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Yield Components of Spring Oats as Affected by Seeding Rate and Fertility Level

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YIELD COMPONENTS OF SPRING OATS AS AFFECTED BY SEEDING RATE AND FERTILITY LEVEL

BY

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SEEDING RATE AND FERTILITY LEVEL

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head, Agronomy Department Date

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INTRODUCTION

Experiments with oats have shown approximately equal yields from a wide range of seeding rates. Also, oats usually respond to an adequate supply of plant food elements.

Yield is a product. As Grafius (12) pointed out, the yield of oats may be represented geometrically as the volume of a rectangular parallelepiped with edges X_1= number of panicles per unit area, X_2= average number of seeds per panicle, and X_3= average weight per seed. Multiplied together $X_1X_2X_3$ equals Y, yield. All changes in the yield components need not be expressed as changes in yield, but all changes in yield must be accompanied by changes in one or more of the components. Therefore, if a single variety seeded at several different rates exhibits approximately equal yields, the yield constancy may be due to changes in one or more of the components. Yield response to different fertility levels must also be related to changes in one or more of the components.

The objectives of this study were to:

1. Investigate the effects of seeding rate and fertility level on yield and yield components.
2. Determine the relative importance of the yield components in influencing yield.
3. Determine the response of certain other agronomic characteristics, namely, heading date, lodging, maturity date, plant height, seedlings per unit area, test weight, and panicles per plant, to seeding rate and fertility level.

4. Evaluate the relationships among yield, yield components and other agronomic characteristics.

REVIEW OF LITERATURE

Effect of Seeding Rate on Yield and Yield Components

Approximately equal yields have been reported from experiments using a wide range of seeding rates. Kiesselbach and Lyness (15) in Nebraska seeded Kherson oats at 4 to 16 pecks per acre at 2-peck increments for 13 years. Yield from rates of 6 to 12 pecks per acre were essentially equal, with only a slight reduction at the 14- and 16-peck rates.

Thurman (28) in Arkansas reported the yield of grain from seeding rates of 6, 12, 16 and 20 pecks per acre did not differ significantly.

Kiesselbach and Ratcliff (16) seeded oats at 4, 8, 10, 12, 14 and 16 pecks per acre during a 4-year period and obtained maximum yields from the 16-peck rate. Grain yields from the 10 to 16 peck rate were not significantly different, suggesting that there is a rather wide range in the acceptable rate of planting.

Mississippi workers (21) used seeding rates of 6, 8, 9, 10, 11, 12 and 14 pecks per acre at the Delta Experiment Station for ten years. Average yields for the ten-year period were similar for all rates.

Dungan and Burlison (6) studied seeding rates from 4 to 18 pecks in Illinois at 1-peck increments and found no significant difference from the rates of 7 to 17 pecks.

Thatcher _et al._ (26) in Ohio found the average yield of oats from seeding rates of 6, 8, 10 and 12 pecks per acre were not significantly different.

Woodward (31) reported oats sown at rates of 30, 60, 90 and 120 pounds per acre gave only minor differences in yields.

Thayer and Rather (27) indicated that increases in seeding rate were offset by decreases in tillering, seed weight, and number of seeds per panicle in barley. They also noted an increase in lodging at the higher seeding rates.

Yield components of oats have been found to be influenced by row spacing (7), date of seeding (9), nitrogen level (10), location (11), and variety (9, 10, 11).

Effect of Fertility Level on Yield and Yield Components

Brown _et al._ (2) and Lamb and Salter (18) reported that oat varieties responded differently to fertility levels.

Some workers (18, 23, 24) have reported non-significant interactions between variety and fertility level for yield. Other reports (2, 17, 32) have shown significant interaction between these two factors.

Lamb and Salter (18) reported that neither varieties nor fertility levels were as important as season in determining oat yields.

Frey (10) reported that grain yield of oats was increased by increased nitrogen fertilization. Increases in yield were due primarily to an increase in number of panicles per plant and number of seeds per panicle, while weight per seed contributed little.

