effect of wheat grown in two row configurations (25-cm ER and 12 x 38-cm PR) on growth and competition of jointed goatgrass (*Aegilops cylindrica*). Spikes  $m^{-1}$  row, dry weight, and grain yield of both winter wheat and jointed goatgrass were reduced when jointed goatgrass was established in the wheat row regardless of row configuration. Row configuration did not significantly affect growth and development of either winter wheat or jointed goatgrass (Fleming and Young, 1986).

Planting systems similar to the PR system have shown more promise with several other crops. These systems are also called twin rows or double rows. Albers (1987) compared soybeans (*Glycine max* [L.] Merr.) planted in conventionally spaced (102 cm) rows with twin-row soybeans (30 x 72 cm). Early maturing cultivars showed a positive yield response to twin rows, while later maturing cultivars did not. The parameter most closely correlated with yield response to twin rows was canopy light interception (CLI). Through vegetative and early reproductive growth phases, twin-row soybeans intercepted a greater portion of incident light than conventional row soybeans. Those cultivars that did maintain this CLI advantage through later reproductive stages resulted in positive yield responses to twin rows; the later maturing cultivars that lost their CLI advantage resulted in similar yield levels between the two row configurations. Higher levels of mutual shading in the twin-row plots appeared to offset the advantage of twin rows.

Under rainfed conditions during the monsoon period in India, yield and leaf area index of sorghum (*Sorghum bicolor*) grown in 30-cm ER and 30 x 90-cm PR were not significantly different (Bandyopadhyay and De, 1986).

Mozingo and Coffelt (1984) reported no significant yield differences between single and twin-row planting patterns for two cultivars of peanuts (*Arachis hypogaea* L.). Wehtje et al. (1984) proposed that twin rows could more effectively suppress weeds and thereby reduce herbicide inputs for peanut production. Reductions in grasses in the twin-row configuration were evident in two out of three years in the check plot, which received no herbicides. Comparable reductions in broadleaves and yield increases due to twin rows were sporadic. It was concluded that weed suppression by twin rows was not consistent enough to allow any reduction in herbicide inputs.

#### Nitrogen Fertilizer Requirement of No-Till Wheat

Nitrogen is an essential constituent of all plant proteins, nucleic acids, and the chlorophyll molecule. It plays an important role in several coenzymes regulating carbohydrate production and utilization (Follett et al., 1981). Adequate N results in vigorous growth and dark green leaves and stems. Adequate, but not excess, N hastens maturity; excess N causes succulent growth, which can result in delayed maturity, lodging, and reduced resistance to disease.

The total predicted N requirement of a crop is calculated by multiplying the potential yield estimate by the N required per unit of

grain yield. The residual soil  $\text{NO}_3^-$ -N is subtracted from this value, and other adjustments based on management are made. The result is the estimated N fertilizer requirement. The quantity of N (soil + fertilizer) needed to optimize wheat yields varies from 33 to 50 kg N  $\text{Mg}^{-1}$  grain, with 40 kg N  $\text{Mg}^{-1}$  grain about average for the northern Great Plains (Halvorson et al., 1987).

Management factors also influence N fertilizer requirement. If the previous crop was a legume, the N fertilizer recommendation can be reduced (Dahnke and Swenson, 1983). Large quantities of mineralizable N or manure applications also reduce the need for N fertilizer (Halvorson et al., 1987). In reduced or no-till systems, an additional 10 to 20 kg N  $\text{ha}^{-1}$  should be added for each  $\text{Mg ha}^{-1}$  of small grain straw or maize residue returned to the soil from the previous crop (Halvorson et al., 1987). Increased N is needed because some of the N is immobilized during microbial decomposition of crop residues (Tomar and Soper, 1981). Black and Siddoway (1977) found that grain yields of winter wheat were generally reduced by increasing stubble height at a given N fertilizer rate. Their study also demonstrated that N fertilization increased grain yields and protein levels more efficiently when wheat was seeded in standing stubble than when seeded where crop residues had been incorporated.

Some researchers have questioned the need for additional N fertilizer in no-till systems. Results of growth chamber and field studies with spring wheat in Saskatchewan showed that placement of N fertilizer below the seed in comparison to broadcast application generally reduced N immobilization, and increased N uptake and efficiency on both no-till and conventional tillage systems. The researchers

concluded that fertilizer management practices for the two contrasting tillage systems should be the same (Carter and Rennie, 1984).

In a study conducted in Colorado, Montana, and Nebraska, Smika et al. (1969) observed that even though straw mulch on the soil surface resulted in lower soil  $\text{NO}_3^-$ -N levels compared to bare soil, there was a concomitant increase in soil moisture under the mulch treatments. Furthermore, in four out of 11 years where grain yields were reduced by the presence of straw mulch, there was no evidence to suggest this was due to an inadequate supply of N. It is known that crop residues left on the soil surface can improve soil moisture status (Black, 1973). This moisture advantage is perhaps more important than any reduction in soil  $\text{NO}_3^-$ -N that may occur under no-till conditions (Smika et al., 1969).

After three years of study in North Dakota, Deibert et al. (1986) concluded there was no reason to suggest that additional N is required for reduced tillage. Their study compared the effect of surface-banded and deep-banded N fertilizer on spring wheat growth and yield in three different tillage systems: no-till, plow-till, and sweep-till. Placement of N fertilizer had little or no effect on growth or yield, indicating that either little N was lost due to volatilization or, if a loss of N occurred, it did not affect crop growth.

Adequate N is required not only for optimum grain yield, but also for grain protein. Adding more N than needed for optimum yield will generally result in an increase in grain protein (Halvorson et al., 1987). Goos et al. (1982) have shown that grain protein content can be used as an indicator of N sufficiency. In North Dakota, spring wheat grain protein below 14% indicated insufficient N (Goos, 1984). For

winter wheat, 12% protein indicated sufficient N for optimum yield of winter wheat (Goos et al., 1982).

Wheat Response to Phosphorus Fertilizer  
Rate and Placement

Phosphorus is required by all plant cells for energy storage and transfer reactions, nutrient absorption, and as a constituent of DNA, RNA, and various coenzymes involved in oxidation-reduction reactions (Follett et al., 1981). Wheat plants that lack adequate P often show delayed maturity and are stunted. Black (1970) found that P fertilization increased the number of adventitious roots and tillers per plant, the number of spikes per hectare, and hastened maturity of spring wheat.

It is estimated that the vegetative and grain portions of the wheat plant require about 6 to 8 kg P Mg<sup>-1</sup> grain for optimum growth (Halvorson et al., 1987). On calcareous soils with NaHCO<sub>3</sub>-extractable P levels above 16 mg kg<sup>-1</sup> soil (high soil test rating), the supply of P from the soil is considered adequate for optimum wheat yields; crops grown on these soils seldom respond to P fertilizer additions (Black, 1982; Dahnke, 1983). On soils with NaHCO<sub>3</sub>-extractable P levels below 10 mg kg<sup>-1</sup> soil, wheat will generally respond to P fertilization (Halvorson et al., 1987).

Phosphorus soil test levels are not completely reliable in predicting wheat response to P fertilizer additions, however, because soil moisture and soil temperature conditions also influence P availability and uptake (Sutton, 1969; Power et al., 1961).

Alessi and Power (1980) studied the residual effects of P fertilization in a six year study with continuous spring wheat. Continued additions of P fertilizer resulted in  $\text{NaHCO}_3$ -extractable P levels above  $15 \text{ mg kg}^{-1}$  soil in many of the plots; nevertheless, annual banding of  $15 \text{ kg P ha}^{-1}$  with the seed still increased yields an average of about 10 percent. Yield responses normally would not be expected on soils this high in P. But since cool soil temperatures can limit P uptake by plants (Sutton, 1969), annual banding of P fertilizer with the seed may be beneficial for spring wheat in the cool springs of the northern Great Plains regardless of soil P levels. The importance of P placement in cool soils was confirmed by Tangmanee (1977). At a soil temperature of  $12.8^\circ\text{C}$ , placement of P fertilizer 5 cm below and 6.3 cm or 7.5 cm to the side of wheat seed was 2.4 times as effective as placement 5 cm below and 20 cm to the side with respect to uptake of fertilizer P by the plants. At  $21.1^\circ\text{C}$ , P uptake was the same for the three placement distances.

There are two basic methods of P application: broadcast and banding. Broadcasting P followed by incorporation with the soil is a common method of P application; however, at low soil test P levels, about 1.5 to 3 times more fertilizer P is recommended for broadcast than band application to obtain the same yield goal (Peterson et al., 1981). It is theorized that this is because band application of P with or near the seed reduces the amount of soil-fertilizer contact, resulting in less or slower P conversion to unavailable forms than would occur with broadcast application (Englestad and Terman, 1980).

Phosphorus that is "fixed" by soil reactions with Ca and Al may become available to crops in future years. Recent long-term P fertility studies have shown that a single, high rate broadcast P application may be effective for as long as 16 years (Halvorson and Black, 1985). Jose and Nilsen (1982) concluded there was a long-term economic advantage of a single, high rate broadcast P application over annual banding of P at several dryland sites in Canada.

Banding of P fertilizer, either at seeding or in a separate application, has largely replaced the practice of broadcasting P fertilizer in the intermediate and low precipitation zones of the western United States (Veseth et al., 1986). The chief advantage of banded P fertilizer has been shown to be increased root-fertilizer contact, i.e., better positional availability of fertilizer, rather than reduced fixation of applied P (Sleight et al., 1984; Dahnke et al., 1986). Since P is relatively immobile in soil, P fertilizer should be placed in a zone where roots are most concentrated and active. Until recently, equipment limitations made it difficult to place P fertilizer below the seed level. Use of new equipment for fertilizer placement plus a better understanding of the rooting patterns of cereals have increased yields of cereal crops, especially under no-till and minimum tillage systems (Veseth et al., 1986).

Klepper et al. (1983) studied the rooting patterns of cereals. Cereals such as wheat have two types of roots: seminal roots and crown or nodal roots. Seminal roots grow out from the main stem at the seed shortly after germination, and thereafter grow downward at a 30 to 45 degree angle. These roots supply all of the crop's nutrient needs until

approximately the time tillers begin to form (four-leaf stage). At about this time, crown roots grow out from the base of the crown. These roots begin by exploring the soil between the rows above the seed depth. Since this zone was void of roots prior to tillering, fertilizer bands placed above the seed or 5 to 8 cm to the side of the seed at seed depth will not be explored by roots until after tillering begins. Placement of fertilizer bands 5 cm below the seed or 5 to 8 cm to the side and 5 cm below the seed will allow seminal roots early access to nutrients, leading to increased early vigor and improved ability to compete with weeds.

Cereals planted in the fall often show different responses to P fertilizer placement than spring-planted cereals. Warmer soil temperatures deeper in the soil profile allow fall-planted cereals to develop vigorous root systems, leading to better root-fertilizer contact for nutrient absorption. Spring-planted cereals encounter cooler, wetter soils with depth; the result is a shorter root system than fall-planted cereals at the same stage of plant development. Consequently, spring cereals are more likely to respond to P banded near the seminal roots than winter cereals (Veseth et al., 1986).

Banding P with the wheat seed has also been shown to enhance early availability of P (McConnell et al., 1986), and to increase dry matter and grain yields, even in soils with medium to high levels of available P (Alessi and Power, 1980). Cabrera et al. (1986) tested the hypothesis that seed-banded N and P could reduce or eliminate uneven growth caused by pre-plant N and P fertilizer bands and increase yields. Seed-banded fertilizer increased tillering and early dry matter production, but

produced no significant increases in grain yield. Read et al. (1977) observed that when  $\text{NaHCO}_3$ -extractable P levels were above  $10 \text{ mg kg}^{-1}$  soil, there was little response to seed-placed P.

Depth of P placement is another important consideration. Since roots do not actively grow in dry soil, deeper placement of P fertilizer should be advantageous in areas where dry conditions prevail during the early part of the growing season (Veseth et al., 1986). This is one of the reasons pre-plant banding of N and P fertilizer at depths of 10 to 15 cm is popular in the Plains states of the United States. In field studies in Kansas, Leikam et al. (1983) found that pre-plant applications of N and P fertilizer in the same band resulted in higher leaf P concentrations and grain yields than pre-plant applications of N with P broadcast or banded with the seed. Results of their study indicate a synergistic effect between  $\text{NH}_4^+$ -N and P when placed in the same band, not simply a positional availability effect due to deeper placement in moist soil. This N-P interaction had earlier been observed by Miller and Ohlrogge (1958).

Possible disadvantages of deep-placed P fertilizer include reduced root-fertilizer contact and increased time required for roots to reach the band (McConnell et al., 1986). Also, in wet years, it may be mechanically impossible to place P below the seed level.

McConnell et al. (1986) sought to determine the optimum depth of P placement for winter wheat. Phosphorus at  $11 \text{ kg P ha}^{-1}$  was applied with the seed, directly above the seed at the soil surface, or midway between 30-cm rows at depths of 0, 5, 10, and 15 cm. Significant grain yield increases due to P occurred at all nine locations, but the magnitude of

response varied greatly. Maximum grain yield occurred when P was placed at 11.9 cm in 1982 and 10.4 cm in 1983. In general, P uptake and yield increased with depth; however, when all nine locations were averaged, there were no significant differences between the optimum P depth and seed-placed P, nor were there significant differences between the surface-applied P treatments and seed-placed P. This was in spite of the fact that all nine locations were low in available P. The researchers concluded that very shallow or even surface-applied P is very effective if placed in an area where root-fertilizer contact is highly probable.

Another method of P placement using a furrow drill that has recently received attention is dribble over the seed (DOS) at planting. Wood et al. (1988) compared DOS placement of P with P banded 2.5 cm below the seed (BBS) and broadcast P. The DOS and BBS methods were found to be equally effective, and superior to broadcast P application. The mechanism of P uptake for DOS placement is a result of soil sloughing into the drill furrow which covers the fertilizer band and allows the crown roots to grow into the covered fertilizer band.

In summary, wheat response to P fertilizer rate and placement is dependent on many factors: soil test P levels, soil P-fixing ability, seasonal precipitation level and timing, soil temperature, and soil moisture. Phosphorus banded with the seed, below the seed, or below and to the side of the seed will generally result in the greatest fertilizer use efficiency and crop response.

### Wheat Response to Potassium Fertilizer

Potassium plays an important role in translocation of sugars in plant cells, and in regulating stomatal openings and electrolyte concentration. It is involved in the activation of more than 60 enzyme systems in plants (Beaton and Sekhon, 1985). Potassium has been shown to advance anthesis in wheat (Haeder and Beringer, 1981), encourage root growth (Tennant, 1976), and to increase grain protein and translocation of nitrogenous compounds from vegetative plant parts to grain (Koch and Mengel, 1977). Grain yield increases from K have been reported by numerous investigators. Haeder and Beringer (1981) reported that yield increases due to K were attributed primarily to an increase in kernel weight and, to a lesser extent, spikes per unit area and kernels per spike. Potassium is also associated with plant strength and resistance to lodging and disease. Skogley (1977) observed that K fertilization increased upper stem diameter and relative breaking force of winter wheat stems.

Wheat and other cereal crops require about as much K as N (Beaton and Sekhon, 1985). An adequate supply of K early in the growing season is especially important (Gasser and Thorburn, 1972). Mengel (1982) noted that K uptake by wheat grown under water-limiting conditions may be only 50 kg K ha<sup>-1</sup>, but may reach 200 kg K ha<sup>-1</sup> under optimum growth conditions. Actual K requirement may greatly exceed these values obtained for K removal, because only 50 to 60% of the plant's maximum K accumulation may remain at maturity (Gregory et al., 1979).

Potassium fertilization of soils with less than 75 mg ammonium acetate-extractable K  $\text{kg}^{-1}$  soil in the top 15 cm will usually result in a significant increase in wheat yields (Halvorson et al., 1987). On calcareous soils with low K soil test levels, 33 to 56 kg K  $\text{ha}^{-1}$  is generally recommended for wheat, depending on the yield potential (Dahnke, 1983; Skogley, 1976).

Soils in the northern Great Plains of the United States are mostly high in available K (Potash and Phosphate Institute Staff, 1985); response to K fertilization would normally not be expected. But in some areas of the northern Great Plains, wheat response to K is poorly correlated to ammonium acetate-extractable K levels (Skogley and Haby, 1981). Extensive field studies in Montana demonstrated a significant response to K-containing fertilizers 47% of the time for winter wheat and 30% of the time for spring wheat, despite most of the soils being high in ammonium acetate-extractable K (Skogley and Haby, 1981). Since potassium uptake by roots is regulated mainly by the rate of diffusion of K ions to the root (Barber, 1985), conditions such as cool soil temperatures or low soil moisture that slow diffusion can also limit K uptake; under these conditions, response to K may occur regardless of soil test levels.

Soil cation exchange capacity (CEC) influences the ability of a soil to replenish soil solution K levels after plant uptake of K (Barber, 1985). For this reason, soil CEC (and texture) also affects crop response to K fertilizer. Wheat grown on coarse-textured or highly leached soils often responds to K fertilizer (Halvorson et al., 1987).

Cultivar differences can also significantly affect K uptake by wheat (Schwartz and Kafkafi, 1978).

## CHAPTER 3

## MATERIALS AND METHODS

Field experiments were conducted at two dryland sites and one irrigated site in north central Montana during the 1987 growing season. Soils at each site are described in Table 1. The Brady and Conrad sites were planted to spring wheat the previous year; the Agawam site was planted to barley.

The experimental design was a randomized split-plot with 15 x 35-cm paired row (PR), 20 x 30-cm PR, and 25-cm equidistant row (ER) configurations as main plot treatments, and various fertilizer rates and placements as subplot treatments. In each of four replications, main plots were randomized and subplots (1.53 x 6.10 m) were completely randomized within each main plot. All of the treatment combinations are shown in Table 2.

The 15 x 35-cm PR main plot was the largest main plot, with a total of 17 subplot treatments including N fertilizer rate (treatments 3, 4, 8, and 11), P fertilizer rate (treatments 2, 4, 5, 6, 13, and 15), and K fertilizer rate (treatments 14 and 16) comparisons. Treatments 22, 23, and 24 from within the 25-cm ER main plot were selected to determine the effect of P fertilizer placement. Two treatments from the 15 x 35-cm PR main plot (4 and 14) and two treatments from the 25-cm ER main plot (23 and 24) were used in a split-plot analysis to determine the main effects

Table 1. Soil characteristics for 1987 no-till spring wheat experiments.

Site	Soil classification	Total NO <sub>3</sub> <sup>-</sup> -N in 0-120 cm <sup>a</sup>	0-15 cm					
			p <sup>b</sup>	K <sup>c</sup>	OM <sup>d</sup>	pH <sup>e</sup>	EC <sup>e</sup>	CaCO <sub>3</sub> equiv. <sup>f</sup>
		kg ha <sup>-1</sup>	<--mg kg <sup>-1</sup> -->		%		dS m <sup>-1</sup>	%
Brady (dryland)	Marias sic Udorthentic Chromusterts	19.3	25.9	996	2.19	8.0	0.71	4.0
Conrad (dryland)	Scobey cl Aridic Argiborolls	22.9	26.3	578	3.44	7.6	0.50	0.0
Agawam (irrigated)	Rothiemay 1 Aridic Calciborolls	148.2	38.6	500	3.65	8.4	0.99	13.0

<sup>a</sup>Soil extraction using method of Sims and Jackson (1971). Color determination by Cd reduction (Willis, 1980).

<sup>b</sup>NaHCO<sub>3</sub>-extractable (Olsen et al., 1954).

<sup>c</sup>NH<sub>4</sub>OAc-extractable (Bower et al., 1952).

<sup>d</sup>Organic matter using method of Sims and Haby (1970) (procedure slightly modified).

<sup>e</sup>Soil pH and electrical conductivity by 2:1 dilution (U.S. Salinity Laboratory Staff, 1954).

<sup>f</sup>Holmgren (1973).

Table 2. Treatments used for no-till spring wheat experiments at Brady, Conrad, and Agawam, Montana, 1987.

Treatment no. <sup>a</sup>	Row configuration <sup>b</sup>	N rate <sup>c</sup>	P rate	P placement	K rate
			kg ha <sup>-1</sup>		kg ha <sup>-1</sup>
1*	15 x 35-cm PR	0	0	--	0
2	15 x 35-cm PR	M	0	--	0
3	15 x 35-cm PR	0	7	seed	0
4*	15 x 35-cm PR	M	7	seed	0
5*	15 x 35-cm PR	M	5	seed	0
6*	15 x 35-cm PR	M	9	seed	0
7	15 x 35-cm PR	L	5	seed	0
8*	15 x 35-cm PR	L	7	seed	0
9	15 x 35-cm PR	L	9	seed	0
10	15 x 35-cm PR	H	5	seed	0
11*	15 x 35-cm PR	H	7	seed	0
12	15 x 35-cm PR	H	9	seed	0
13*	15 x 35-cm PR	M	24	seed	0
14*	15 x 35-cm PR	M	7	side <sup>d</sup>	0
15*	15 x 35-cm PR	M	15	seed	0
16*	15 x 35-cm PR	M	7	side <sup>d</sup>	28 <sup>e</sup>
17*	15 x 35-cm PR	H	9	side <sup>d</sup>	28 <sup>e</sup>
19	20 x 30-cm PR	M	7	side <sup>f</sup>	0
21	20 x 30-cm PR	M	5	side <sup>f</sup>	0
22*	25-cm ER	M	7	below <sup>g</sup>	0
23*	25-cm ER	M	7	side <sup>d</sup>	0
24*	25-cm ER	M	7	seed	0
25	25-cm ER	M	5	below <sup>g</sup>	0
26	25-cm ER	M	5	side <sup>d</sup>	0

\*Plant samples taken from these treatments.