Pendleton and Dungan (22) found that addition of nitrogen to winter wheat increased grain yield and tillers per plant but decreased kernel weight.

Brown et al. (2) reported an increase in tillers per foot of row from the application of fertilizer to oats.

Effect of Seeding Rate and Fertility Level on Other Plant Characteristics

Woodward (31) found that lighter seeding rates produced stiffer straw, larger heads and kernels, and higher test weight than heavier rates in small grains.

Pendleton and Dungan (22) studied the effect of six seeding rates, from 3 to 18 pecks with 3-peck increments, and four nitrogen levels, 0, 30, 60 and 90 pounds of elemental nitrogen on four wheat varieties. They found varieties responded differently to both seeding rate and to nitrogen application. Increases in seeding rate decreased plant height, test weight, seed weight and number of panicles per plant, but hastened heading date. Nitrogen application increased plant height and number of panicles per plant but decreased test weight and seed weight and delayed heading date.

Brown et al. (2) found that increased fertilization hastened heading date by two days, gave taller plants and longer panicles in oats. Weight per bushel was increased by a medium application of fertilizer but was decreased at the high fertility level.

MATERIALS AND METHODS

Varieties Used

Following is a brief description of the six varieties of spring oats grown in each study:

1. Andrew: early, medium height.
2. Garland: medium early, medium short.
3. Lodi: late, tall.
4. Mo. 0-205: medium early, medium tall.
5. Rodney: late, tall.
6. Tippecanoe: early, short.

These varieties were selected to give a representation of the variation found in oat varieties grown in the North Central Region of the United States in regard to maturity, height, and other plant characteristics of interest in the study.

Experimental Procedures

The study consisted of two experiments, each conducted at four locations - Brookings, Davis, Garden City and Ipswich, South Dakota in 1965. Data on some characteristics were not available from the Ipswich location since the nursery was lost prior to completion of harvest.

Seeding rates of 4, 8, 12 and 16 pecks per acre were used as variables in the seeding rate experiment. The experimental design was a randomized complete block with four replications. Plot size was 14 feet long and four feet wide with rows one foot apart. A uniform application of fertilizer consisting of 30 pounds of nitrogen and 9 pounds of phosphorus per acre was applied.

In the fertility experiment, three levels of fertility - 0+0+0, 30+9+0 and 60+18+0 expressed as N+P+K pounds per acre were applied. All plots were seeded at 8 pecks per acre with rows one foot apart. The experimental design was a split plot where the whole plots were fertility levels and the subplots were varieties. In both experiments the fertilizer was applied with the seed using a plot seeder. Germination tests and seed weight determinations were obtained for each variety to give a comparable number of plants per linear foot of row. All nurseries were sprayed with a fungicide (Manzate-D) at approximately 2-week intervals from the middle of June until harvest to control foliar diseases. The dates of seeding at the four locations - Brookings, Davis, Garden City and Ipswich were April 30, April 16, May 7 and May 3, respectively.

Collection of Data

Data were obtained for plot yield, sample yield, seedlings per unit area, panicles per unit area, 200-seed weight, panicles per plant, seeds per panicle, test weight, plant height, lodging, heading date and maturity date. Plot yields were obtained from the two center rows after trimming to 12 feet to eliminate border effects. Number of seedlings per unit area was obtained after complete emergence by plant counts made on a 2-foot section of each yield row.

The 2-foot sections were marked with plot stakes and number of panicles per unit area was determined from these sections at maturity. Number of panicles per plant was determined by dividing number of panicles per unit area by the number of seedlings per unit area. Each 2-foot section was harvested separately. Sample yields were determined by the total weight of threshed grain from the 2-foot sections of each plot. Weight per seed was obtained from a 200-seed sample from each 2-foot section. Number of seeds per panicle was calculated using seed weight, grain weight of 2-foot section and number of panicles per unit area. Plant height, lodging, heading date and maturity date were obtained from each whole plot.