<sup>a</sup>Treatments 18 and 20 deleted from experiment. Treatment means for treatments 17, 21, 25, and 26 listed in Appendix C.

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>0, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

<sup>d</sup>7.5 cm to side and 5 cm below seed.

<sup>e</sup>56 kg K ha<sup>-1</sup> at Agawam.

<sup>f</sup>10 cm to side and 5 cm below seed.

<sup>g</sup>5 cm below seed.

of row configuration and P fertilizer placement. Treatments 14, 19, and 23 were used to compare all three row configurations.

Just prior to planting, each site was sprayed with glyphosate [N-(phosphonomethyl) glycine] at a rate of  $1.68 \text{ kg ha}^{-1}$  active ingredient (a.i.). Weeds were controlled by hand throughout the growing season.

All plots were seeded in late April with an adjustable row space, deep fertilizer banding, no-till planter constructed by the Western Triangle Research Center staff (Kushnak and Thaut, 1986). A seeding rate of  $215 \text{ seeds m}^{-2}$  was used at the Brady and Conrad sites; at Agawam the seeding rate was  $325 \text{ seeds m}^{-2}$ . Spring wheat (cv. 'Rambo') was seeded directly into untilled stubble at each site. Prior to planting, crop residue samples from three randomly selected  $1.49\text{-m}^2$  plots were taken from each site and weighed to estimate residue amounts. Amounts of crop residue present at seeding were  $3240$ ,  $3480$ , and  $1600 \text{ kg ha}^{-1}$  at the Brady, Conrad, and Agawam sites, respectively. All sites were seeded in east-west oriented rows.

Phosphorus fertilizer rates were based on a recommended rate of  $7 \text{ kg P ha}^{-1}$  at all sites. Rates of 0, 0.75, 1.0, 1.25, 2.0, and 3.33 times the recommended rate were applied as monoammonium phosphate (11-53-0) either with the seed, 5 cm below the seed, or 7.5 cm to the side and 5 cm below the seed at the time of seeding.

In the  $15 \times 35\text{-cm}$  and  $20 \times 30\text{-cm}$  PR configurations, P which was placed to the side and below the seed was applied as a single band between the paired rows; P which was placed with the seed was applied to two separate bands, one band per seed row.

Potassium fertilizer rates of 0 and 28 kg K ha<sup>-1</sup> (56 at Agawam) were applied as KCl (0-0-60) and placed 7.5 cm to the side and 5 cm below the seed at the time of seeding.

Nitrogen fertilizer rates were based on a recommended rate of 40 kg N Mg<sup>-1</sup> grain at all sites. Rates of 0, 0.75, 1.0, and 1.25 times the recommended rate were topdressed as NH<sub>4</sub>NO<sub>3</sub> (34-0-0) just after seedling emergence. These rates were designated 0 (none), L (low), M (medium), and H (high), respectively (Table 2).

Whole plant samples (tops only) were taken from selected treatments at three growth stages: Feekes stage 8-9 (last leaf visible), Feekes stage 10-10.1 (late boot/ears just visible), and Feekes stage 11.4 (dead ripe) (Large, 1954). Fifteen cm of row were taken at each sampling, except 30 cm of row were taken from treatment 1 (check plot). All plant samples were dried at 50 to 60°C, weighed, and ground in a Wiley Mill. Total Kjeldahl N in the plant tissue was determined by autoanalysis (Bremner and Mulvaney, 1982; Technicon Industrial Systems, 1974). Plant P concentration was determined on a 0.25 g sample digested in nitric and perchloric acid using an ICP spectrophotometer. Plant K concentration was also determined on a 0.25 g sample digested in nitric and perchloric acid using atomic absorption spectroscopy (treatments 14, 16, and 17 only). Total N, P, and K uptake were calculated by multiplying dry matter at each growth stage by N, P, or K concentration of the plant sample harvested.

Plant height to the top ligule was measured at spike emergence, and total plant height was measured at harvest. Number of days from seeding to spike emergence was recorded.

Tiller counts were taken after anthesis from two randomly selected 61-cm lengths of row in each plot. The number of tillers  $m^{-2}$  was then calculated by using the average of these two values.

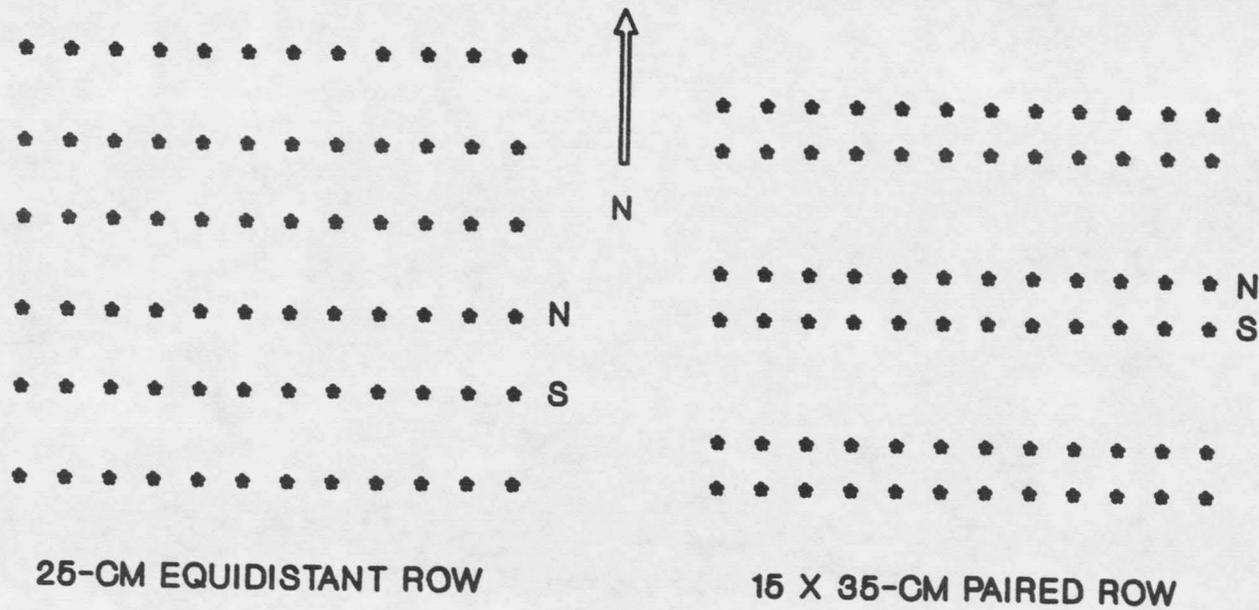
To investigate whether or not shading was responsible for growth differences due to row configuration, one row was designated N (north) and one row was designated S (south) in each of treatments 4, 14, 23, and 24. Tiller counts were then taken separately in the N and S rows. These rows were also harvested separately (Fig. 2). Harvest index was determined for these four treatments by dividing grain yield by total dry matter production at harvest.

At maturity, plots at all sites were harvested mechanically with a small plot combine. In the 15 x 35-cm and 20 x 30-cm PR plots, only the center two rows of each plot were harvested (0.51 x 3.66 m). In the 25-cm ER plots, three rows from the center of each plot were harvested (0.76 x 3.66 m). This difference in size of harvested areas was taken into account during computations. Grain was dried and weighed (total and weight per 100 kernels). Kernels per spike was calculated from tiller counts, grain yield, and weight per 100 kernels. Grain test weight was determined, and grain samples were analyzed for total protein in the Montana State University Cereal Quality Lab (American Association of Cereal Chemists, 1983).

Climatic data were collected at each site. A rain gauge and evaporation tub were installed at each site, and soil temperature measurements were taken periodically at the 50-cm depth. Soil temperature data are presented in Appendix A. Soil water contents

Figure 2

**DIAGRAM SHOWING LOCATION OF ROWS SAMPLED  
TO DETERMINE MAIN EFFECTS OF ROW POSITION**



(gravimetric and 1.5 MPa) were determined from samples taken prior to planting, at heading, and at harvest.

### Statistical Methods

Analysis of variance (ANOVA) procedures were used to test significance of treatment main effects and interactions. Unless otherwise stated, differences between treatment means are reported at the 0.05 significance level. Since there were no significant row configuration x site interactions, a combined ANOVA across all three sites was conducted using treatments 4, 14, 23, and 24, with sites as main plots, two row configurations as subplots, and two P fertilizer placements as sub-subplots (Appendix B; Tables 24 and 25). Another combined ANOVA was conducted using treatments 14, 19, and 23, with sites as main plots and three row configurations as subplots (Tables 3, 12, and 16). To determine the main effect of row position, treatments 4 and 14 were used for a split-plot analysis, with two P fertilizer placements as main plots, and two row positions as subplots (north and south rows considered as random effects). Treatments 23 and 24 were analyzed similarly to determine the main effect of row position in the 25-cm ER configuration (Table 26; Appendix D). A combined ANOVA across both the 15 x 35-cm PR and the 25-cm ER configurations was then conducted, with row configurations as main plots, two P fertilizer placements as subplots, and two row positions as sub-subplots (Appendix D). The MSUSTAT statistical package was used for all statistical analyses (Lund, 1988).

## CHAPTER 4

## RESULTS AND DISCUSSION

Effect of Paired Rows

When all three row configurations were compared, grain yields were significantly reduced in the 15 x 35-cm paired rows (PR) at the Brady and Conrad sites (Fig. 3, Table 3). The 20 x 30-cm PR and 25-cm equidistant row (ER) configurations responded similarly in terms of grain yield and yield components at each of the three sites (Table 3).

Yield differences across sites were correlated with growing season precipitation levels (Table 4). The Brady site was the driest and produced the lowest yields. Several weeks of drought during boot and heading stages further reduced yield potential, resulting in smaller kernels and lower kernel weights than the other two sites (Tables 3 and 5). The Conrad site was subjected to moderate moisture stress prior to heading, while the Agawam site was not affected by moisture stress throughout the growing season (Tables 6 and 7). In addition to irrigation, the Agawam site also received the most rainfall, resulting in the highest yields of the three sites (Table 4, Fig. 3).

The number of kernels per spike is determined by conditions from the beginning of inflorescence through anthesis (Evans et al., 1975). It is likely that moisture stress was the cause of reduced kernels per spike in the 15 x 35-cm PR at the Brady and Conrad sites (Fig. 4). This

Figure 3

### EFFECT OF THREE ROW CONFIGURATIONS ON GRAIN YIELD OF SPRING WHEAT, 1987

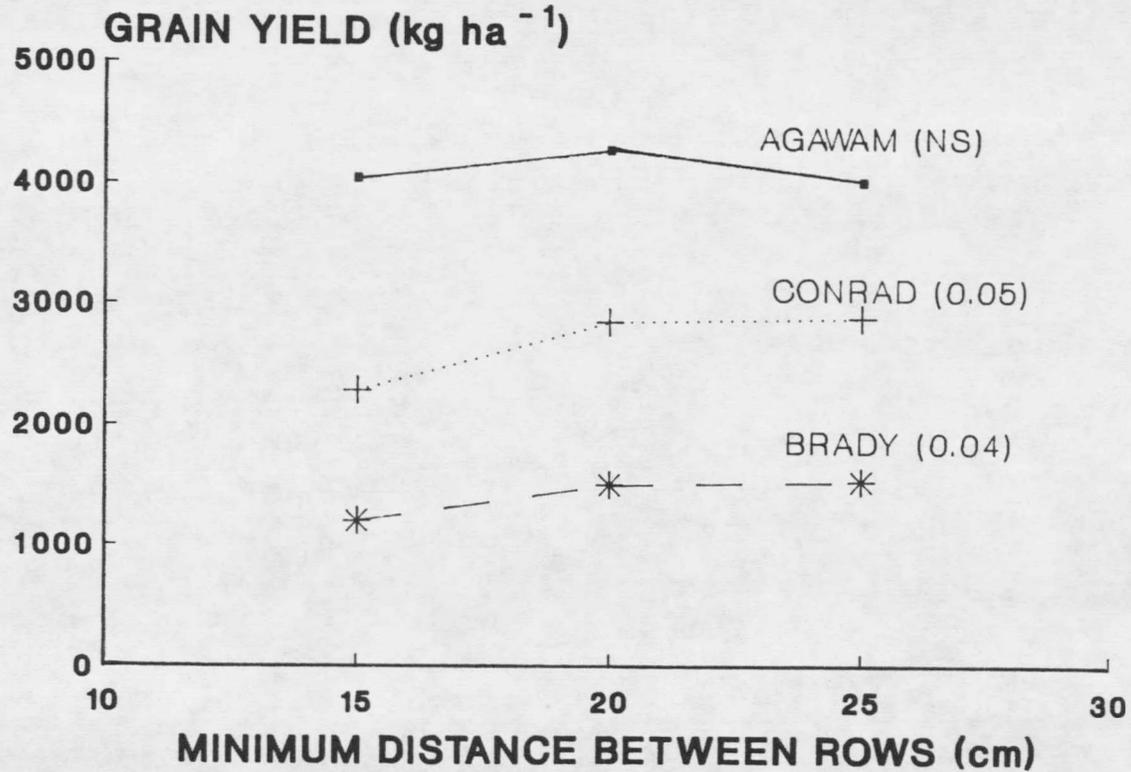


Table 3. Effect of three row configurations on grain yield and yield components of no-till spring wheat, 1987.<sup>a</sup>

Row configuration <sup>b</sup>	Site			Mean of all sites
	Brady	Conrad	Agawam	
<u>Grain yield (kg ha<sup>-1</sup>)</u>				
15 x 35-cm PR	1198	2280	4034	2504
20 x 30-cm PR	1498	2842	4268	2870
25-cm ER	1528	2879	4004	2804
LSD (0.05)	270	479	NS	310
Significance level	0.04	0.05	0.77	0.06
CV (%)	11.1	10.1	13.6	13.3
<u>Tillers m<sup>-2</sup></u>				
15 x 35-cm PR	301	341	577	406
20 x 30-cm PR	286	342	581	403
25-cm ER	315	371	587	424
LSD (0.05)	NS	NS	NS	NS
Significance level	0.63	0.13	0.87	0.20
CV (%)	13.7	5.2	4.9	7.4
<u>Kernels spike<sup>-1</sup></u>				
15 x 35-cm PR	15.6	18.6	21.5	18.5
20 x 30-cm PR	19.6	24.2	22.0	21.9
25-cm ER	18.8	21.3	20.8	20.3
LSD (0.05)	2.6	NS	NS	1.7
Significance level	0.02	0.11	0.66	0.01
CV (%)	8.3	12.8	8.6	9.7
<u>Kernel weight (g 100 seeds<sup>-1</sup>)</u>				
15 x 35-cm PR	2.55	3.60	3.27	3.14
20 x 30-cm PR	2.71	3.43	3.32	3.15
25-cm ER	2.65	3.68	3.27	3.20
LSD (0.05)	NS	NS	NS	NS
Significance level	0.23	0.07	0.89	0.57
CV (%)	4.5	2.9	5.6	4.4

<sup>a</sup>Treatments 14, 19, and 23 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

NS = Not significant at  $P \leq 0.05$ .

decrease was significant at the Brady site, as well as in the combined analysis of variance (ANOVA) across all sites (Table 3). Figure 4 shows that site differences due to row configuration were most pronounced in the 15 x 35-cm PR. In the 25-cm ER, the number of kernels per spike was similar at all three sites. This suggests that under conditions of moisture stress, wheat planted in PR is placed at a disadvantage compared to ER.

Table 4. Climatic data for no-till spring wheat experiments, 1987.

Site	Growing season precipitation (incl. irrigation)	Class A open pan evaporation	Time period <sup>a</sup>
	<-----mm----->		days
<i>Brady</i> -- dryland	123	499	75
<i>Conrad</i> -- dryland	140	427	67
<i>Agawam</i> -- irrigated	238	594	98

<sup>a</sup>Time period during which precipitation amounts and evaporation measurements were taken.

Results of a study with sorghum by Steiner (1986) indicated that high plant populations were detrimental under conditions of moisture stress. High plant populations and narrow row spacings both resulted in a shift in seasonal water use to the vegetative period in a dry year, leaving less water available for grain filling; consequently, grain water use efficiency (WUE) was significantly reduced.

Table 5. Soil water data from Brady site, 1987.

Depth	Soil water content					
	Seeding (gravimetric only)	1.5 MPa tension <sup>a</sup>	Heading		Harvest	
			Gravimetric	Plant available <sup>b</sup>	Gravimetric	Plant available <sup>b</sup>
cm	←-----kg H <sub>2</sub> O kg <sup>-1</sup> soil-----→					
0-15	0.21					
15-30	0.27					
30-60	0.26					
60-120	0.19					
0-8		0.17	0.12	--	0.19	0.02
8-28		0.18	0.20	0.02	0.23	0.05
28-76		0.19	0.19	--	0.23	0.04
76-107		0.19	0.14	--	0.18	--
107-130		0.16	0.15	--	0.16	--

<sup>a</sup>Average of two replicates. Soil samples dried at 60°C.

<sup>b</sup>Gravimetric - 1.5 MPa value.

Table 6. Soil water data from Conrad site, 1987.

Depth	Soil water content					
	Seeding (gravimetric only)	1.5 MPa tension <sup>a</sup>	Heading		Harvest	
			Gravimetric	Plant available <sup>b</sup>	Gravimetric	Plant available <sup>b</sup>
<i>cm</i>	←-----kg H <sub>2</sub> O kg <sup>-1</sup> soil-----→					
0-15	0.15					
15-30	0.17					
30-60	0.14					
60-120	0.15					
0-5		0.10	0.07	--	0.05	--
5-13		0.12	0.12	--	0.13	0.01
13-25		0.11	0.17	0.06	0.11	--
25-41		0.11	0.20	0.09	0.16	0.05
41-76		0.12	0.16	0.04	0.17	0.05
76-114		0.12	0.13	0.01	0.14	0.02
114-137		0.12	0.12	--	0.15	0.03

<sup>a</sup>Average of two replicates. Soil samples dried at 60°C.

<sup>b</sup>Gravimetric - 1.5 MPa value.

Table 7. Soil water data from Agawam site, 1987.

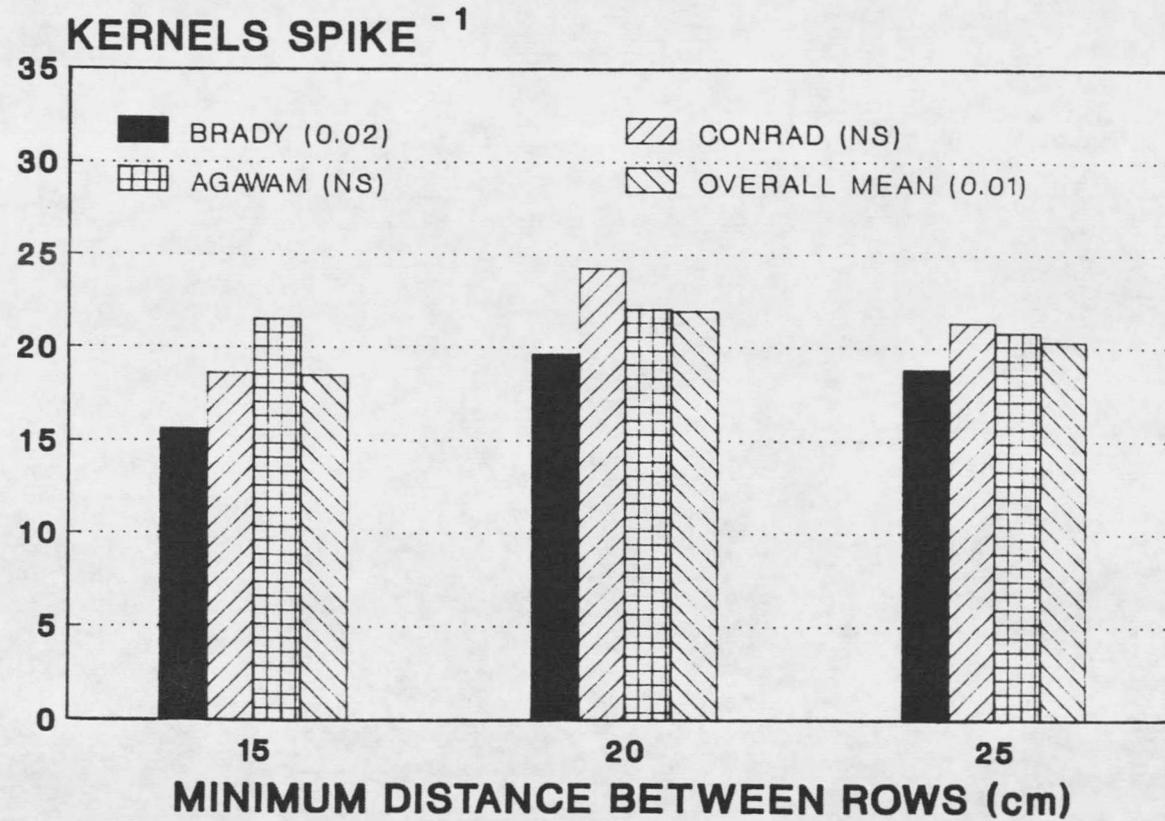
Depth	Soil water content					
	Seeding (gravimetric only)	1.5 MPa tension <sup>a</sup>	Heading		Harvest	
			Gravimetric	Plant available <sup>b</sup>	Gravimetric	Plant available <sup>b</sup>
<i>cm</i>	←-----kg H <sub>2</sub> O kg <sup>-1</sup> soil-----→					
0-15	0.19					
15-30	0.13					
30-60	0.13					
60-120	0.12					
0-5		0.13	0.14	0.01	0.21	0.08
5-15		0.14	0.21	0.07	0.20	0.06
15-28		0.09	0.17	0.08	0.13	0.04
28-51		0.08	0.13	0.05	0.11	0.03
51-91		0.11	0.18	0.07	0.14	0.03
91-127		0.12	0.16	0.04	0.17	0.05
127-152		0.13	0.16	0.03	0.20	0.07

<sup>a</sup>Average of two replicates. Soil samples dried at 60°C.

<sup>b</sup>Gravimetric - 1.5 MPa value.

Figure 4

# EFFECT OF THREE ROW CONFIGURATIONS ON KERNEL NUMBER OF SPRING WHEAT, 1987



Seeding rate studies with wheat have shown similar results. In two of three years, increased sowing density increased early crop evapotranspiration (ET), as reflected by lower soil moisture levels at anthesis (Doyle and Fischer, 1979). The third year was a wet year; soil moisture levels both at anthesis and maturity were not significantly affected by sowing density. Increased early competition for limited water in the PR as compared to ER may have been one reason for grain yield reductions in the PR at Brady and Conrad. Paired rows effectively increase the plant population early in the growing season because the plants encounter space occupied by adjacent plants at an earlier growth stage than when planted in ER.

A comparison of the 15 x 35-cm PR and 25-cm ER configurations showed a significant yield reduction due to PR only at the Conrad site (Fig. 5; Table 8). A similar trend was observed, however, at the Brady site. Yield differences due to row configuration were small at the irrigated Agawam site. In the combined ANOVA across sites, the yield reduction due to PR was significant at  $P \leq 0.01$  (Table 8; Appendix B). Although not statistically compared, two other PR treatments (17 and 21) also resulted in lower yields than ER treatments 25 and 26 (Appendix C).

Tiller numbers were consistently lower in the PR treatments (Table 9). This reduction was significant at  $P \leq 0.07$  in the combined ANOVA across sites. This response is consistent with the findings of Doyle (1980) and Auld et al. (1983) who have shown that increased early plant competition can reduce tillering.

Although row configuration effects on kernels per spike were not significant at the individual sites, the combined ANOVA showed a

Figure 5

## MAIN EFFECT OF TWO ROW CONFIGURATIONS ON GRAIN YIELD OF SPRING WHEAT, 1987

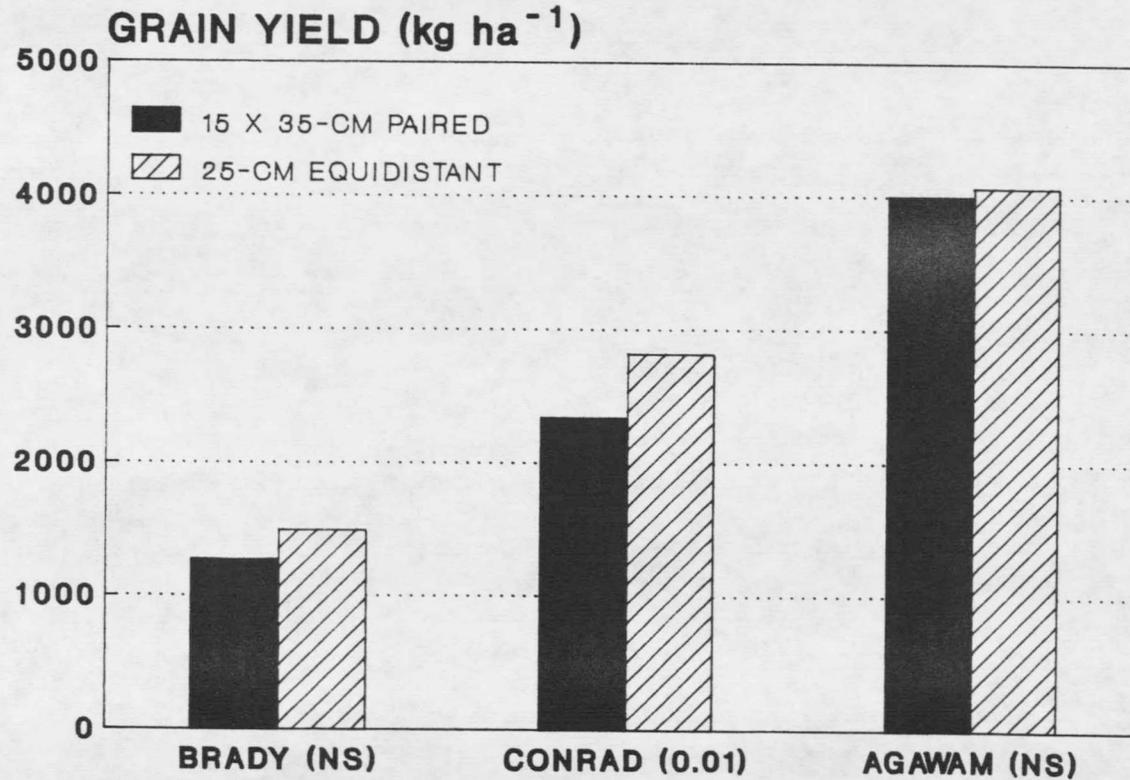


Table 8. Main effects of row configuration and P fertilizer placement on grain yield of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
	<-----kg ha <sup>-1</sup> ----->			
<i>Row configuration (RC)<sup>b</sup></i>				
15 x 35 cm-PR	1268	2341**	4001	2537**
25 cm-ER	1488	2819	4067	2791
Significance level	0.19	0.01	0.70	0.01
CV (%)	19.0	6.5	7.8	9.6
<i>P placement (PPL)</i>				
With seed	1393	2581	4049	2674
Side <sup>c</sup>	1363	2579	4019	2654
Significance level	0.48	0.99	0.91	0.84
<i>RC x PPL interaction</i>	*	NS	NS	NS

\*,\*\*Significant at 0.05 and 0.01 probability levels, respectively.

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>7.5 cm to side and 5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

Table 9. Main effects of row configuration and P fertilizer placement on tiller density of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
	<-----tillers m <sup>-2</sup> ----->			
<u>Row configuration (RC)<sup>b</sup></u>				
15 x 35 cm-PR	293	340	570	401
25 cm-ER	304	361	585	417
Significance level	0.49	0.29	0.15	0.07
CV (%)	10.0	9.3	2.7	6.6
<u>P placement (PPL)</u>				
With seed	289	345	572	402
Side <sup>c</sup>	308	356	582	415
Significance level	0.38	0.30	0.77	0.15
<u>RC x PPL interaction</u>	NS	NS	NS	NS

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>7.5 cm to side and 5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

reduction due to PR that was significant at  $P \leq 0.08$  (Table 10). The yield component least affected by row configuration was kernel weight (Tables 11 and 3). This agrees with the conclusions of Ketata et al. (1976). Grain test weight (Tables 12 and 13), grain protein (Tables 12 and 14), heading date (Tables 15 and 16), plant height at heading (Tables 16 and 17), plant height at harvest (Tables 16 and 17), and harvest index (Table 18) were also not significantly affected by row configuration.

Table 18 shows results indicating that P fertilizer placed with the seed at the Brady site resulted in a higher harvest index than P placed 7.5 cm to the side and 5 cm below the seed, when averaged over both row configurations. This is due to similar grain yields (Table 8), but more dry matter production at harvest (Feekes stage 11.4) in the side-placed P treatment compared with the seed-placed P treatment (Table 19). The effects of P fertilizer placement are discussed in greater detail in a later section.

Dry matter and nutrient uptake data from plant samples taken at three growth stages gave further insight into specific effects of row configuration. At Feekes stage 8-9, there was more dry matter produced by the PR as compared to ER at two of three sites, significant at  $P \leq 0.06$  at Agawam (Table 19). Differences in tissue N and P concentration, and N and P uptake were slight at Feekes stage 8-9 (Tables 20, 21, 22, and 23), but generally favored the PR. Phosphorus uptake from the PR at Agawam was significantly more than from ER (Table 23).

Field observations indicated vigorous early growth in the PR, as reported by Papendick et al. (1984). This may have been a soil temperature effect. In the PR treatments, the zone of soil disturbance

Table 10. Main effects of row configuration and P fertilizer placement on kernels per spike of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
	<-----kernels spike <sup>-1</sup> ----->			
<u>Row configuration (RC)<sup>b</sup></u>				
15 x 35 cm-PR	16.9	19.1	21.6	19.2
25 cm-ER	19.1	21.3	21.3	20.6
Significance level	0.18	0.23	0.66	0.08
CV (%)	14.4	14.4	7.2	12.2
<u>P placement (PPL)</u>				
With seed	18.8	20.5	21.8	20.4
Side <sup>c</sup>	17.2	19.9	21.1	19.4
Significance level	0.13	0.65	0.48	0.12
<u>RC x PPL interaction</u>	NS	NS	NS	NS

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>7.5 cm to side and 5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

Table 11. Main effects of row configuration and P fertilizer placement on kernel weight of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
	<-----g 100 seeds <sup>-1</sup> ----->			
<u>Row configuration (RC)<sup>b</sup></u>				
15 x 35 cm-PR	2.57	3.62	3.23	3.14
25 cm-ER	2.60	3.68	3.25	3.17
Significance level	0.68	0.61	0.78	0.46
CV (%)	4.7	5.1	4.5	4.8
<u>P placement (PPL)</u>				
With seed	2.57	3.66	3.21	3.15
Side <sup>c</sup>	2.60	3.64	3.27	3.17
Significance level	0.55	0.57	0.53	0.56
<u>RC x PPL interaction</u>	NS	NS	NS	NS

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>7.5 cm to side and 5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

Table 12. Effect of three row configurations on grain test weight and grain protein of no-till spring wheat, 1987.<sup>a</sup>

Row configuration <sup>b</sup>	Site			Mean of all sites
	Brady	Conrad	Agawam	
<i>Grain test weight (kg m<sup>-3</sup>)</i>				
15 x 35-cm PR	769.9	824.3	790.0	794.7
20 x 30-cm PR	769.0	820.2	775.0	788.0
25-cm ER	776.7	828.6	798.8	801.4
LSD (0.05)	NS	NS	NS	NS
Significance level	0.80	0.40	0.13	0.08
CV (%)	2.3	0.9	1.8	1.7
<i>Grain protein (%)</i>				
15 x 35-cm PR	15.6	13.7	14.8	14.7
20 x 30-cm PR	15.4	14.0	14.5	14.6
25-cm ER	15.2	13.9	14.0	14.4
LSD (0.05)	NS	NS	NS	NS
Significance level	0.63	0.84	0.57	0.49
CV (%)	3.4	3.8	6.6	4.7

<sup>a</sup>Treatments 14, 19, and 23 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

NS = Not significant at  $P \leq 0.05$ .

Table 13. Main effects of row configuration and P fertilizer placement on grain test weight of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
	<-----kg m <sup>-3</sup> ----->			
<u>Row configuration (RC)<sup>b</sup></u>				
15 x 35-cm PR	780.1	824.2	784.9	796.4
25-cm ER	778.1	826.3	794.6	799.6
Significance level	0.73	0.33	0.13	0.20
CV (%)	1.3	0.4	1.2	1.0
<u>P placement (PPL)</u>				
With seed	784.9	824.1	785.1	797.9
Side <sup>c</sup>	773.4	826.4	794.3	798.1
Significance level	0.26	0.39	0.14	0.99
<u>RC x PPL interaction</u>	NS	NS	NS	NS

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>7.5 cm to side and 5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

Table 14. Main effects of row configuration and P fertilizer placement on grain protein of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
	<-----% protein----->			
<u>Row configuration (RC)<sup>b</sup></u>				
15 x 35-cm PR	15.5	13.7	14.8	14.7
25-cm ER	15.3	13.7	13.8	14.3
Significance level	0.67	0.98	0.07	0.10
CV (%)	4.2	5.7	4.7	4.9
<u>P placement (PPL)</u>				
With seed	15.4	13.6	14.3	14.4
Side <sup>c</sup>	15.4	13.8	14.4	14.5
Significance level	1.0	0.46	0.60	0.41
<u>RC x PPL interaction</u>	NS	NS	NS	NS

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>7.5 cm to side and 5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

Table 15. Main effects of row configuration and P fertilizer placement on heading date of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
<i>&lt;-Days from seeding to spike emergence-&gt;</i>				
<i>Row configuration (RC)<sup>b</sup></i>				
15 x 35-cm PR	60.9	59.3	60.6	60.3
25-cm ER	61.1	59.0	60.9	60.3
Significance level	0.50	0.64	0.18	0.69
CV (%)	1.1	1.6	0.5	1.1
<i>P placement (PPL)</i>				
With seed	61.0	59.1	60.8	60.3
Side <sup>c</sup>	61.0	59.1	60.8	60.3
Significance level	1.0	1.0	1.0	1.0
<i>RC x PPL interaction</i>	NS	NS	NS	NS

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>7.5 cm to side and 5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

Table 16. Effect of three row configurations on heading date, plant height at heading, and plant height at harvest of no-till spring wheat, 1987.<sup>a</sup>

Row configuration <sup>b</sup>	Site			Mean of all sites
	Brady	Conrad	Agawam	
<i>Heading date (days from seeding to spike emergence)</i>				
15 x 35-cm PR	60.8	59.0	60.5	60.1
20 x 30-cm PR	61.5	58.5	61.0	60.3
25-cm ER	61.3	59.3	61.0	60.5
LSD (0.05)	NS	NS	NS	NS
Significance level	0.18	0.47	0.42	0.25
CV (%)	0.8	1.3	0.9	1.0
<i>Plant height at heading (cm)<sup>c</sup></i>				
15 x 35-cm PR	33.0	36.2	49.5	39.6
20 x 30-cm PR	32.7	35.2	48.9	38.9
25-cm ER	32.7	34.6	50.5	39.3
LSD (0.05)	NS	NS	NS	NS
Significance level	0.88	0.15	0.45	0.45
CV (%)	3.1	2.7	3.3	3.1
<i>Plant height at harvest (cm)<sup>d</sup></i>				
15 x 35-cm PR	44.8	63.5	78.4	62.2
20 x 30-cm PR	46.4	62.9	74.6	61.3
25-cm ER	44.8	64.1	79.7	62.9
LSD (0.05)	NS	NS	NS	NS
Significance level	0.52	0.47	0.14	0.28
CV (%)	4.7	1.8	4.1	3.7

<sup>a</sup>Treatments 14, 19, and 23 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>Feekes growth stage 10.1; height measured to top ligule.

<sup>d</sup>Feekes growth stage 11.4.

NS = Not significant at  $P \leq 0.05$ .

Table 17. Main effects of row configuration and P fertilizer placement on height at heading and harvest of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
<u>Plant height at heading (cm)<sup>b</sup></u>				
<u>Row configuration (RC)<sup>c</sup></u>				
15 x 35-cm PR	33.7	35.7	50.2	39.9
25-cm ER	32.5	35.1	50.2	39.3
Significance level	0.13	0.31	1.0	0.15
CV (%)	3.3	2.9	3.3	3.2
<u>P placement (PPL)</u>				
With seed	33.3	35.4	50.3	39.7
Sided <sup>d</sup>	32.9	35.4	50.0	39.4
Significance level	0.41	1.0	0.62	0.38
<u>RC x PPL interaction</u>	NS	*	NS	NS
<u>Plant height at harvest (cm)<sup>e</sup></u>				
<u>Row configuration (RC)<sup>c</sup></u>				
15 x 35-cm PR	45.4	63.5	79.2	62.7
25-cm ER	44.8	63.8	80.0	62.9
Significance level	0.77	0.60	0.14	0.83
CV (%)	9.0	1.7	1.0	3.9
<u>P placement (PPL)</u>				
With seed	45.4	63.5	80.2	63.0
Sided <sup>d</sup>	44.8	63.8	79.1	62.6
Significance level	0.54	0.70	0.42	0.44
<u>RC x PPL interaction</u>	NS	NS	NS	NS

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>Feekes growth stage 10.1; height measured to top ligule.

<sup>c</sup>PR = Paired row; ER = Equidistant row.

<sup>d</sup>7.5 cm to side and 5 cm below seed.

<sup>e</sup>Feekes growth stage 11.4.

NS = Not significant at  $P \leq 0.05$ .

Table 18. Main effects of row configuration and P fertilizer placement on harvest index of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site		
	Brady	Conrad	Agawam
	<-----harvest index----->		
<u>Row configuration (RC)<sup>b</sup></u>			
15 x 35-cm PR	0.29	0.34	0.31
25-cm ER	0.30	0.37	0.29
Significance level	0.73	0.31	0.62
CV (%)	17.8	12.8	18.3
<u>P placement (PPL)</u>			
With seed	0.32**	0.36	0.28
Side <sup>c</sup>	0.26	0.34	0.33
Significance level	0.01	0.55	0.09
<u>RC x PPL interaction</u>	NS	NS	NS

\*\*Significant at  $P \leq 0.01$ .

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>7.5 cm to side and 5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

Table 19. Main effects of row configuration and P fertilizer placement on dry matter production at three growth stages of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
<u>Growth stage 8-9<sup>b</sup> (g m<sup>-2</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	197	99	268	188
25-cm ER	187	112	228	175
Significance level	0.67	0.73	0.06	0.38
CV (%)	22.2	60.7	11.2	26.0
<u>P placement</u>				
With seed	211*	113	266	196*
Side <sup>d</sup>	173	98	230	167
Significance level	0.02	0.26	0.26	0.02
<u>Growth stage 10-10.1 (g m<sup>-2</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	324	209	536	356
25-cm ER	369	238	502	370
Significance level	0.20	0.46	0.48	0.52
CV (%)	15.8	30.7	16.1	19.2
<u>P placement</u>				
With seed	343	235	556**	378*
Side <sup>d</sup>	350	212	483	348
Significance level	0.78	0.40	0.01 <sup>e</sup>	0.04
<u>Growth stage 11.4 (g m<sup>-2</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	452	699*	1305	819*
25-cm ER	514	777	1413	902
Significance level	0.14	0.05	0.23	0.02
CV (%)	13.1	6.5	10.7	11.1
<u>P placement</u>				
With seed	440**	723	1467	877
Side <sup>d</sup>	526	753	1251	843
Significance level	0.01	0.38	0.12	0.43

\*, \*\*Significant at 0.05 and 0.01 probability levels, respectively.

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>Feekes scale.

<sup>c</sup>PR = Paired row; ER = Equidistant row.

<sup>d</sup>7.5 cm to side and 5 cm below seed.

<sup>e</sup>Row configuration x P placement interaction significant at  $P \leq 0.05$ .

Table 20. Main effects of row configuration and P fertilizer placement on tissue N concentration at three growth stages of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
<u>Growth stage 8-9<sup>b</sup> (g kg<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	35.5	43.5	42.7	40.6
25-cm ER	33.4	42.7	43.4	39.8
Significance level	0.45	0.85	0.34	0.65
CV (%)	14.0	17.8	3.1	13.2
<u>P placement</u>				
With seed	33.2	43.4	43.9	40.1
Sided <sup>d</sup>	35.7	42.9	42.3	40.3
Significance level	0.13 <sup>e</sup>	0.63	0.07	0.84 <sup>e</sup>
<u>Growth stage 10-10.1 (g kg<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	24.2	31.8	31.4	29.1
25-cm ER	24.2	29.3	30.5	28.0
Significance level	0.99	0.21	0.64	0.30
CV (%)	16.3	10.1	10.7	12.1
<u>P placement</u>				
With seed	24.0	30.0	31.7	28.6
Sided <sup>d</sup>	24.4	31.1	30.2	28.5
Significance level	0.65	0.17	0.28	0.99
<u>Growth stage 11.4 (g kg<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	16.0	15.8	13.9	15.2
25-cm ER	15.7	14.5	14.8	15.0
Significance level	0.53	0.34	0.69	0.75
CV (%)	6.2	15.6	28.6	18.5
<u>P placement</u>				
With seed	16.0	15.2	13.7	15.0
Sided <sup>d</sup>	15.8	15.0	15.0	15.3
Significance level	0.81	0.71	0.24	0.49 <sup>e</sup>

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>Feekes scale.

<sup>c</sup>PR = Paired row; ER = Equidistant row.

<sup>d</sup>7.5 cm to side and 5 cm below seed.

<sup>e</sup>Row configuration x P placement interaction significant at  $P \leq 0.05$ .

Table 21. Main effects of row configuration and P fertilizer placement on N uptake at three growth stages of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
<u>Growth stage 8-9<sup>b</sup> (kg ha<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	69.6	43.1	115.3	76.0
25-cm ER	60.8	45.8	98.9	68.5
Significance level	0.44	0.81	0.12	0.19
CV (%)	30.1	45.1	14.2	25.5
<u>P placement</u>				
With seed	69.0	47.9	116.8	77.9*
Side <sup>d</sup>	61.4	41.0	97.3	66.6
Significance level	0.06	0.24	0.22	0.04
<u>Growth stage 10-10.1 (kg ha<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	78.0	66.2	167.8	104.0
25-cm ER	90.4	68.7	154.4	104.5
Significance level	0.39	0.77	0.54	0.99
CV (%)	29.3	22.8	24.3	27.0
<u>P placement</u>				
With seed	81.8	69.1	176.2*	109.0
Side <sup>d</sup>	86.7	65.7	146.0	99.4
Significance level	0.63	0.65	0.04	0.10
<u>Growth stage 11.4 (kg ha<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	72.8	110.2	180.3	121.1
25-cm ER	79.7	112.3	205.7	132.5
Significance level	0.13	0.86	0.40	0.25
CV (%)	8.8	19.8	26.6	25.6
<u>P placement</u>				
With seed	70.0*	109.9	199.6	126.5
Side <sup>d</sup>	82.4	112.6	186.4	127.1
Significance level	0.02	0.63 <sup>e</sup>	0.27	0.89 <sup>e</sup>

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>Feekes scale.