Data Analyses

Data for eight missing values were estimated by the method presented by Cochran and Cox (3). Analyses of variance and covariance were computed for all characteristics studied in each experiment. Components of variance for yield and yield components were estimated according to the expectation of mean squares given in Tables 1 and 2, summed and expressed as percentage of total variability.

The means of grain yields and yield components were calculated and converted to a relative basis using the first treatment as 100%.

Table 1. Analysis of variance used for the seeding rate experiment.

Source of variation	Degrees of freedom	Expectation of mean squares
Locations (L)	$(\ell-1)$	$\sigma_e^2 + svp\sigma_{R:L}^2 + rsvp\sigma_L^2$
Replications in locations (R/L)	$\ell(r-1)$	$\sigma_e^2 + svp\sigma_{R:L}^2$
Seeding rates (S)	$(s-1)$	$\sigma_e^2 + vp\sigma_{RS:L}^2 + \ell rvp\sigma_S^2$
LS	$(\ell-1)(s-1)$	$\sigma_e^2 + vp\sigma_{RS:L}^2 + rvp\sigma_{LS}^2$
RS/L	$\ell(r-1)(s-1)$	$\sigma_e^2 + vp\sigma_{RS:L}^2$
Varieties (V)	$(v-1)$	$\sigma_e^2 + sp\sigma_{RV:L}^2 + \ell rsp\sigma_V^2$
LV	$(\ell-1)(v-1)$	$\sigma_e^2 + sp\sigma_{RV:L}^2 + rsp\sigma_{LV}^2$
RV/L	$\ell(r-1)(v-1)$	$\sigma_e^2 + sp\sigma_{RV:L}^2$
SV	$(s-1)(v-1)$	$\sigma_e^2 + p\sigma_{RSV:L}^2 + \ell rp\sigma_{SV}^2$
LSV	$(\ell-1)(s-1)(v-1)$	$\sigma_e^2 + p\sigma_{RSV:L}^2 + rp\sigma_{LSV}^2$
RSV/L	$\ell(r-1)(s-1)(v-1)$	$\sigma_e^2 + p\sigma_{RSV:L}^2$
Residual	$\ell srv(p-1)$	σ_e^2
Total	$\ell rsvp-1$	

ℓ: number of locations; r: number of replications; s: number of seeding rates;
v: number of varieties; p: number of subsamples.

Table 2. Analysis of variance used for the fertility experiment.

Source of variation	Degrees of freedom	Expectation of mean squares
Locations (L)	$(\ell-1)$	$\sigma_e^2 + fvp\sigma_a^2 + rfvp\sigma_L^2$
Error a	$\ell(r-1)$	$\sigma_e^2 + fvp\sigma_a^2$
Fertility levels (F)	$(f-1)$	$\sigma_e^2 + vp\sigma_b^2 + \ell rvp\sigma_F^2$
LF	$(\ell-1)(f-1)$	$\sigma_e^2 + vp\sigma_b^2 + rvp\sigma_{LF}^2$
Error b	$\ell(r-1)(f-1)$	$\sigma_e^2 + vp\sigma_b^2$
Varieties (V)	$(v-1)$	$\sigma_e^2 + fp\sigma_c^2 + \ell rfp\sigma_V^2$
LV	$(\ell-1)(v-1)$	$\sigma_e^2 + fp\sigma_c^2 + rfp\sigma_{LV}^2$
Error c	$\ell(r-1)(v-1)$	$\sigma_e^2 + fp\sigma_c^2$
FV	$(f-1)(v-1)$	$\sigma_e^2 + p\sigma_d^2 + \ell rp\sigma_{FV}^2$
LFV	$(\ell-1)(f-1)(v-1)$	$\sigma_e^2 + p\sigma_d^2 + rp\sigma_{LFV}^2$
Error d	$\ell(r-1)(f-1)(v-1)$	$\sigma_e^2 + p\sigma_d^2$
Residual	$\ell frv(p-1)$	σ_e^2
Total	$\ell rfvp-1$	

ℓ: number of locations; r: number of replications; f: number of fertility levels;
v: number of varieties; p: number of subsamples.