<sup>c</sup>PR = Paired row; ER = Equidistant row.

<sup>d</sup>7.5 cm to side and 5 cm below seed.

<sup>e</sup>Row configuration x P placement interaction significant at  $P \leq 0.05$ .

Table 22. Main effects of row configuration and P fertilizer placement on tissue P concentration at three growth stages of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
<u>Growth stage 8-9<sup>b</sup> (g kg<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	3.1	3.7	3.6	3.5
25-cm ER	3.1	3.5	3.4	3.3
Significance level	0.97	0.47	0.38	0.39
CV (%)	17.4	11.0	9.4	12.7
<u>P placement</u>				
With seed	3.0	3.5	3.6	3.4
Sided <sup>d</sup>	3.2	3.7	3.4	3.4
Significance level	0.20	0.25	0.38	0.39 <sup>e</sup>
<u>Growth stage 10-10.1 (g kg<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	2.6	2.7	2.6	2.6
25-cm ER	2.3	2.7	2.6	2.5
Significance level	0.22	0.72	1.0	0.26
CV (%)	16.5	7.0	14.5	13.0
<u>P placement</u>				
With seed	2.4*	2.6	2.6	2.5
Sided <sup>d</sup>	2.5	2.8	2.6	2.6
Significance level	0.02	0.11	0.87	0.10
<u>Growth stage 11.4 (g kg<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	1.8	1.5	1.3	1.5
25-cm ER	1.8	1.4	1.4	1.5
Significance level	0.85	0.34	0.18	1.0
CV (%)	26.5	10.7	11.9	19.9
<u>P placement</u>				
With seed	1.9	1.4	1.3	1.5
Sided <sup>d</sup>	1.7	1.5	1.4	1.5
Significance level	0.35 <sup>e</sup>	0.22	0.50	0.72 <sup>e</sup>

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>Feekes scale.

<sup>c</sup>PR = Paired row; ER = Equidistant row.

<sup>d</sup>7.5 cm to side and 5 cm below seed.

<sup>e</sup>Row configuration x P placement interaction significant at  $P \leq 0.05$ .

Table 23. Main effects of row configuration and P fertilizer placement on P uptake at three growth stages of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site			Mean of all sites
	Brady	Conrad	Agawam	
<u>Growth stage 8-9<sup>b</sup> (kg ha<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	6.1	3.7	9.7*	6.5
25-cm ER	5.8	4.0	7.7	5.9
Significance level	0.82	0.82	0.02	0.31
CV (%)	37.9	70.8	8.9	33.9
<u>P placement</u>				
With seed	6.4	4.0	9.6	6.6
Side <sup>d</sup>	5.6	3.7	7.9	5.7
Significance level	0.09	0.64	0.29	0.10
<u>Growth stage 10-10.1 (kg ha<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	8.3	5.7	14.0	9.3
25-cm ER	8.4	6.3	13.2	9.3
Significance level	0.91	0.52	0.70	1.0
CV (%)	16.7	30.0	26.8	26.6
<u>P placement</u>				
With seed	7.9	6.0	14.6	9.5
Side <sup>d</sup>	8.8	6.0	12.6	9.1
Significance level	0.25	0.89	0.14	0.42
<u>Growth stage 11.4 (kg ha<sup>-1</sup>)</u>				
<u>Row configuration<sup>c</sup></u>				
15 x 35-cm PR	8.4	10.5	16.7	11.8
25-cm ER	8.9	10.9	20.0	13.3
Significance level	0.51	0.41	0.13	0.04*
CV (%)	18.4	8.9	17.3	16.9
<u>P placement</u>				
With seed	8.3	9.9	19.4	12.5
Side <sup>d</sup>	9.0	11.5	17.3	12.6
Significance level	0.31 <sup>e</sup>	0.16	0.36	0.92 <sup>e</sup>

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>Feekes scale.

<sup>c</sup>PR = Paired row; ER = Equidistant row.

<sup>d</sup>7.5 cm to side and 5 cm below seed.

<sup>e</sup>Row configuration x P placement interaction significant at  $P \leq 0.05$ .

is wider than in the ER; this effectively reduces the amount of crop residue in that zone. While crop residue *per se* may not affect wheat growth (Whitfield and Smika, 1971), decreasing amounts of crop residue generally result in higher soil temperatures and faster plant growth early in the growing season (Carter and Rennie, 1985). Sharratt has observed higher between-row soil temperatures in PR as compared to ER barley (B.S. Sharratt, USDA-ARS, Fairbanks, AK, 1988, personal communication).

At Feekes stage 10-10.1, the differences due to row configuration were very slight. In terms of dry matter, however, the ER showed an increasing growth advantage with time compared to the PR. By harvest (Feekes stage 11.4), the ER at the Conrad site produced significantly more dry matter than the PR (Fig. 6, Table 19). A non-significant row configuration x growth stage interaction was observed at all three sites. In terms of dry matter, this interaction was significant at  $P \leq 0.02$  in the combined ANOVA across sites (Fig. 7, Table 24). In terms of N and P uptake, this same interaction was significant at  $P \leq 0.08$  (Fig. 8, Table 24). Phosphorus uptake at harvest was also significantly more in the ER than in the PR in the combined ANOVA (Table 23).

When the data were averaged over three sites, two P placements, and all three growth stages, the ER produced more dry matter than the PR (Table 25). Table 25 also shows results indicating that dry matter and N uptake were significantly increased by P fertilizer placement with the seed as compared to 7.5 cm to the side and 5 cm below the seed. Site differences were significant in all parameters except tissue P

Figure 6

**MAIN EFFECT OF TWO ROW CONFIGURATIONS ON  
DRY MATTER PRODUCTION AT CONRAD, 1987**  
(means averaged over two P placements)

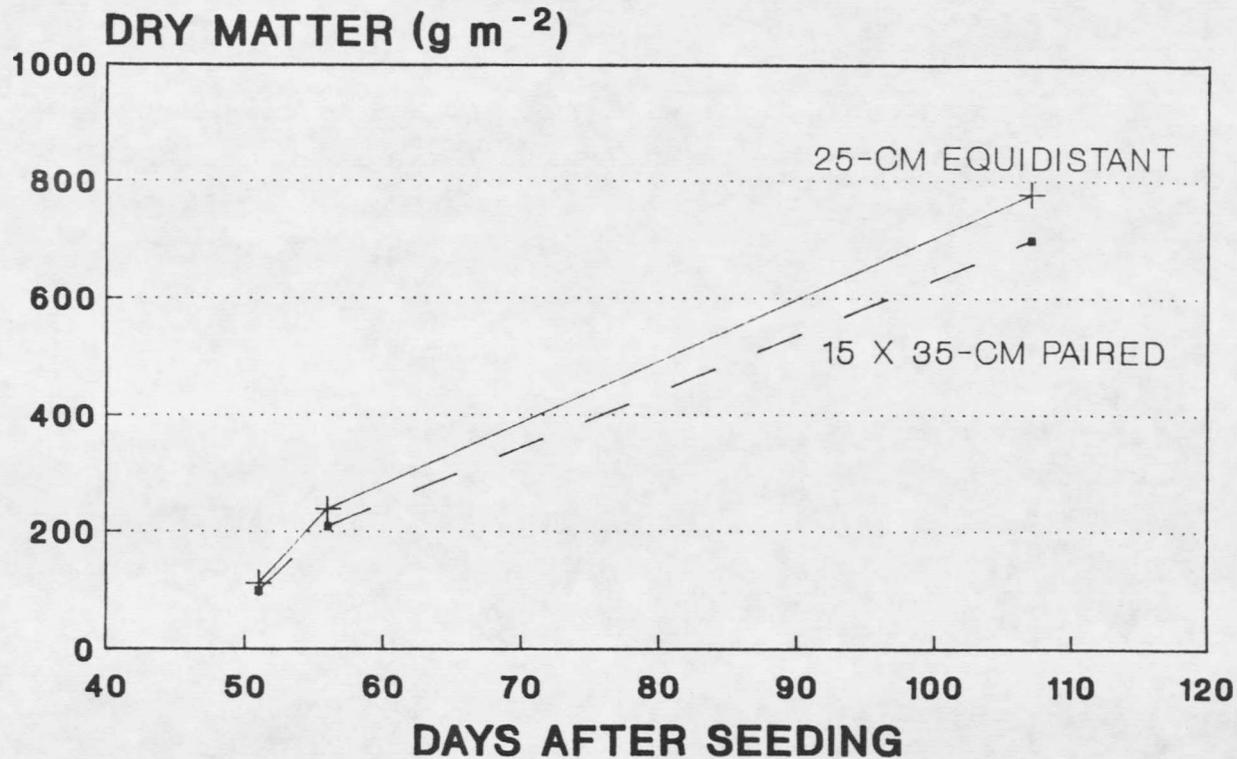


Figure 7

# MAIN EFFECT OF TWO ROW CONFIGURATIONS ON DRY MATTER OF SPRING WHEAT, 1987

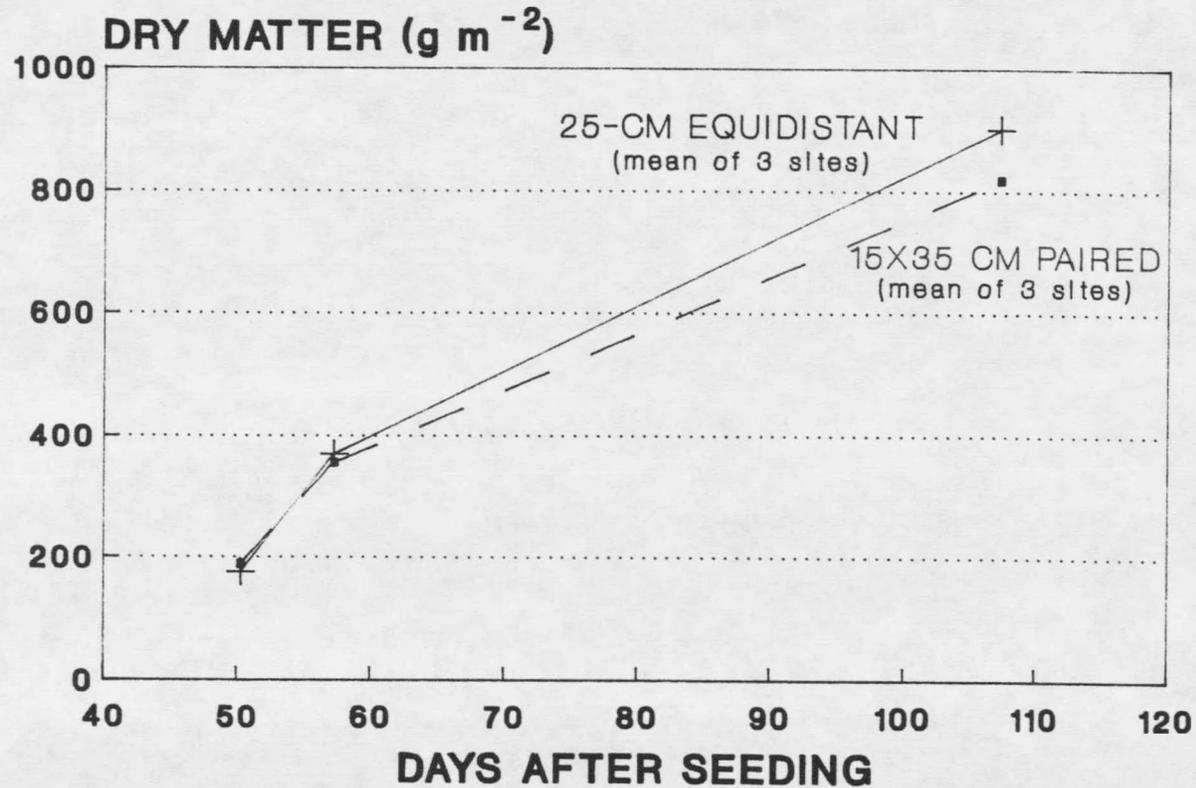


Table 24. Analysis of variance over all sites and growth stages (GS) for effects of row configuration (RC) and P fertilizer placement (PPL) on tissue N and P concentration, N and P uptake, and dry matter production of no-till spring wheat, 1987.<sup>a</sup>

Source	df	N concen- tration	N uptake	P concen- tration	P uptake	Dry matter Production
<-----significance level----->						
Site	2	**	**	NS	**	**
Error (a)	9					
RC	1	NS	NS	NS	NS	*
RC x Site	2	NS	NS	NS	NS	NS
Error (b)	9					
PPL	1	NS	*	NS	NS	*
Site x PPL	2	NS	*	NS	*	**
RC x PPL	1	NS	0.08	NS	**	0.06
Site x RC x PPL	2	NS	NS	NS	NS	NS
GS	2	**	**	**	**	**
Site x GS	4	**	**	**	**	**
RC x GS	2	NS	0.08	NS	0.08	*
Site x RC x GS	4	NS	NS	NS	NS	NS
PPL x GS	2	NS	NS	NS	NS	NS
Site x PPL x GS	4	NS	NS	NS	NS	**
RC x PPL x GS	2	*	NS	**	*	NS
Site x RC x PPL x GS	4	NS	NS	NS	NS	NS
Residual	90					
Total	143					

\*,\*\*Significant at 0.05 and 0.01 probability levels, respectively.

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

NS = Not significant at  $P \leq 0.10$ .

Figure 8

## MAIN EFFECT OF TWO ROW CONFIGURATIONS ON P UPTAKE OF SPRING WHEAT, 1987

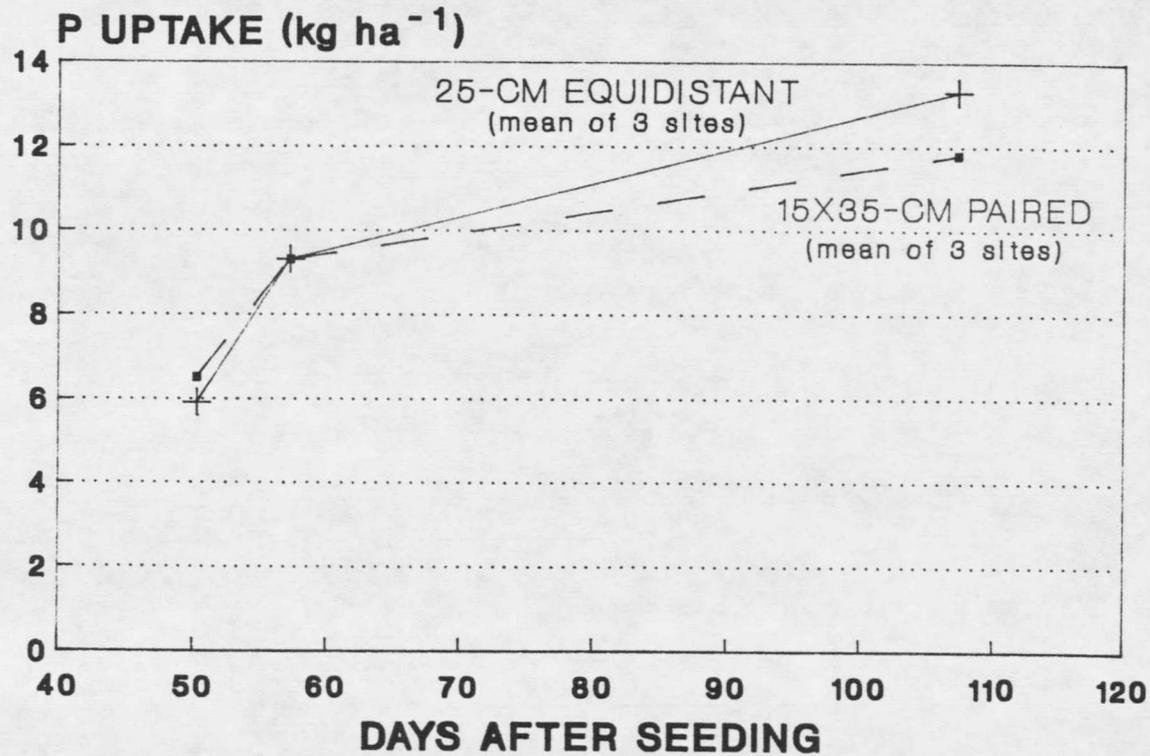


Table 25. Main effects of site, row configuration, P fertilizer placement, and growth stage on tissue N and P concentration, N and P uptake, and dry matter production of no-till spring wheat, 1987.<sup>a</sup>

Treatment	N concentration	N uptake	P concentration	P uptake	Dry matter Production
	$g\ kg^{-1}$	$kg\ ha^{-1}$	$g\ kg^{-1}$	$kg\ ha^{-1}$	$g\ m^{-2}$
<u>Site</u>					
Brady	24.8	75.2	2.4	7.7	341
Conrad	29.6	74.4	2.6	6.8	356
Agawam	29.5	153.7	2.5	13.6	709
LSD (0.05)	1.9	4.9	NS	2.1	39
Significance level	0.00	0.00	0.49	0.00	0.00
<u>Row configuration (RC)<sup>b</sup></u>					
15 x 35-cm PR	28.3	100.4	2.5	9.2	454*
25-cm ER	27.6	101.8	2.5	9.5	482
Significance level	0.41	0.18	0.24	0.52	0.02
<u>P placement (PPL)</u>					
With seed	27.9	104.5*	2.5	9.6	484*
Side <sup>c</sup>	28.0	97.7	2.5	9.1	453
Significance level	0.74	0.05	0.20	0.29	0.03
<u>Growth stage (GS)<sup>d</sup></u>					
8-9	40.2	72.2	3.4	6.2	182
10-10.1	28.6	104.2	2.6	9.3	363
11.4	15.1	126.8	1.5	12.6	860
LSD (0.05)	1.0	8.3	0.1	0.9	34
Significance level	0.00	0.00	0.00	0.00	0.00

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>PR = Paired row; ER = Equidistant row.

<sup>c</sup>7.5 cm to side and 5 cm below seed.

<sup>d</sup>Feekes scale.

NS = Not significant at  $P \leq 0.05$ .

concentration. Tissue N and P concentrations decreased with each successive growth stage, probably due to a dilution effect (Table 25).

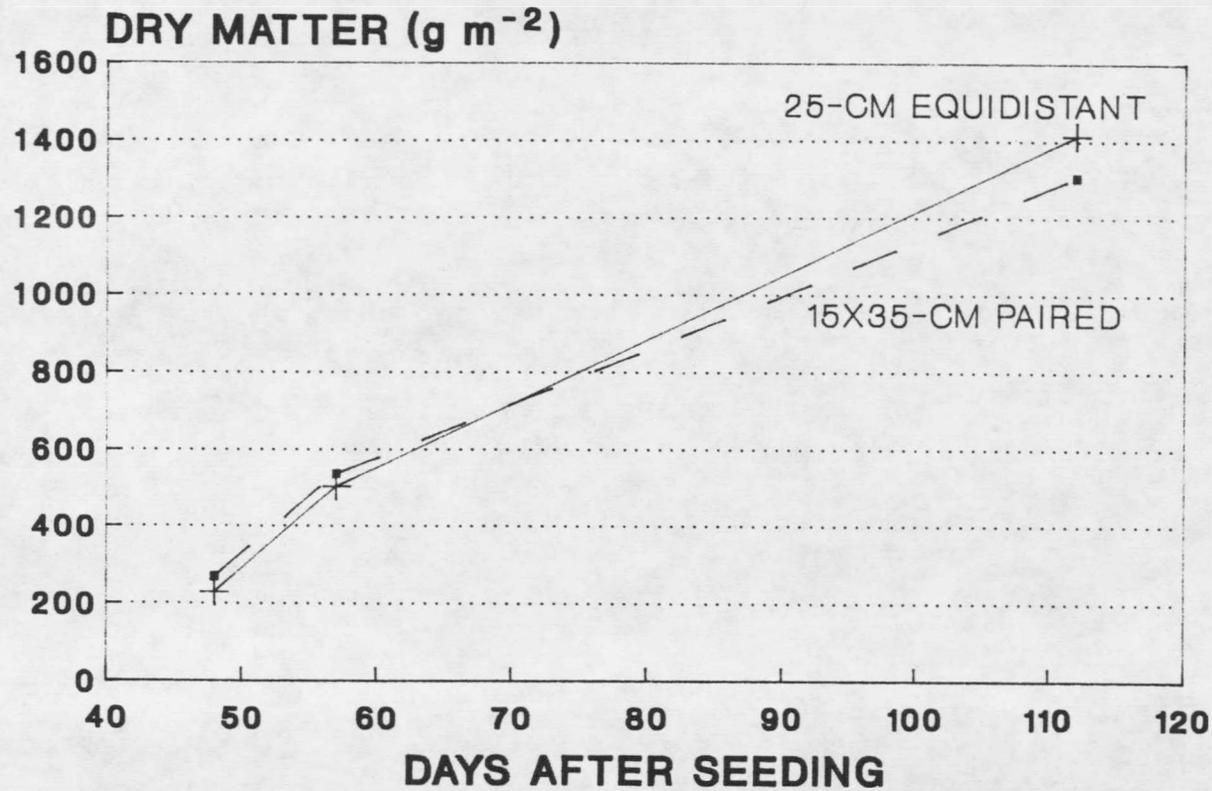
There are several possible reasons why ER showed an increasing growth advantage with time as compared to PR. The influence of moisture has already been mentioned, but this fails to explain the data presented graphically in Figure 9. The irrigated Agawam site was not noticeably affected by moisture shortage (Table 7), yet the ER still showed a dry matter production advantage with time as compared to PR.

Water use efficiency (WUE) is one possible explanation for this response. It is known that in humid areas, evaporation from the soil surface ( $E_s$ ) is a significant component of total ET (Loomis, 1983; Doyle and Fischer, 1979). For this reason, high seeding densities and/or narrow row spacings that lead to early canopy closure can reduce  $E_s$  and improve WUE (Asrar et al., 1984; Doyle and Fischer, 1979). The ER had formed a complete canopy by about Feekes stage 10, whereas the PR never did form a continuous canopy. In this respect, PR approximated an ER spacing somewhat wider than 25 cm. The wider row spacing thus approximated by PR could have caused increased  $E_s$  losses, especially under irrigation. Since increased amounts of residue generally reduce  $E_s$  losses (Bond and Willis, 1969), the fact that the Agawam site had less than half as much crop residue at planting as the other sites could also have caused relatively high  $E_s$  losses.

Although dry matter production was adversely affected by PR at the Agawam site, grain yield was not (Figures 3 and 5). This is somewhat difficult to explain, but the taller plants with a more well-developed root system may have more effectively utilized several late-season

Figure 9

# MAIN EFFECT OF TWO ROW CONFIGURATIONS ON DRY MATTER PRODUCTION AT AGAWAM, 1987



rainfall events. Late-season rains were too late for the Brady site, as evidenced by low kernel weights (Table 3). In addition to more total seasonal precipitation, the Conrad and Agawam sites took 10 to 20 days longer to mature, resulting in higher yields and higher kernel weights.

In a study in Texas with winter wheat, Gerik and Morrison (1985) found that during years of adequate precipitation, wheat plants in rows adjacent to controlled-traffic zones compensated for the absence of wheat within these zones by producing more tillers and grain than plants in rows between controlled-traffic zones. In a dry year, no such compensation took place; tillering and grain yields were reduced by the absence of wheat in the controlled-traffic zones. At the Agawam site where moisture was not limiting, compensation among yield components could have resulted in similar yields across all row configurations (Tables 6-11).

Plant shading is another factor that could have caused a growth disadvantage in the PR. In a study with winter wheat, McMaster et al. (1987) found that a 50% light reduction from one week before booting through the first week of grain fill (six weeks total) reduced grain yields by 32%, due mostly to tiller mortality, but also to decreased kernel number and size. With only one exception, grain yields, yield components, and grain test weight of wheat within treatments 4, 14, 23, and 24 were not significantly affected by row position at any of the sites (Table 26 and Appendix D). At the Agawam site, however, there was a significant row configuration x row position interaction for grain yield. The row designated north (N) in the ER produced  $109 \text{ kg ha}^{-1}$  more grain than the south (S) row, but in the PR the south row produced  $318 \text{ kg ha}^{-1}$  more grain than the north row (Table 26). Since all plots were

Table 26. Main effect of row position at two row configurations on grain yield, yield components, and grain test weight of no-till spring wheat at Agawam site, 1987.\*

Configuration	Row position	Grain yield	Tiller density	Kernels per spike	Kernel weight	Grain test weight
		<i>kg ha<sup>-1</sup></i>	<i>tillers m<sup>-2</sup></i>	<i>no.</i>	<i>g 100 seeds<sup>-1</sup></i>	<i>kg m<sup>-3</sup></i>
15 x 35-cm PR <sup>a</sup>	North	3843	557	21.3	3.22	779.8
	South	4161	582	22.1	3.23	789.4
	Significance level	NS <sup>b</sup>	NS	NS	NS	NS
25-cm ER <sup>c</sup>	North	4100	587	21.4	3.24	793.9
	South	3991	583	21.3	3.21	798.6
	Significance level	NS	NS	NS	NS	NS

\*Means averaged over two P placements.

<sup>a</sup>Paired row. Treatments 4 and 14 used for this analysis (see Table 2).

<sup>b</sup>P placement x row position interaction significant at  $P \leq 0.05$ .

<sup>c</sup>Equidistant row. Treatments 23 and 24 used for this analysis (see Table 2).

NS = Not significant at  $P \leq 0.05$ .

planted in east-west rows, this could reflect greater shading in the north row as compared to the south row under PR seeding.

At Agawam, where wheat plants were the tallest (Tables 16 and 17), plants in the north row of the PR appeared slightly etiolated just prior to harvest. The north rows also appeared to have increased lodging due to wind. South/north shading and/or mutual shading could have adversely affected dry matter production at Agawam. The higher seeding rate used at Agawam would likely result in a higher degree of shading (Asrar et al., 1984). Auld et al. (1983) found that low seeding rates resulting in wheat plant populations less than 200 plants  $m^{-2}$  were disadvantageous when wheat was sown in rectangular as compared to square planting patterns. At higher seeding rates, grain yields were similar in rectangular and square planting patterns. It was postulated that wheat sown at lower seeding rates was less able to utilize available space. Seeding rates at Brady and Conrad were lower than at Agawam (215 seeds  $m^{-2}$  vs. 325 seeds  $m^{-2}$ ), and this coupled with moisture differences could have influenced response to row configuration. However, there were no significant row configuration x site interactions for any of the parameters (Table 24 and Appendix B).

No visual effects of shading were observed at Brady and Conrad. The combined ANOVA across both row configurations indicated, with one exception, that no significant row configuration x row position interactions existed (Appendix D). Although shading may have been partially responsible for grain yield reductions at Brady and Conrad, the data suggest that it was not an important factor.

In conclusion, where PR affected wheat response, it was in a negative manner. The 20 x 30-cm PR were not significantly different than the 25-cm ER, but grouping the wheat rows in a 15 x 35-cm PR configuration resulted in grain yield reductions at both dryland sites. Results of this study with a single cultivar of spring wheat indicate that under no-till conditions, there is no advantage to planting spring wheat in a PR configuration.

### Effect of Nitrogen Fertilizer Rate

#### Effect on Grain Yield, Yield Components, and Growth

Grain yields were significantly increased by N applications at the dryland Brady and Conrad sites, but not at Agawam (Fig. 10 and Table 27). Residual soil  $\text{NO}_3^-$ -N was very high at Agawam (Table 1), and was the probable cause of the lack of N response at that site.

Tiller number was increased significantly by N fertilizer only at the Conrad site (Table 27). This type of positive response has also been reported by Holliday (1963) and Campbell et al. (1977). Black (1970, 1982) found that N promoted tillering only when adequate P was present.

Added N caused a large and significant increase in kernels per spike at Brady (Table 27), with a similar trend at the other sites. Kernel weight was consistently reduced by added N (Table 28). In a study with winter wheat, Frederick and Marshall (1985) found that N increased kernels per spike at five of eight locations, but that high N rates decreased kernel weight, and this decrease was primarily responsible for reductions in yield. Campbell et al. (1977) also reported decreased

Figure 10

## EFFECT OF N FERTILIZER RATE ON GRAIN YIELD OF SPRING WHEAT, 1987

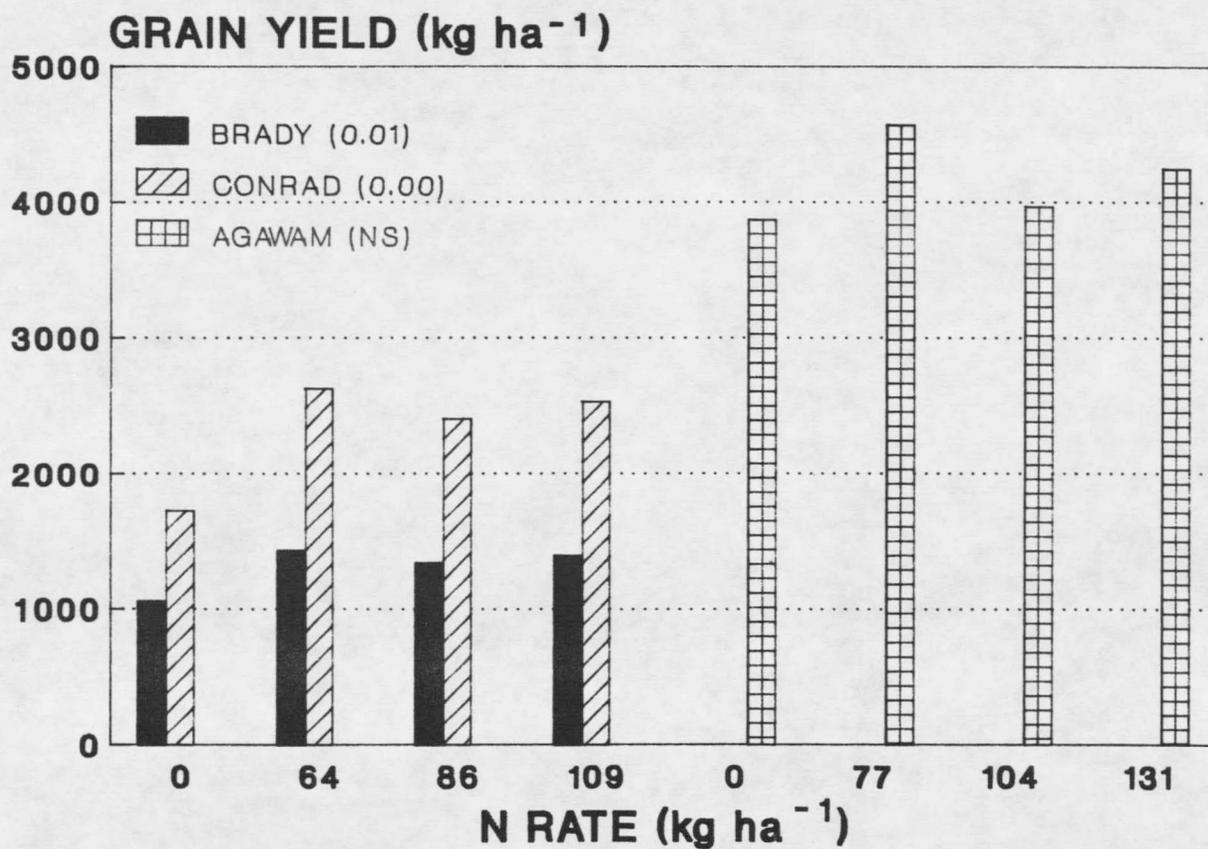


Table 27. Effect of N fertilizer rate on grain yield, tiller density, and kernels per spike of no-till spring wheat, 1987.<sup>a</sup>

N rate <sup>b</sup>	Grain yield			Tiller density			Kernels per spike		
	<-----Site----->			<-----Site----->			<-----Site----->		
	Brady	Conrad	Agawam	Brady	Conrad	Agawam	Brady	Conrad	Agawam
	<-----kg ha <sup>-1</sup> ----->			<-----tillers m <sup>-2</sup> ----->			<-----no.----->		
0	1054	1723	3871	284	241	520	11.4	17.3	20.4
L	1429	2627	4570	290	357	561	18.1	20.9	23.4
M	1339	2403	3968	284	339	562	18.1	19.7	21.8
H	1392	2529	4249	291	351	592	19.1	21.0	21.6
LSD (0.05)	211	314	NS	NS	44	NS	3.5	NS	NS
Signif. level	0.01	0.00	0.48	0.99	0.00	0.18	0.00	0.29	0.16

<sup>a</sup>Treatments 3, 4, 8, and 11 used for this analysis (see Table 2).

<sup>b</sup>0, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

NS = Not significant at  $P \leq 0.05$ .

Table 28. Effect of N fertilizer rate on kernel weight, grain test weight, and grain protein of no-till spring wheat, 1987.<sup>a</sup>

N rate <sup>b</sup>	Kernel weight			Grain test weight			Grain protein		
	<-----Site----->			<-----Site----->			<-----Site----->		
	Brady	Conrad	Agawam	Brady	Conrad	Agawam	Brady	Conrad	Agawam
	<----g 100 seeds <sup>-1</sup> ---->			<-----kg m <sup>-3</sup> ----->			<-----%----->		
0	3.36	4.13	3.66	806.9	833.7	814.7	10.2	11.9	12.1
L	2.71	3.53	3.48	793.7	819.4	795.1	14.8	12.8	13.6
M	2.59	3.65	3.19	790.2	824.1	779.9	15.4	13.7	14.9
H	2.49	3.44	3.31	761.5	809.9	783.8	16.7	14.4	15.1
LSD (0.05)	0.17	0.22	NS	26.9	NS	20.4	0.8	1.0	1.5
Signif. level	0.00	0.00	0.06	0.02	0.47	0.02	0.00	0.01	0.01

<sup>a</sup>Treatments 3, 4, 8, and 11 used for this analysis (see Table 2).

<sup>b</sup>0, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

NS = Not significant at  $P \leq 0.05$ .

kernel weights with increasing levels of N. In contrast, Black (1970) found that kernels per spike and kernel weight were not significantly influenced by N fertilization.

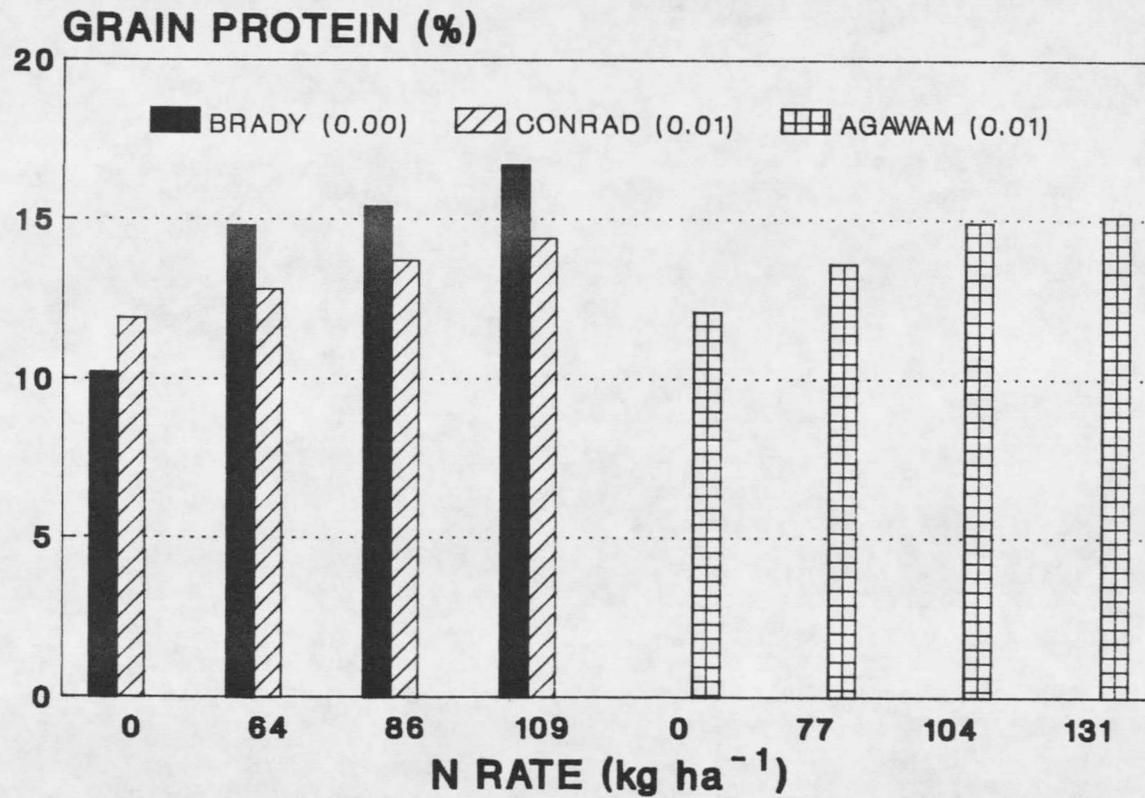
Grain test weight was similarly reduced by N additions (but not significantly at the Conrad site) (Table 28). This is consistent with the findings of Roth et al. (1984), who observed lower test weights at high N rates.

Grain protein was consistently increased by added N, even at the Agawam site (Fig. 11 and Table 28). The high protein contents at Brady were probably due to moisture stress. Smika and Greb (1973) found a negative correlation between grain protein content of winter wheat and precipitation during a 15-day period 40 to 55 days prior to maturity.

The low rate of N resulted in the highest grain yields at all sites (Fig. 10), but assuming that about 14% protein indicates adequate N (Goos, 1984), the medium N rate would be optimum for both yield and protein at all sites (86 kg ha<sup>-1</sup> at Brady and Conrad; 104 kg ha<sup>-1</sup> at Agawam). This rate was based on an N recommendation of 40 kg N Mg<sup>-1</sup> grain, which is identical to that suggested by Halvorson et al. (1987) for wheat in the northern Great Plains. Based on the results of this study with a single cultivar, it does not appear necessary to increase N rates for spring wheat grown in a no-till system, as suggested by Deibert et al. (1986). In this study where wheat was planted directly into standing stubble, rather than where crop residues had been incorporated, there was probably little immobilization of topdressed N fertilizer (Black and Siddoway, 1977; Parsons, 1984).

Figure 11

## EFFECT OF N FERTILIZER RATE ON GRAIN PROTEIN OF SPRING WHEAT, 1987



In regard to other parameters, heading date was not significantly affected by N at Brady and Conrad, but was delayed slightly at Agawam ( $P = 0.04$ ) (Table 29). Black (1970) found that without P fertilizer, N delayed maturity of spring wheat; however, when P was adequate, N did not delay maturity. Plant height at heading was increased by N at all sites ( $P \leq 0.07$  at Conrad), while plant height at harvest was increased by N only at Conrad (Table 29).

Effect on Dry Matter Production,  
Nutrient Concentration, and  
Nutrient Uptake

Plant samples were taken only from the low, medium, and high N rates (treatments 4, 8, and 11). The Brady location was the most responsive to added N in terms of dry matter (Table 30), tissue N concentration and N uptake (Table 31), and P uptake (Table 32). Nitrogen fertilization did not significantly affect any of these parameters at Conrad (Tables 30-32). Yields at Brady were only about half of the yield goal ( $1400 \text{ kg ha}^{-1}$  vs.  $2690 \text{ kg ha}^{-1}$ ). This may partly explain why dry matter and nutrient uptake responses to N were greatest at Brady. At Agawam, tissue N concentration was significantly increased by N (Table 32). Tissue N and P concentration decreased with each successive growth stage, as expected (Bauer et al., 1987). There were significant N rate x growth stage interactions at Brady (Tables 30-32).

In summary, the medium and high N rates did not increase grain yields above the low rate at all sites (Fig. 10), and did not significantly increase dry matter at Conrad and Agawam (Table 30). Differences between the low, medium, and high N rates were slight for most other

Table 29. Effect of N fertilizer rate on heading date, plant height at heading, and plant height at harvest of no-till spring wheat, 1987.<sup>a</sup>

N rate <sup>b</sup>	Heading date			Plant height at heading <sup>c</sup>			Plant height at harvest <sup>d</sup>		
	<-----Site----->			<-----Site----->			<-----Site----->		
	Brady	Conrad	Agawam	Brady	Conrad	Agawam	Brady	Conrad	Agawam
	<--Days from seeding to spike emergence-->			<-----cm----->					
0	61.0	60.1	59.5	29.5	33.3	44.5	46.4	59.6	76.5
L	60.8	60.0	61.0	34.0	35.2	49.9	46.4	64.8	81.6
M	61.0	59.5	60.8	34.3	35.2	50.8	46.0	63.5	80.0
H	61.0	59.5	60.8	33.7	36.2	50.2	45.1	63.5	78.1
LSD (0.05)	NS	NS	1.1	1.4	NS	2.8	NS	0.4	NS
Signif. level	0.79	0.36	0.04	0.00	0.07	0.01	0.69	0.01	0.14

<sup>a</sup>Treatments 3, 4, 8, and 11 used for this analysis (see Table 2).

<sup>b</sup>0, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

<sup>c</sup>Feekes growth stage 10.1. Height measured to top ligule.

<sup>d</sup>Feekes growth stage 11.4.

NS = Not significant at  $P \leq 0.05$ .

Table 30. Main effects of N fertilizer rate and growth stage on dry matter production of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site		
	Brady	Conrad	Agawam
	←-----g m <sup>-2</sup> ----->		
<i>N rate</i> <sup>b</sup>			
0 <sup>c</sup>	146	212	489
L	315	342	696
M	310	323	736
H	371	330	650
LSD (0.05)	28	NS	NS
Significance level	0.00	0.80	0.38
<i>Growth stage (GS)</i> <sup>d</sup>			
8-9	196	85	256
10-10.1	303	198	515
11.4	497	713	1310
LSD (0.05)	28	59	125
Significance level	0.00	0.00	0.00
CV (%)	10.0	21.1	21.3
<i>N rate x GS interaction</i>	**	NS	NS

\*\*Significant at  $P \leq 0.01$ .

<sup>a</sup>Treatments 4, 8, and 11 used for this analysis (see Table 2).

<sup>b</sup>0, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

<sup>c</sup>Treatment 1 not included in statistical analysis.

<sup>d</sup>Feekes scale.

NS = Not significant at  $P \leq 0.05$ .

Table 31. Main effects of N fertilizer rate and growth stage on tissue N concentration and N uptake of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site					
	Brady		Conrad		Agawam	
	N concentration	N uptake	N concentration	N uptake	N concentration	N uptake
	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>
<i>N rate<sup>b</sup></i>						
O <sup>c</sup>	15.5	19.3	22.4	35.0	22.2	87.8
L	23.7	63.5	29.6	64.4	29.5	151.6
M	25.7	72.0	30.3	70.5	29.7	158.7
H	28.7	91.7	31.0	70.4	32.3	163.9
LSD (0.05)	2.9	8.9	NS	NS	1.9	NS
Significance level	0.00	0.00	0.38	0.57	0.01	0.59
<i>Growth stage (GS)<sup>d</sup></i>						
8-9	36.3	71.0	45.3	38.2	44.0	112.5
10-10.1	26.4	79.9	30.6	60.3	32.3	166.2
11.4	15.3	76.2	15.1	106.8	15.1	195.6
LSD (0.05)	2.9	NS	1.9	13.3	1.9	24.4
Significance level	0.00	0.14	0.00	0.00	0.00	0.00
CV (%)	13.1	13.9	7.5	23.0	7.3	18.3
<i>N rate x GS interaction</i>	NS	*	NS	NS	NS	NS

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4, 8, and 11 used for this analysis (see Table 2).

<sup>b</sup>O, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

<sup>c</sup>Treatment 1 not included in statistical analysis.

<sup>d</sup>Feekes scale.

NS = Not significant at  $P \leq 0.05$ .

Table 32. Main effects of N fertilizer rate and growth stage on tissue P concentration and P uptake of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site					
	Brady		Conrad		Agawam	
	P concentration	P uptake	P concentration	P uptake	P concentration	P uptake
	g kg <sup>-1</sup>	kg ha <sup>-1</sup>	g kg <sup>-1</sup>	kg ha <sup>-1</sup>	g kg <sup>-1</sup>	kg ha <sup>-1</sup>
<i>N rate</i> <sup>b</sup>						
0 <sup>c</sup>	2.8	3.8	2.8	4.8	2.5	11.1
L	2.5	7.3	2.6	6.4	2.6	13.7
M	2.5	7.1	2.6	6.0	2.5	13.7
H	2.6	8.9	2.6	6.0	2.7	14.1
LSD (0.05)	NS	1.1	NS	NS	NS	NS
Significance level	0.81	0.01	0.93	0.73	0.26	0.94
<i>Growth stage (GS)</i> <sup>d</sup>						
8-9	3.1	6.1	3.6	3.1	3.7	9.4
10-10.1	2.5	7.6	2.7	5.4	2.7	13.8
11.4	1.9	9.6	1.4	9.8	1.4	18.2
LSD (0.05)	0.3	1.1	0.3	1.3	0.3	2.9
Significance level	0.00	0.00	0.00	0.00	0.00	0.00
CV (%)	15.1	16.9	12.5	25.9	13.4	24.6
<i>N rate x GS interaction</i>	NS	**	NS	NS	NS	NS

\*\*Significant at  $P \leq 0.01$ .

<sup>a</sup>Treatments 4, 8, and 11 used for this analysis (see Table 2).

<sup>b</sup>0, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

<sup>c</sup>Treatment 1 not included in statistical analysis.

<sup>d</sup>Feekes scale.

NS = Not significant at  $P \leq 0.05$ .

parameters, except grain protein was progressively increased with increasing N at all sites (Fig. 11, Appendix E). At Agawam, high residual soil  $\text{NO}_3^-$ -N levels were probably responsible for lack of response to N.

Since all of the various N fertilizer rates were within the 15 x 35-cm PR main plot, it was not possible to determine if a row configuration x N rate interaction existed. But an N recommendation of 40 kg N  $\text{Mg}^{-1}$  grain seems applicable to PR as well as ER planting systems for no-till spring wheat.

#### N x P Interaction

Three N rates (low, medium, and high) and three P rates (5, 7, and 9 kg  $\text{ha}^{-1}$ ) from within the 15 x 35-cm PR main plot were analyzed in a 3 x 3 factorial to determine the combined effects of N and P fertilizer (Appendix E). The effects of N fertilizer averaged over three P rates were similar to that described above (Tables 27-29). Phosphorus fertilizer rates of 5, 7, and 9 kg P  $\text{ha}^{-1}$  did not significantly affect yield, yield components, or any of the other parameters when averaged over the low, medium, and high N rates. No significant N x P interactions were evidenced, except for grain test weight at Agawam.

#### Effect of Phosphorus Fertilizer

##### Effect of P Fertilizer Rate

Only the Conrad site showed a significant grain yield response to P (Table 33). This response was not predicted by the P soil test used (Olsen et al., 1954) (Table 1). Experiments conducted on the same soil

Table 33. Effect of P fertilizer rate on grain yield, tiller density, and kernels per spike of no-till spring wheat, 1987.<sup>a</sup>

P rate	Grain yield			Tiller density			Kernels per spike		
	<-----Site----->			<-----Site----->			<-----Site----->		
	Brady	Conrad	Agawam	Brady	Conrad	Agawam	Brady	Conrad	Agawam
kg ha <sup>-1</sup>	<-----kg ha <sup>-1</sup> ----->			<-----tillers m <sup>-2</sup> ----->			<-----no.----->		
0	1380	2588	4178	282	360	578	18.2	19.4	20.9
5	1266	2746	4100	287	359	545	17.2	21.6	22.8
7	1339	2403	3968	284	339	562	18.1	19.7	21.8
9	1379	2603	4159	299	341	585	17.8	21.8	21.0
15	1283	2711	3888	282	390	612	17.5	19.9	19.8
24	1195	2869	4101	328	353	576	14.7	23.4	23.0
LSD (0.05)	NS	266	NS	NS	NS	NS	NS	NS	NS
Signif. level	0.26	0.05	0.95	0.19	0.42	0.08	0.20	0.11	0.07

<sup>a</sup>Treatments 2, 4, 5, 6, 13, and 15 used for this analysis (see Table 2).

NS = Not significant at P ≤ 0.05.

(high P soil test) near this site in 1986 also showed significant responses to P fertilizer (G.D. Kushnak, unpublished data, Montana Agricultural Experiment Station, Conrad, MT). Spring wheat response to seed-banded P on high-P soils has also been reported by Alessi and Power (1980).

Yield components were not significantly influenced by P rate (Tables 33 and 34). Grain protein was increased by P at Brady ( $P \leq 0.06$ ) and Agawam ( $P \leq 0.09$ ) (Table 34). The kernel is a major sink for P retranslocated within the plant (Mohamed and Marshall, 1979). Sutton et al. (1983) pointed out that dry conditions during grain fill can limit P uptake; this in turn may inhibit the translocation of P to the kernels. Under these conditions, P additions may increase grain protein even on high-P soils.

Phosphorus fertilizer hastened heading date by about two days at Brady, with a similar trend at Conrad (Table 35) (Black, 1970). At Brady, plant height at maturity was reduced by P at the 24 kg ha<sup>-1</sup> rate (Table 35). Plant heights at heading were similar for all P rates.

Plant samples taken from the 5, 7, 9, 15, and 24 kg ha<sup>-1</sup> P rate plots indicated that dry matter production was increased by P applications at Brady and Conrad ( $P \leq 0.07$ ) (Table 36). There was a significant P rate x growth stage interaction at Brady for dry matter production and N uptake (Tables 36 and 37), probably due to the dry conditions there. This is further evidenced by the fact that maximum total N and P uptake at Brady occurred at Feekes stage 10-10.1, while at Conrad and Agawam, N and P uptake (at least in aerial plant parts) continued to increase through maturity (Tables 37 and 38).

Table 34. Effect of P fertilizer rate on kernel weight, grain test weight, and grain protein of no-till spring wheat, 1987.<sup>a</sup>

P rate	Kernel weight			Grain test weight			Grain protein		
	<-----Site----->			<-----Site----->			<-----Site----->		
	Brady	Conrad	Agawam	Brady	Conrad	Agawam	Brady	Conrad	Agawam
<i>kg ha<sup>-1</sup></i>	<----g 100 seeds <sup>-1</sup> ---->			<-----kg m <sup>-3</sup> ----->			<-----%----->		
0	2.63	3.70	3.47	763.8	812.4	783.8	15.5	13.7	13.9
5	2.55	3.56	3.29	792.4	833.3	778.9	15.7	13.4	14.8
7	2.59	3.65	3.19	790.2	824.1	779.9	15.4	13.7	14.9
9	2.56	3.53	3.38	787.9	819.4	793.2	15.7	13.4	14.5
15	2.60	3.52	3.21	797.9	818.8	788.5	15.5	13.5	15.0
24	2.49	3.47	3.19	791.5	823.4	794.3	16.2	13.8	15.2
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Signif. level	0.14	0.13	0.40	0.08	0.67	0.27	0.06	0.88	0.09

<sup>a</sup>Treatments 2, 4, 5, 6, 13, and 15 used for this analysis (see Table 2).

NS = Not significant at  $P \leq 0.05$ .

Table 35. Effect of P fertilizer rate on heading date, plant height at heading, and plant height at harvest of no-till spring wheat, 1987.<sup>a</sup>

P rate	<u>Heading date</u>			<u>Plant height at heading<sup>b</sup></u>			<u>Plant height at harvest<sup>c</sup></u>		
	<-----Site----->			<-----Site----->			<-----Site----->		
	Brady	Conrad	Agawam	Brady	Conrad	Agawam	Brady	Conrad	Agawam
<i>kg ha<sup>-1</sup></i>	<--Days from seeding to spike emergence-->			<-----cm----->					
0	61.8	60.3	60.8	34.3	34.6	47.9	45.4	64.1	78.1
5	61.0	59.3	60.3	33.0	35.9	49.9	45.1	63.2	77.8
7	61.0	59.5	60.8	34.3	35.2	50.8	46.0	63.5	80.0
9	60.8	59.3	60.5	32.4	35.6	48.9	45.4	64.1	77.8
15	60.5	59.5	61.0	34.3	35.2	49.5	44.1	64.1	76.8
24	59.8	59.0	60.8	33.0	36.8	50.2	41.6	63.6	78.1
LSD (0.05)	0.6	NS	NS	NS	NS	NS	2.3	NS	NS
Signif. level	0.00	0.28	0.49	0.10	0.10	0.36	0.01	0.94	0.70

<sup>a</sup>Treatments 2, 4, 5, 6, 13, and 15 used for this analysis (see Table 2).

<sup>b</sup>Feekes growth stage 10.1. Height measured to top ligule.

<sup>c</sup>Feekes growth stage 11.4.

NS = Not significant at  $P \leq 0.05$ .

Table 36. Main effects of P fertilizer rate and growth stage on dry matter production of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site		
	Brady	Conrad	Agawam
	<-----g m <sup>-2</sup> ----->		
<u>P rate (kg ha<sup>-1</sup>)</u>			
5	342	349	776
7	310	323	736
9	385	343	658
15	345	370	679
24	351	398	693
LSD (0.05)	39	NS	NS
Significance level	0.01	0.07	0.36
<u>Growth stage (GS)<sup>b</sup></u>			
8-9	210	117	265
10-10.1	370	216	532
11.4	460	729	1327
LSD (0.05)	30	41	99
Significance level	0.00	0.00	0.00
CV (%)	13.6	18.2	21.9
<u>P rate x GS interaction</u>	**	NS	NS

\*\*Significant at  $P \leq 0.01$ .

<sup>a</sup>Treatments 4, 5, 6, 13, and 15 used for this analysis (see Table 2).

<sup>b</sup>Feekes scale.

NS = Not significant at  $P \leq 0.05$ .

Table 37. Main effects of P fertilizer rate and growth stage on tissue N concentration and N uptake of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site					
	Brady		Conrad		Agawam	
	N concentration	N uptake	N concentration	N uptake	N concentration	N uptake
	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>
<i>P rate (kg ha<sup>-1</sup>)</i>						
5	23.6	69.0	30.4	75.9	30.8	178.1
7	25.7	72.0	30.3	70.5	29.7	158.7
9	24.7	81.8	30.2	73.1	30.2	156.5
15	22.9	71.5	30.7	78.6	31.0	164.6
24	22.2	73.1	29.9	86.2	31.3	159.3
LSD (0.05)	2.6	NS	NS	NS	NS	NS
Significance level	0.03	0.23	0.96	0.09	0.36	0.55
<i>Growth stage (GS)<sup>b</sup></i>						
8-9	34.1	69.9	44.6	50.5	43.7	115.9
10-10.1	22.2	82.3	30.8	66.0	33.1	175.7
11.4	14.7	68.0	15.5	112.6	15.0	198.7
LSD (0.05)	2.0	9.0	1.7	9.1	1.3	22.0
Significance level	0.00	0.00	0.00	0.00	0.00	0.00
CV (%)	13.1	19.2	8.8	18.8	6.8	21.1
<i>P rate x GS interaction</i>	NS	*	NS	NS	NS	NS

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4, 5, 6, 13, and 15 used for this analysis (see Table 2).

<sup>b</sup>Feekes scale.

NS = Not significant at  $P \leq 0.05$ .

Table 38. Main effects of P fertilizer rate and growth stage on tissue P concentration and P uptake of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site					
	Brady		Conrad		Agawam	
	P concen- tration	P uptake	P concen- tration	P uptake	P concen- tration	P uptake
	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>
<u>P rate (kg ha<sup>-1</sup>)</u>						
5	2.6	7.9	2.6	7.1	2.8	17.3
7	2.5	7.1	2.6	6.0	2.5	13.7
9	2.7	9.1	2.6	6.7	2.6	13.6
15	2.5	8.1	2.5	7.2	2.9	15.6
24	2.7	9.0	2.7	8.1	2.9	15.5
LSD (0.05)	NS	NS	NS	1.1	0.2	2.6
Significance level	0.79	0.07	0.16	0.01	0.01	0.03
<u>Growth stage (GS)<sup>b</sup></u>						
8-9	3.4	7.2	3.6	4.2	3.8	10.0
10-10.1	2.5	9.1	2.7	5.9	2.8	14.9
11.4	1.8	8.4	1.5	10.8	1.6	20.5
LSD (0.05)	0.3	1.2	0.1	0.9	0.2	2.0
Significance level	0.00	0.01	0.00	0.00	0.00	0.00
CV (%)	19.6	23.0	8.5	19.4	9.1	20.5
<u>P rate x GS interaction</u>	NS	NS	NS	*	NS	NS

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4, 5, 6, 13, and 15 used for this analysis (see Table 2).

<sup>b</sup>Feekes scale.

NS = Not significant at  $P \leq 0.05$ .

Tissue N concentration was decreased by P additions above the 7 kg ha<sup>-1</sup> rate at Brady, but was unaffected by P at Conrad and Agawam (Table 37). Phosphorus uptake was affected by P at all sites; at Brady and Conrad it was increased ( $P \leq 0.07$  at Brady), but at Agawam it was decreased by P additions (Table 38). At high soil test P levels, addition of P fertilizer normally has little effect on P uptake (Fixen and Leikam, 1988). These results indicate that certain factors can significantly influence P uptake, even in high-P soils.

#### Effect of P Fertilizer Placement

Data from treatments 4, 14, 23, and 24 indicate that there were no significant differences in grain yield between seed-placed P and P placed 7.5 cm to the side and 5 cm below the seed, when averaged over two row configurations (Table 8). Seed-placed P generally produced more dry matter and resulted in more N uptake at the first two sampled growth stages, but these differences largely disappeared by harvest (Tables 19 and 21). Dry conditions early in the growing season were probably responsible for an early growth advantage to seed-placed P. Power et al. (1961) found that as soil water supplies decreased, the percentage of total plant P derived from fertilizer P generally increased. Studies by Cabrera et al. (1986) and McConnell et al. (1986) have demonstrated that early growth advantages due to seed-placed P often do not result in higher yields.

Data from treatments 22, 23, and 24 from within the 25-cm ER main plot revealed few differences between the three P fertilizer placements (Tables 39-44). At Agawam, a grain yield advantage was evidenced when

Table 39. Effect of P fertilizer placement on grain yield and yield components of no-till spring wheat, 1987.<sup>a</sup>

Site	P placement	Grain yield	Tiller density	Kernels spike <sup>-1</sup>	Kernel weight
		kg ha <sup>-1</sup>	tillers m <sup>-2</sup>	no.	g 100 seeds <sup>-1</sup>
<i>Brady</i>	With seed	1448	294	19.4	2.55
	Side <sup>b</sup>	1528	315	18.8	2.65
	Below <sup>c</sup>	1589	287	20.6	2.70
	LSD (0.05)	NS	NS	NS	NS
	Significance level	0.27	0.70	0.58	0.23
	CV (%)	7.3	15.8	12.4	4.2
<i>Conrad</i>	With seed	2759	351	21.4	3.68
	Side <sup>b</sup>	2879	371	21.3	3.68
	Below <sup>c</sup>	2778	334	23.2	3.64
	LSD (0.05)	NS	NS	NS	NS
	Significance level	0.88	0.10	0.43	0.83
	CV (%)	12.6	5.6	9.9	2.9
<i>Agawam</i>	With seed	4130	582	21.8	3.23
	Side <sup>b</sup>	4004	587	20.8	3.27
	Below <sup>c</sup>	4606	617	22.7	3.28
	LSD (0.05)	368	NS	1.1	NS
	Significance level	0.02	0.29	0.02	0.85
	CV (%)	5.0	5.2	3.0	3.5

<sup>a</sup>Treatments 22, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>7.5 cm to side and 5 cm below seed.

<sup>c</sup>5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

Table 40. Effect of P fertilizer placement on grain test weight and grain protein of no-till spring wheat, 1987.<sup>a</sup>

P Placement	Grain test weight			Grain protein		
	Brady	Conrad	Agawam	Brady	Conrad	Agawam
	<-----kg m <sup>-3</sup> ----->			<-----%----->		
With seed	779.5	824.1	790.2	15.5	13.5	13.7
Side <sup>b</sup>	776.7	828.6	798.8	15.2	13.9	14.0
Below <sup>c</sup>	785.1	824.6	790.2	14.8	13.6	13.9
LSD (0.05)	NS	NS	NS	NS	NS	NS
Significance level	0.78	0.57	0.24	0.11	0.38	0.57
CV (%)	2.1	0.8	0.9	2.4	2.5	3.0

<sup>a</sup>Treatments 22, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>7.5 cm to side and 5 cm below seed.

<sup>c</sup>5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

Table 41. Effect of P fertilizer placement on heading date, plant height at heading, and plant height at harvest of no-till spring wheat, 1987.<sup>a</sup>

Site	P placement	Heading date	Plant height at heading <sup>b</sup>	Plant height at harvest <sup>c</sup>
		<i>Days from seeding to spike emergence</i>	<-----cm----->	
<i>Brady</i>	With seed	61.0	32.4	44.8
	Side <sup>d</sup>	61.3	32.7	44.8
	Below <sup>e</sup>	61.5	33.3	46.4
	LSD (0.05)	NS	NS	NS
	Signif. level	0.42	0.42	0.68
	CV (%)	0.8	3.0	6.3
<i>Conrad</i>	With seed	58.8	35.6	63.5
	Side <sup>d</sup>	59.3	34.6	64.1
	Below <sup>e</sup>	58.8	36.5	64.1
	LSD (0.05)	NS	1.1	NS
	Signif. level	0.30	0.02	0.67
	CV (%)	0.8	1.8	1.8
<i>Agawam</i>	With seed	60.8	49.9	80.3
	Side <sup>d</sup>	61.0	50.5	79.7
	Below <sup>e</sup>	60.5	48.6	80.7
	LSD (0.05)	NS	NS	NS
	Signif. level	0.24	0.07	0.77
	CV (%)	0.6	1.9	2.3

<sup>a</sup>Treatments 22, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>Feekes growth state 10.1. Height measured to top ligule.

<sup>c</sup>Feekes growth stage 11.4.

<sup>d</sup>7.5 cm to side and 5 cm below seed.

<sup>e</sup>5 cm below seed.

NS = Not significant at  $P \leq 0.05$ .

Table 42. Main effects of P fertilizer placement and growth stage on dry matter production of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site		
	Brady	Conrad	Agawam
	<-----g m <sup>-2</sup> ----->		
<u>P placement (PPL)</u>			
With seed	352	390	790
Side <sup>b</sup>	361	361	638
Below <sup>c</sup>	325	396	803
LSD (0.05)	NS	NS	107
Significance level	0.33	0.27	0.01
<u>Growth stage (GS)<sup>d</sup></u>			
8-9	183	111	231
10-10.1	353	239	511
11.4	503	797	1490
LSD (0.05)	51	46	107
Significance level	0.00	0.00	0.00
CV (%)	17.5	14.2	17.0
<u>PPL x GS interaction</u>	NS	NS	NS

<sup>a</sup>Treatments 22, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>7.5 cm to side and 5 cm below seed.

<sup>c</sup>5 cm below seed.

<sup>d</sup>Feekes scale.

NS = Not significant at  $P \leq 0.05$ .

Table 43. Main effects of P fertilizer placement and growth stage on tissue N concentration and N uptake of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site					
	Brady		Conrad		Agawam	
	N concentration	N uptake	N concentration	N uptake	N concentration	N uptake
	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>	<i>g kg<sup>-1</sup></i>	<i>kg ha<sup>-1</sup></i>
<i>P placement (PPL)</i>						
With seed	23.1	75.2	28.7	80.8	29.9	169.8
Side <sup>b</sup>	25.8	78.7	28.9	70.4	29.3	136.2
Below <sup>c</sup>	26.0	73.0	28.0	77.6	29.3	165.6
LSD (0.05)	2.6	NS	NS	NS	NS	22.9
Significance level	0.05	0.67	0.72	0.22	0.78	0.01
<i>Growth stage (GS)<sup>d</sup></i>						
8-9	34.8	62.4	42.2	45.2	43.5	100.2
10-10.1	24.4	86.7	28.9	67.7	30.4	156.0
11.4	15.6	77.9	14.6	115.9	14.6	215.3
LSD (0.05)	2.6	13.1	2.3	12.2	1.9	22.9
Significance level	0.00	0.01	0.00	0.00	0.00	0.00
CV (%)	12.3	20.6	9.7	19.0	7.5	17.3
<i>PPL x GS interaction</i>	*	NS	NS	NS	NS	NS

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 22, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>7.5 cm to side and 5 cm below seed.

<sup>c</sup>5 cm below seed.

<sup>d</sup>Feekes scale.

NS = Not significant at  $P \leq 0.05$ .

Table 44. Main effects of P fertilizer placement and growth stage on tissue P concentration and P uptake of no-till spring wheat, 1987.<sup>a</sup>

Treatment	Site					
	Brady		Conrad		Agawam	
	P concen- tration	P uptake	P concen- tration	P uptake	P concen- tration	P uptake
	g kg <sup>-1</sup>	kg ha <sup>-1</sup>	g kg <sup>-1</sup>	kg ha <sup>-1</sup>	g kg <sup>-1</sup>	kg ha <sup>-1</sup>
<i>P placement (PPL)</i>						
With seed	2.4	7.9	2.4	7.3	2.5	15.4
Side <sup>b</sup>	2.4	7.5	2.7	6.9	2.4	11.9
Below <sup>c</sup>	2.5	7.4	2.3	6.5	2.6	18.0
LSD (0.05)	NS	NS	0.2	NS	NS	3.2
Significance level	0.74	0.70	0.02	0.25	0.35	0.01
<i>Growth stage (GS)<sup>d</sup></i>						
8-9	3.1	5.7	3.5	3.9	3.4	7.8
10-10.1	2.3	8.1	2.6	6.2	2.6	13.6
11.4	1.8	9.0	1.3	10.5	1.6	23.9
LSD (0.05)	0.3	1.3	0.2	1.0	0.3	3.2
Significance level	0.00	0.00	0.00	0.00	0.00	0.00
CV (%)	14.1	20.1	10.7	16.8	13.4	24.8
<i>PPL x GS interaction</i>	NS	NS	NS	NS	NS	*

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 22, 23, and 24 used for this analysis (see Table 2).

<sup>b</sup>7.5 cm to side and 5 cm below seed.

<sup>c</sup>5 cm below seed.

<sup>d</sup>Feekes scale.

NS = Not significant at  $P \leq 0.05$ .

P was placed 5 cm below the seed (Table 39). The calculated value of kernels per spike was also significantly increased.

Yield components, grain test weight, and grain protein were not significantly affected by P placement (Tables 39 and 40). Phosphorus placed 5 cm below the seed caused a slight height advantage over the other two placements at heading stage at the Conrad site (Table 41). With this exception, heading date and plant height were not affected by P placement (Table 41).

At Agawam, dry matter production, N uptake, and P uptake were less with P placed 7.5 cm to the side and 5 cm below the seed (side) than with P placed with the seed or 5 cm below the seed (Tables 42-44). There was a similar trend at Conrad for dry matter and N uptake (Tables 42 and 43). When averaged over three growth stages, the differences in dry matter production, N uptake, and P uptake at Brady were not significant (Tables 42-44); however, Tables 19 and 21 contain data showing that harvest dry matter production and N uptake were significantly more with "side" as compared to seed-placed P. The "side" and "below" positions resulted in more N in plant tissue at Brady (Table 43). The "side" position was best in terms of tissue P concentration at Conrad (Table 44). These different responses to P placement across sites resulted in a number of site x P placement interactions (Table 24). Such interactions have also been reported in a study of optimum P placement depth by McConnell et al. (1986).

In summary, there were few responses to P rate or placement, probably due to high P soil test levels (Table 1). Prior to the initiation of these studies, an attempt was made to locate sites with low

soil P levels, but such sites were not found in time for spring planting. The dryland Conrad site showed the only significant grain yield response to P rate, and the irrigated Agawam site showed a yield advantage when P was placed 5 cm below the seed. On these high-P soils, small amounts of P fertilizer may be added to maintain fertility at a high level (Halvorson et al., 1987), but P placement is not an important consideration as long as root-fertilizer contact is good (McConnell et al., 1986; Veseth et al., 1986).

#### Row Configuration x P Placement Interaction

There is no definitive explanation for several row configuration x P placement interactions that were present (Table 24); however, *in situ* observation of rooting patterns showed that although roots generally did proceed downward at a 30 to 45 degree angle, as reported by Klepper et al. (1983), the roots in the "side" treatments of the 15 x 35-cm PR plots intersected at a point below the placed P fertilizer band. This decreased root-fertilizer contact coupled with dry soil conditions may have disadvantaged the "side" treatments, especially during the early growth stages (Tables 19 and 21).

#### Effect of K Fertilizer Rate

The Conrad site showed the only significant grain yield response to K fertilizer (Table 45). As with P, this response to K was not predicted by the soil test used, because the Scobey soil was high in available K (Table 1). All three sites showed earlier heading dates due to K ( $P \leq 0.10$  at Agawam) (Fig. 12 and Table 47). Wheat height at

Table 45. Effect of K fertilizer on grain yield and yield components of no-till spring wheat, 1987.<sup>a</sup>

Site	K Rate	Grain yield	Tiller density	Kernels spike <sup>-1</sup>	Kernel weight
	kg ha <sup>-1</sup>	kg ha <sup>-1</sup>	tillers m <sup>-2</sup>	no.	g 100 seeds <sup>-1</sup>
<u>Brady</u>	0	1198	301	15.6	2.55
	28	1313	290	16.9	2.62
LSD (0.05)		NS	NS	NS	NS
Significance level contrast		0.23	0.57	0.28	0.29
<u>Conrad</u>	0	2280*	341	18.6	3.60
	28	2563	355	20.5	3.54
LSD (0.05)		266	NS	NS	NS
Significance level contrast		0.04	0.51	0.22	0.44
<u>Agawam</u>	0	4034	577	21.5	3.27
	56	3955	611	19.7	3.28
LSD (0.05)		NS	NS	NS	NS
Significance level contrast		0.83	0.24	0.15	0.94

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 14 and 16 used for contrast (see Table 2).

NS = Not significant at  $P \leq 0.05$ .

Table 46. Effect of K fertilizer on grain test weight and grain protein of no-till spring wheat, 1987.<sup>a</sup>

Site	K rate	Grain test weight	Grain protein
	$kg\ ha^{-1}$	$kg\ m^{-3}$	%
<i>Brady</i>	0	769.9	15.6
	28	790.6	15.0
	LSD (0.05)	NS	NS
	Significance level contrast	0.11	0.08
<i>Conrad</i>	0	824.3	13.7
	28	831.0	13.6
	LSD (0.05)	NS	NS
	Significance level contrast	0.55	0.65
<i>Agawam</i>	0	790.0	14.8
	56	788.3	14.8
	LSD (0.05)	NS	NS
	Significance level contrast	0.84	0.99

<sup>a</sup>Treatments 14 and 16 used for contrast (see Table 2).

NS = Not significant at  $P \leq 0.05$ .

Figure 12

## EFFECT OF K FERTILIZER RATE ON HEADING DATE OF SPRING WHEAT, 1987

DAYS FROM SEEDING TO SPIKE EMERGENCE

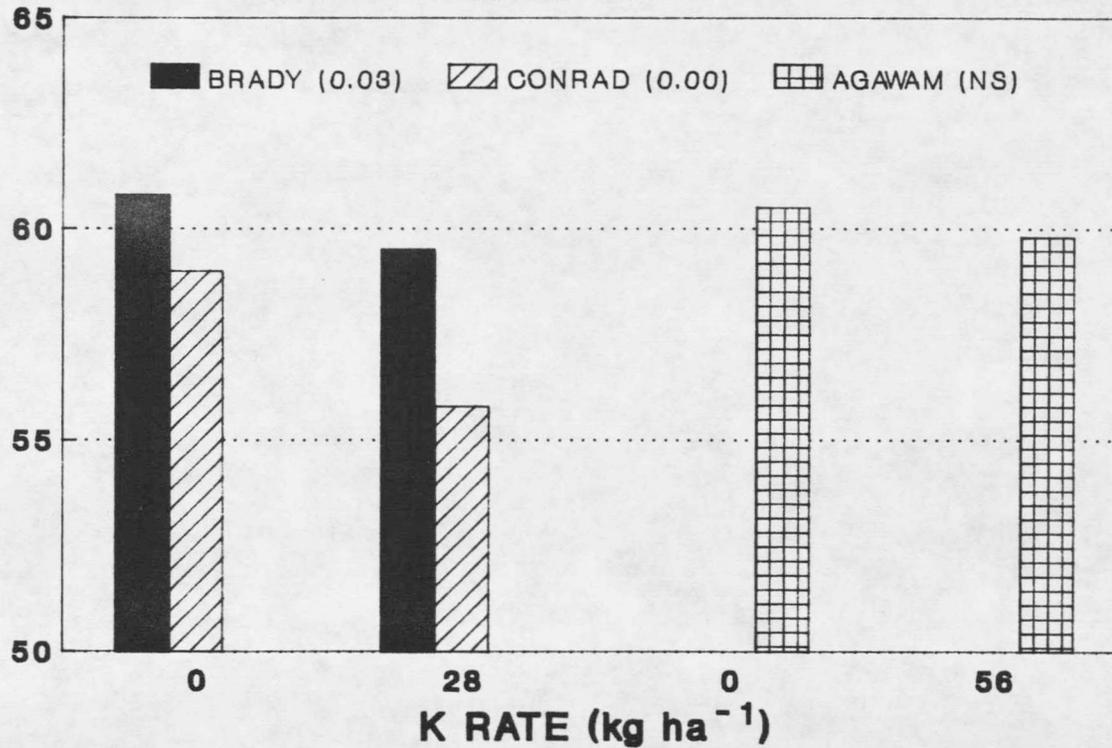


Table 47. Effect of K fertilizer on heading date, plant height at heading, and plant height at harvest of no-till spring wheat, 1987.<sup>a</sup>

Site	K rate	Heading date	Plant height at heading <sup>b</sup>	Plant height at harvest <sup>c</sup>
	kg ha <sup>-1</sup>	Days from seeding to spike emergence	<-----cm----->	
<u>Brady</u>	0	60.8*	33.0*	44.8
	28	59.5	34.6	45.1
	LSD (0.05) Signif. level contrast	0.8 0.03	1.6 0.05	NS 0.75
<u>Conrad</u>	0	59.0**	36.2	63.5
	28	55.8	35.9	63.2
	LSD (0.05) Signif. level contrast	0.9 0.00	NS 0.67	NS 0.77
<u>Agawam</u>	0	60.5	49.5	78.4
	56	59.8	49.5	78.1
	LSD (0.05) Signif. level contrast	NS 0.10	NS 1.0	NS 0.86

\*,\*\*Significant at 0.05 and 0.01 probability levels, respectively.

<sup>a</sup>Treatments 14 and 16 used for contrast (see Table 2).

<sup>b</sup>Feekes growth stage 10.1. Height measured to top ligule.

<sup>c</sup>Feekes growth stage 11.4

NS = Not significant at  $P \leq 0.05$ .

heading was increased by K at Brady (Table 47). Dry conditions during the early growing season at Brady and Conrad probably limited the diffusion of K to the roots (Barber, 1985; Schaff and Skogley, 1982; Skogley and Schaff, 1985), and resulted in these responses to K, despite high soil test K levels. Field observations indicated that earlier heading dates also resulted in earlier maturity in the treatments receiving K.

Tissue K concentration and K uptake, though generally increased by K, were not significantly affected by K fertilizer at any of the sites (Table 48). Tissue N concentration was significantly decreased by K at both Brady and Conrad (Table 49). This was probably an N-K interaction. Nitrogen-potassium interactions have been extensively reviewed by Murphy (1980). Whether the above decrease in total N was the result of a simple N-K interaction or a result of multiple interactions is difficult to determine. Other studies have shown that N source is a major determinant of N-K interactions in plants (Dibb and Thompson, 1985).

Table 48. Mean effect of K fertilizer averaged over three growth stages (GS) on tissue K concentration, K uptake, and dry matter production of no-till spring wheat, 1987.<sup>a,b</sup>

Site	K rate	K concentration	K uptake	Dry matter production
	$kg\ ha^{-1}$	$g\ kg^{-1}$	$kg\ ha^{-1}$	$g\ m^{-2}$
<i>Brady</i>	0	28.2	78.1	339
	28	27.4	86.1	375
LSD (0.05)		NS	NS	NS
Signif. level contrast		0.52	0.34	0.19
<i>Conrad</i>	0	27.9	55.4	348
	28	26.9	62.5	377
LSD (0.05)		NS	NS	NS
Signif. level contrast		0.28	0.12	0.21
<i>Agawam</i>	0	28.3	144.6	670
	56	32.1	157.4	693
LSD (0.05)		NS	NS	NS
Signif. level contrast		0.25	0.43	0.63

<sup>a</sup>Treatments 14 and 16 used for contrast (see Table 2).

<sup>b</sup>No significant K rate x GS interactions at any of the sites.

NS = Not significant at  $P \leq 0.05$ .

Table 49. Mean effect of K fertilizer averaged over three growth stages (GS) on tissue N and P concentration and N and P uptake of no-till spring wheat, 1987.<sup>a,b</sup>

Site	K rate	N concentration	N uptake	P concentration	P uptake
	kg ha <sup>-1</sup>	g kg <sup>-1</sup>	kg ha <sup>-1</sup>	g kg <sup>-1</sup>	kg ha <sup>-1</sup>
<i>Brady</i>	0	24.8*	74.9	2.6	8.1
	28	21.7	73.0	2.5	8.6
	LSD (0.05)	2.9	NS	NS	NS
	Signif. level contrast	0.04	0.78	0.84	0.47
<i>Conrad</i>	0	30.4*	75.8	2.7	7.2
	28	28.4	79.3	2.7	7.9
	LSD (0.05)	1.9	NS	NS	NS
	Signif. level contrast	0.04	0.48	0.66	0.30
<i>Agawam</i>	0	29.0	150.3	2.5	13.3
	56	29.8	159.8	2.7	15.5
	LSD (0.05)	NS	NS	NS	NS
	Signif. level contrast	0.48	0.41	0.16	0.20

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 14 and 16 used for contrast (see Table 2).

<sup>b</sup>No significant K rate x GS interactions at any of the sites.

NS = Not significant at  $P \leq 0.05$ .

## CHAPTER 5

## SUMMARY AND CONCLUSIONS

The primary objective of this study was to determine the effect of paired rows (PR) on growth and yield of spring wheat in a no-till system. Previous work with wheat has often revealed no significant yield differences between PR and ER planting systems.

These experiments were conducted at two dryland sites and one irrigated site. Grain yields were mainly a function of growing season precipitation, with the irrigated Agawam site producing the highest yields. Grain yields were significantly reduced in the 15 x 35-cm PR at both dryland sites; yields at Agawam were similar across all three row configurations. The 20 x 30-cm PR and 25-cm ER configurations responded similarly in terms of grain yield and yield components at all three sites. Kernels per spike and tiller density were the yield components responsible for yield decreases at Brady and Conrad.

Tissue samples taken at three growth stages showed that although early growth differences due to row configuration were slight, the 25-cm ER showed an increasing growth advantage with time compared to the 15 x 35-cm PR. In the combined ANOVA across sites, there was a significant row configuration x growth stage interaction for dry matter production.

There are several possible explanations for these responses. At Brady and Conrad where dry conditions prevailed during the early growing

season, increased plant competition for limited water could have reduced tillering in the 15 x 35-cm PR. The 15 x 35-cm PR never did form a continuous crop canopy; this may have reduced water use efficiency compared to the 25-cm ER. Effects of plant shading were visually observed at Agawam. The row designated south in the 15 x 35-cm PR plots yielded more than the north row, resulting in a significant row configuration x row position interaction, probably due to shading.

Results of this study provide more evidence that under no-till conditions there is no advantage to planting spring wheat in PR. Where the 15 x 35-cm PR affected growth or yield, it was in a negative manner. Interestingly, however, the 20 x 30-cm PR yielded nearly as well or better than the 25-cm ER.

This study has confirmed and quantified the observation of other researchers that PR often produce vigorous early plant growth compared to ER. This phenomenon needs to be further researched. When the exact causes are identified, it may be possible to utilize PR advantageously by precisely matching row configuration and fertilizer placement with crop water use patterns. Paired-row or twin-row configurations have shown promise with other crops. Research should be directed toward the crops/cropping systems most likely to respond to PR. Albers (1987) has noted that early-maturing cultivars of soybeans were more responsive to twin rows than later-maturing cultivars. This may be true for other crops as well.

The effects of row configuration on irrigated wheat (and other small grains) should be further researched. Results of this one-year study suggest that while the extra water from irrigation may overcome the

adverse effects of early plant competition in the PR, shading in the PR can be detrimental, especially as seeding rates are increased. Under irrigation there is also the concern that plants in PR may not fully exploit water and nutrients in the zone between each set of rows.

Secondary objectives of this study were to determine optimum N, P, and K rates for spring wheat in a PR planting system, and to determine optimum placement of P fertilizer. Nitrogen significantly increased grain protein at all sites. Grain yields were significantly increased at Brady and Conrad, but not at Agawam, probably due to high residual soil  $\text{NO}_3^-$ -N levels. Considering both yield and protein, an N rate of 40 kg N  $\text{Mg}^{-1}$  grain was optimum. This quantity of N (soil + fertilizer) is commonly recommended for wheat in the northern Great Plains; results of this study indicate that it is applicable to PR as well as ER planting systems for no-till spring wheat.

All three sites were high in P and K. Positive responses to P or K fertilizer were evidenced for only a few of the parameters. Yields at Conrad showed a positive response to both P and K fertilizer. At Agawam, there was a yield advantage when P was placed 5 cm below the seed. Seed-placed P generally produced more dry matter and resulted in more N uptake than the other P placements at the first two sampled growth stages, but these differences largely disappeared by harvest. On these high-P soils, small amounts of P fertilizer may be added to maintain fertility at a high level, but P placement is not an important consideration as long as root-fertilizer contact is good. Despite high soil K levels, K additions resulted in earlier heading dates at two of three sites. This again

underscores the need for an improved K soil test that will more accurately correlate soil test levels with crop response.

Since nearly all of the N, P, and K fertilizer rates were within the 15 x 35-cm PR main plot, it was not possible to determine if row configuration x fertilizer rate interactions existed. Future research may reveal an optimum row configuration-fertilizer placement combination for PR planting systems, but little information is available to suggest that row configuration has any significant influence on fertilizer requirement.

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## LITERATURE CITED

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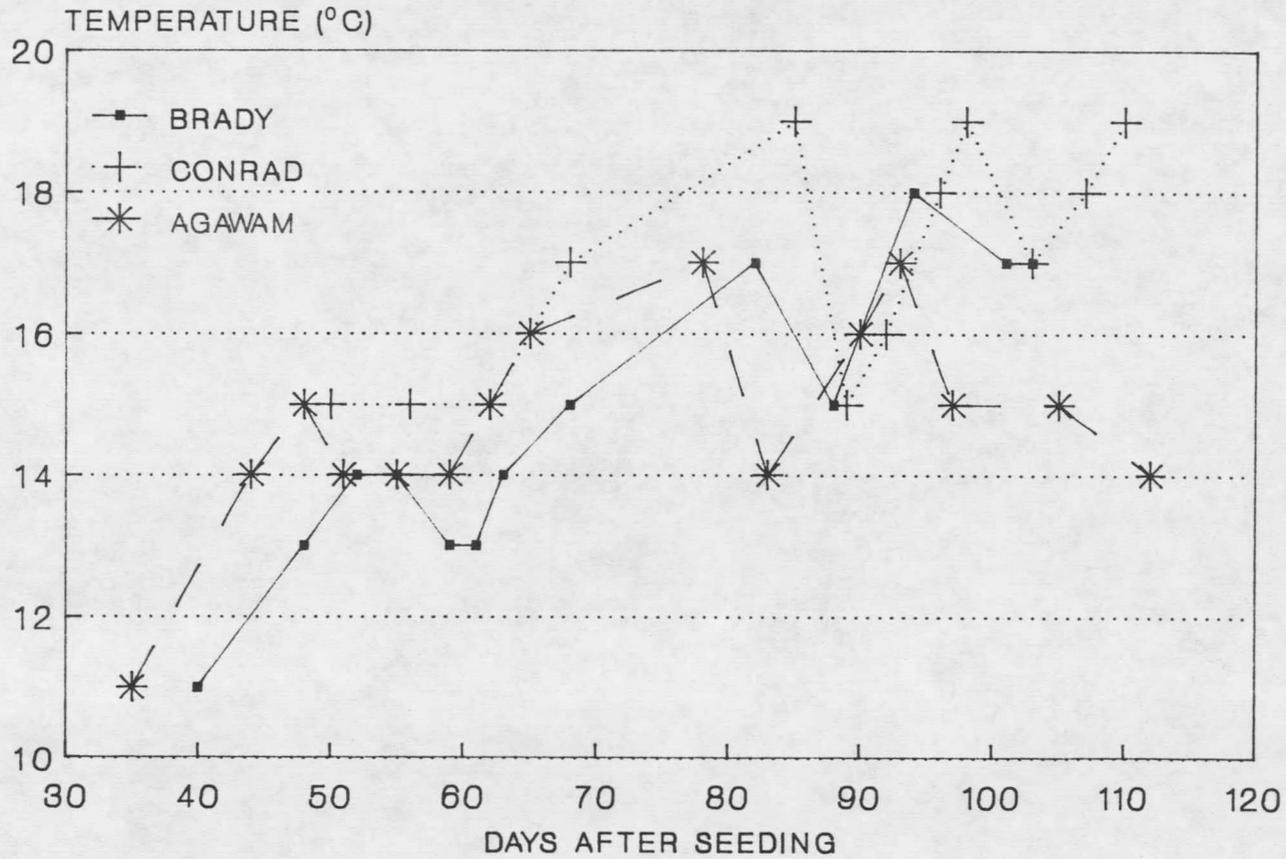
APPENDICES

APPENDIX A

FIGURE 13

Figure 13

**SOIL TEMPERATURES AT BRADY, CONRAD, AND  
AGAWAM SITES, 1987 (50 cm depth)**



APPENDIX B

TABLE 50

Table 50. Analysis of variance over all sites for effects of row configuration (RC) and P fertilizer placement (PPL) on grain yield, yield components, grain test weight, protein, heading date, and plant height of no-till spring wheat, 1987.<sup>a</sup>

Source	df	Grain yield	Tiller density	Kernels spike <sup>-1</sup>	Kernel weight	Grain test weight	Grain protein	Heading date	Heading height	Harvest height
<-----significance level----->										
Site	2	**	**	**	**	**	**	**	**	**
Error (a)	9									
RC	1	**	0.07	0.08	NS	NS	0.10	NS	NS	NS
RC x Site	2	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error (b)	9									
PPL	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
PPL x Site	2	NS	NS	NS	NS	0.09	NS	NS	NS	NS
RC x PPL	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
RC x PPL x Site	2	NS	NS	NS	NS	NS	NS	NS	*	NS
Residual	18									
Total	47									

\*,\*\*Significant at 0.05 and 0.01 probability levels, respectively.  
<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).  
 NS = Not significant at P ≤ 0.10.

APPENDIX C

TABLE 51

Table 51. Treatment means for treatments 17, 21, 25, and 26 of no-till spring wheat experiments, 1987 (see Table 2).

Treatment no.	Site			Mean of all sites
	Brady	Conrad	Agawam	
<i>Grain yield (kg ha<sup>-1</sup>)</i>				
17	1256	2614	4101	2657
21	1460	2490	4047	2666
25	1580	2593	4686	2953
26	1592	2817	4423	2944
<i>Tillers m<sup>-2</sup></i>				
17	291	362	623	425
21	286	356	564	402
25	278	376	591	415
26	275	353	596	408
<i>Kernels spike<sup>-1</sup></i>				
17	17.9	20.5	19.8	19.4
21	18.7	20.8	22.8	20.8
25	20.8	19.1	23.3	21.1
26	21.8	23.0	23.5	22.8
<i>Kernel weight (g 100 seeds<sup>-1</sup>)</i>				
17	2.40	3.56	3.31	3.09
21	2.70	3.44	3.13	3.09
25	2.73	3.60	3.40	3.24
26	2.66	3.51	3.18	3.12
<i>Grain test weight (kg m<sup>-3</sup>)</i>				
17	786.4	826.3	786.4	799.7
21	774.8	820.2	776.1	790.4
25	770.9	821.1	782.5	791.5
26	767.1	823.7	777.4	789.4
<i>Grain protein (%)</i>				
17	16.8	14.3	14.8	15.3
21	15.1	14.2	14.2	14.5
25	15.1	13.5	13.6	14.1
26	15.2	13.5	14.1	14.3

Table 51--Continued.

Treatment no.	Site			Mean of all sites
	Brady	Conrad	Agawam	
<i>Heading date (days from seeding to spike emergence)</i>				
17	59.0	55.8	60.0	58.3
21	61.8	58.7	61.1	60.5
25	62.0	59.1	60.5	60.5
26	61.8	59.5	61.0	60.8
<i>Plant height to top ligule at heading (cm)</i>				
17	33.7	35.9	49.9	39.8
21	33.7	34.3	49.9	39.3
25	32.7	35.6	48.9	39.1
26	33.3	34.3	50.0	39.2
<i>Plant height at harvest (cm)</i>				
17	43.8	61.3	80.0	61.7
21	47.6	63.5	76.7	62.6
25	46.4	62.7	80.3	63.1
26	46.7	63.2	79.9	63.3
<i>Dry matter production (g m<sup>-2</sup>) (average of three sampling dates)</i>				
17	398	379	716	498
<i>Tissue N concentration (g kg<sup>-1</sup>) (average of three sampling dates)</i>				
17	25.4	28.0	30.5	28.0
<i>N uptake (kg ha<sup>-1</sup>) (average of three sampling dates)</i>				
17	90.6	76.6	65.7	77.6
<i>Tissue P concentration (g kg<sup>-1</sup>) (average of three sampling dates)</i>				
17	2.5	2.5	2.6	2.5

Table 51--Continued.

Treatment no.	Site			Mean of all sites
	Brady	Conrad	Agawam	
	<i>P uptake (kg ha<sup>-1</sup>) (average of three sampling dates)</i>			
17	9.2	7.3	14.0	10.2
	<i>Tissue K concentration (g kg<sup>-1</sup>) (average of three sampling dates)</i>			
17	28.5	27.5	33.2	29.7
	<i>K uptake (kg ha<sup>-1</sup>) (average of three sampling dates)</i>			
17	99.2	65.5	165.6	110.1

APPENDIX D

TABLES 52-56

Table 52. Analysis of variance over two row configurations (RC) for effects of P fertilizer placement (PPL) and row position (POS) on grain yield, yield components, and grain test weight of no-till spring wheat at Agawam site, 1987.<sup>a</sup>

Source	df	Grain yield	Tiller density	Kernels spike <sup>-1</sup>	Kernel weight	Grain test weight
←-----significance level-----→						
RC	1	NS	NS	NS	NS	NS
Error (a)	3					
PPL	1	NS	NS	NS	NS	NS
RC x PPL	1	NS	NS	NS	NS	NS
Error (b)	6					
POS	1	NS	NS	NS	NS	*
RC x POS	1	*	NS	NS	NS	NS
PPL x POS	1	*	NS	**	NS	NS
RC x PPL x POS	1	NS	NS	NS	NS	NS
Residual	15					
Total	31					

\*,\*\*Significant at 0.05 and 0.01 probability levels, respectively.  
<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).  
 NS = Not significant at  $P \leq 0.05$ .

Table 53. Main effect of row position at two row configurations on grain yield, yield components, and grain test weight of no-till spring wheat at Brady site, 1987.\*

Configuration	Row position	Grain yield	Tiller density	Kernels per spike	Kernel weight	Grain test weight
		<i>kg ha<sup>-1</sup></i>	<i>tillers m<sup>-2</sup></i>	<i>no.</i>	<i>g 100 seeds<sup>-1</sup></i>	<i>kg m<sup>-3</sup></i>
15 x 35-cm PR <sup>a</sup>	North	1302	292	17.4	2.59	782.9
	South	1234	294	16.6	2.54	776.4
Significance level		NS	NS	NS	NS <sup>b</sup>	NS
25-cm ER <sup>c</sup>	North	1482	304	19.0	2.57	774.0
	South	1492	310	19.3	2.55	776.2
Significance level		NS	NS	NS	NS	NS

\*Means averaged over two P placements.

<sup>a</sup>Paired row. Treatments 4 and 14 used for this analysis (see Table 2).

<sup>b</sup>P placement x row position interaction significant at  $P \leq 0.02$ .

<sup>c</sup>Equidistant row. Treatments 23 and 24 used for this analysis (see Table 2).

NS = Not significant at  $P \leq 0.05$ .

Table 54. Analysis of variance over two row configurations (RC) for effects of P fertilizer placement (PPL) and row position (POS) on grain yield, yield components, and grain test weight of no-till spring wheat at Brady site, 1987.<sup>a</sup>

Source	df	Grain yield	Tiller density	Kernels spike <sup>-1</sup>	Kernel weight	Grain test weight
←-----significance level-----→						
RC	1	NS	NS	NS	NS	NS
Error (a)	3					
PPL	1	NS	NS	NS	NS	NS
RC x PPL	1	*	NS	NS	NS	NS
Error (b)	6					
POS	1	NS	NS	NS	NS	NS
RC x POS	1	NS	NS	NS	NS	NS
PPL x POS	1	*	NS	NS	*	NS
RC x PPL x POS	1	NS	NS	NS	NS	NS
Residual	15					
Total	31					

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

NS = Not significant at  $P \leq 0.05$ .

Table 55. Main effect of row position at two row configurations on grain yield, yield components, and grain test weight of no-till spring wheat at Conrad site, 1987.\*

Configuration	Row position	Grain yield	Tiller density	Kernels per spike	Kernel weight	Grain test weight
		<i>kg ha<sup>-1</sup></i>	<i>tillers m<sup>-2</sup></i>	<i>no.</i>	<i>g 100 seeds<sup>-1</sup></i>	<i>kg m<sup>-3</sup></i>
15 x 35-cm PR <sup>a</sup>	North	2273	340	18.6	3.65	822.6
	South	2411	340	19.8	3.59	825.3
Significance level		NS	NS	NS	NS	NS
25-cm ER <sup>b</sup>	North	2763	367	20.7	3.64	827.3
	South	2824	355	21.3	3.74	829.0
Significance level		NS	NS	NS	NS	NS

\*Means averaged over two P placements.

<sup>a</sup>Paired row. Treatments 4 and 14 used for this analysis (see Table 2).

<sup>b</sup>Equidistant row. Treatments 23 and 24 used for this analysis (see Table 2).

NS = Not significant at  $P \leq 0.05$ .

Table 56. Analysis of variance over two row configurations (RC) for effects of P fertilizer placement (PPL) and row position (POS) on grain yield, yield components, and grain test weight of no-till spring wheat at Conrad site, 1987.<sup>a</sup>

Source	df	Grain yield	Tiller density	Kernels spike <sup>-1</sup>	Kernel weight	Grain test weight
<-----significance level----->						
RC	1	*	NS	NS	*	NS
Error (a)	3					
PPL	1	NS	NS	NS	NS	NS
RC x PPL	1	NS	NS	NS	NS	NS
Error (b)	6					
POS	1	NS	NS	NS	NS	NS
RC x POS	1	NS	NS	NS	*	NS
PPL x POS	1	NS	NS	*	NS	NS
RC x PPL x POS	1	NS	NS	NS	NS	NS
Residual	15					
Total	31					

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4, 14, 23, and 24 used for this analysis (see Table 2).

NS = Not significant at  $P \leq 0.05$ .

APPENDIX E

TABLES 57-61

Table 57. Effect of N and P fertilizer rate on grain yield and tiller density of no-till spring wheat, 1987.<sup>a</sup>

N rate <sup>b</sup>	P rate	Grain yield			Tiller density			
		<-----Site----->			<-----Site----->			
		Brady	Conrad	Agawam	Brady	Conrad	Agawam	
	kg ha <sup>-1</sup>	<-----kg ha <sup>-1</sup> ----->			<-----tillers m <sup>-2</sup> ----->			
0 <sup>c</sup>	0	1046	1843	3612	240	225	457	
L	5	1408	2581	4458	273	378	578	
	7	1429	2627	4570	290	357	561	
	9	1423	2699	4116	299	340	577	
M	5	1266	2746	4100	287	359	545	
	7	1339	2403	3968	284	339	562	
	9	1379	2603	4159	299	341	585	
H	5	1349	2792	3898	286	367	592	
	7	1392	2529	4249	291	351	592	
	9	1276	2682	3959	285	395	586	
<u>N rate means</u>		L	1420	2636	4381	287	358	572
		M	1328	2584	4075	290	347	564
		H	1339	2668	4035	288	371	590
LSD (0.05)			NS	NS	NS	NS	NS	NS
Signif. level			0.12	0.55	0.22	0.90	0.10	0.12
<u>P rate means</u>		5	1341	2706	4152	282	368	572
		7	1387	2520	4263	288	349	572
		9	1359	2661	4078	294	359	583
LSD (0.05)			NS	NS	NS	NS	NS	NS
Signif. level			0.62	0.06	0.69	0.31	0.25	0.61
CV (%)			8.4	7.0	12.4	6.5	7.5	5.4
<u>N rate x P rate interaction</u>			NS	NS	NS	NS	NS	NS

<sup>a</sup>Treatments 4-12 used for this analysis (see Table 2).

<sup>b</sup>0, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

<sup>c</sup>Treatment 1 not included in statistical analysis.

NS = Not significant at  $P \leq 0.05$ .

Table 58. Effect of N and P fertilizer rate on kernels per spike and kernel weight of no-till spring wheat, 1987.<sup>a</sup>

N rate <sup>b</sup>	P rate	Kernels spike <sup>-1</sup>			Kernel weight		
		<-----Site----->			<-----Site----->		
		Brady	Conrad	Agawam	Brady	Conrad	Agawam
	kg ha <sup>-1</sup>	<-----no.----->			<-----g 100 seeds <sup>-1</sup> ----->		
O <sup>c</sup>	0	12.9	19.9	20.9	3.42	4.13	3.81
L	5	18.8	18.5	21.7	2.73	3.68	3.54
	7	18.1	20.9	23.4	2.71	3.53	3.48
	9	17.5	22.1	21.3	2.73	3.58	3.33
M	5	17.2	21.6	22.8	2.55	3.56	3.29
	7	18.1	19.7	21.8	2.59	3.65	3.19
	9	17.8	21.8	21.0	2.56	3.53	3.38
H	5	18.6	22.0	20.5	2.51	3.53	3.22
	7	19.1	21.0	21.6	2.49	3.44	3.31
	9	18.7	20.4	21.4	2.39	3.34	3.14
<u>N rate means</u>							
	L	18.1	20.5	22.1	2.72	3.59	3.45
	M	17.7	21.0	21.9	2.57	3.58	3.28
	H	18.8	21.1	21.2	2.46	3.44	3.22
LSD (0.05)		NS	NS	NS	0.07	0.10	0.14
Signif. level		0.29	0.78	0.33	0.00	0.00	0.01
<u>P rate means</u>							
	5	18.2	20.7	21.6	2.60	3.59	3.35
	7	18.5	20.5	22.3	2.60	3.54	3.32
	9	18.0	21.4	21.3	2.56	3.48	3.28
LSD (0.05)		NS	NS	NS	NS	NS	NS
Signif. level		0.80	0.56	0.31	0.51	0.08	0.64
CV (%)		9.2	10.4	7.4	3.4	3.2	5.1
<u>N rate x P rate interaction</u>		NS	NS	NS	NS	NS	NS

<sup>a</sup>Treatments 4-12 used for this analysis (see Table 2).

<sup>b</sup>0, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

<sup>c</sup>Treatment 1 not included in statistical analysis.

NS = Not significant at  $P \leq 0.05$ .

Table 59. Effect of N and P fertilizer rate on grain test weight and grain protein of no-till spring wheat, 1987.<sup>a</sup>

N rate <sup>b</sup>	P rate	Grain test weight			Grain protein		
		<-----Site----->			<-----Site----->		
		Brady	Conrad	Agawam	Brady	Conrad	Agawam
	kg ha <sup>-1</sup>	<-----kg m <sup>-3</sup> ----->			<-----%----->		
O <sup>c</sup>	0	792.8	849.4	817.2	9.6	11.7	11.3
L	5	797.3	820.5	804.8	14.4	13.2	13.3
	7	793.7	819.4	795.1	14.8	12.8	13.6
	9	813.6	828.8	785.7	14.3	12.9	14.8
M	5	792.4	833.3	778.9	15.7	13.4	14.8
	7	790.2	824.1	779.9	15.4	13.7	14.9
	9	787.9	819.4	793.2	15.7	13.4	14.5
H	5	757.4	822.4	774.8	16.8	13.7	15.1
	7	761.5	809.9	783.8	16.7	14.4	15.1
	9	774.1	826.3	778.6	16.8	14.2	15.4
<u>N rate means</u>							
	L	801.5	822.9	795.1	14.5	12.9	13.9
	M	790.2	825.6	784.0	15.6	13.5	14.7
	H	764.3	819.4	779.0	16.8	14.1	15.2
	LSD (0.05)	12.5	NS	9.0	0.4	0.4	0.7
	Signif. level	0.00	0.67	0.00	0.00	0.00	0.00
<u>P rate means</u>							
	5	782.4	825.4	786.1	15.6	13.4	14.4
	7	781.9	817.8	786.2	15.6	13.6	14.5
	9	791.9	824.8	785.8	15.6	13.5	14.9
	LSD (0.05)	NS	NS	NS	NS	NS	NS
	Signif. level	0.19	0.47	0.99	0.95	0.60	0.30
	CV (%)	1.9	2.0	1.4	3.1	3.6	5.4
<u>N rate x P rate interaction</u>		NS	NS	*	NS	NS	NS

\*Significant at  $P \leq 0.05$ .

<sup>a</sup>Treatments 4-12 used for this analysis (see Table 2).

<sup>b</sup>0, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

<sup>c</sup>Treatment 1 not included in statistical analysis.

NS = Not significant at  $P \leq 0.05$ .

Table 60. Effect of N and P fertilizer rate on heading date of no-till spring wheat, 1987.<sup>a</sup>

N rate <sup>b</sup>	P rate kg ha <sup>-1</sup>	Heading date		
		-----Site----->		
		Brady	Conrad	Agawam
		-----Days from seeding to spike emergence----->		
O <sup>c</sup>	0	61.5	60.8	60.3
L	5	61.0	59.8	60.8
	7	60.8	60.0	61.0
	9	60.5	59.5	60.8
M	5	61.0	59.3	60.3
	7	61.0	59.5	60.8
	9	60.8	59.3	60.5
H	5	61.3	59.0	60.5
	7	61.0	59.5	60.8
	9	61.3	59.0	61.0
<u>N rate means</u>	L	60.8	59.8	60.8
	M	60.9	59.3	60.5
	H	61.2	59.2	60.8
LSD (0.05)		NS	NS	NS
Signif. level		0.10	0.13	0.45
<u>P rate means</u>	5	61.1	59.3	60.5
	7	60.9	59.7	60.8
	9	60.8	59.3	60.8
LSD (0.05)		NS	NS	NS
Signif. level		0.41	0.32	0.45
CV (%)		0.7	1.2	1.1
<u>N rate x P rate interaction</u>		NS	NS	NS

<sup>a</sup>Treatments 4-12 used for this analysis (see Table 2).

<sup>b</sup>O, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

<sup>c</sup>Treatment 1 not included in statistical analysis.

NS = Not significant at P ≤ 0.05.

Table 61. Effect of N and P fertilizer rate on plant height at heading and plant height at harvest of no-till spring wheat, 1987.<sup>a</sup>

N rate <sup>b</sup>	P rate	Plant height at heading <sup>c</sup>			Plant height at harvest <sup>d</sup>		
		<-----Site----->			<-----Site----->		
		Brady	Conrad	Agawam	Brady	Conrad	Agawam
	kg ha <sup>-1</sup>	<-----cm----->					
0 <sup>e</sup>	0	29.2	32.7	43.8	46.0	60.0	76.5
L	5	34.0	34.0	49.5	47.0	63.2	81.3
	7	34.0	35.2	49.9	46.4	64.8	81.6
	9	33.3	35.9	50.5	47.0	63.5	78.4
M	5	33.0	35.9	49.9	45.1	63.2	77.8
	7	34.3	35.2	50.8	46.0	63.5	80.0
	9	32.4	35.6	48.9	45.4	64.1	77.8
H	5	33.7	35.2	51.8	45.4	64.1	78.7
	7	33.7	36.2	50.2	45.1	63.5	78.1
	9	34.3	35.9	49.9	43.5	63.8	79.7
<u>N rate means</u>							
	L	33.8	35.0	50.0	46.8	63.8	80.4
	M	33.2	35.6	49.9	45.5	63.6	78.5
	H	33.9	35.8	50.6	44.7	63.8	78.9
LSD (0.05)		NS	NS	NS	1.3	NS	NS
Signif. level		0.22	0.27	0.40	0.01	0.88	0.23
<u>P rate means</u>							
	5	33.6	35.0	50.4	45.8	63.5	79.3
	7	34.0	35.6	50.3	45.8	63.9	79.9
	9	33.3	35.8	49.7	45.3	63.8	78.6
LSD (0.05)		NS	NS	NS	NS	NS	NS
Signif. level		0.26	0.27	0.51	0.62	0.66	0.56
CV (%)		2.8	3.2	2.8	3.3	1.8	3.6
<u>N rate x P rate interaction</u>		NS	NS	NS	NS	NS	NS

<sup>a</sup>Treatments 4-12 used for this analysis (see Table 2).

<sup>b</sup>0, L, M, H = 0, 64, 86, and 109 kg N ha<sup>-1</sup>, respectively, at the Brady and Conrad sites; 0, 77, 104, and 131 kg N ha<sup>-1</sup>, respectively, at the Agawam site.

<sup>c</sup>Feekes growth stage 10.1. Height measured to top ligule.

<sup>d</sup>Feekes growth stage 11.4.

<sup>e</sup>Treatment 1 not included in statistical analysis.

NS = Not significant at P ≤ 0.05.

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