Simple correlations were computed between all combinations of characters studied. Selected correlations between yield and the yield components were partitioned into their direct and indirect effects by the use of path coefficient analyses as described by Li (19) and by Dewey and Lu (5).

RESULTS AND DISCUSSION

Seeding Rate Experiment

Analyses of Variance

Significance levels for all sources of variation including main effects and interactions are shown in Table 3 for the seeding rate experiment.

There were no differences among sample yields at different seeding rates, but differences among plot yields were significant at the .05 level. Duncan's New Multiple Range Test showed significant differences in yield between the 4-peck rate and the other three seeding rates. No significant difference was found between the yields from seeding rates of 8 to 16 pecks.

Changes in seeding rate caused highly significant differences in heading date, maturity date, plant height, seedlings per unit area, panicles per unit area, test weight, seeds per panicle and panicles per plant (Table 3). Varieties showed highly significant differences for all characteristics except sample yield. Significant responses to location were found for all characteristics except lodging. The significant location X variety interaction (LV) for all characteristics except sample yield indicated that varieties differed in their response to the different locations. Seeds per panicle showed highly significant differences for all main effects and interactions tested, indicating this component to be significantly affected by all changes in environmental conditions.

Table 3. Significance levels for all sources of variation in the seeding rate experiment.

Source ǂ of variation	Heading ‡ date	Lodging ‡	Maturity ‡ date	Seed wt.†	Plant ‡ height	Seedlings ‡ per unit area
L	**	NS	**	**	**	*
R/L	*	**	NS	*	**	**
S	**	NS	**	NS	**	**
LS	NS	**	**	**	*	NS
RS/L	NS	NS	NS	NS	NS	**
V	**	**	**	**	**	**
LV	**	**	**	**	**	*
RV/L	NS	NS	NS	**	NS	NS
SV	**	NS	*	NS	NS	NS
LSV	NS	NS	NS	*	NS	**
RSV/L	-	-	-	**	-	NS

* Significant at .05 level; ** Significant at .01 level; NS No significant difference.
\- No subsamples since determination was made on whole plot; therefore no test of significance. † Based on three locations; ‡ Based on four locations.
ǂ Symbols; L, locations; R/L, replications in locations; S, seeding rates; V, varieties.

Table 3. (continued) Significance levels for all sources of variation in the seeding rate experiment.

Source ‡ of variation	Panicles † per unit area	Test wt.†	Seeds per † panicle	Panicles † per plant	Sample † yield	Plot † yield
L	**	**	**	*	**	**
R/L	NS	**	**	**	**	**
S	**	**	**	**	NS	*
LS	*	NS	**	**	NS	NS
RS/L	NS	**	**	**	**	NS
V	**	**	**	**	NS	**
LV	**	**	**	**	NS	*
RV/L	NS	**	**	NS	**	NS
SV	**	*	**	**	NS	NS
LSV	NS	**	**	*	NS	NS
RSV/L	NS	-	**	NS	**	-

* Significant at .05 level; ** Significant at .01 level; NS No significant difference.
\- No subsamples since determination was made on whole plot; therefore no test of significance. † Based on three locations; ǂ Based on four locations.
‡ Symbols; L, locations; R/L, replications in locations; S, seeding rates; V, varieties.

Heading date, maturity date, panicles per unit area, test weight, seeds per panicle and panicles per plant showed significant seeding rate X variety interactions (SV) indicating that varieties differed in their response to changes in seeding rate for these characteristics.

Figures 1 and 2 show the relative response of varieties to changes in seeding rate for the two components, panicles per unit area and seeds per panicle, respectively, which showed highly significant seeding rate X variety interactions. Garland and Lodi showed the largest increase in panicles per unit area (Figure 1), but the greatest decrease in seeds per panicle (Figure 2) with increases in seeding rate. Mo. 0-205 and Rodney showed less increase in panicles per unit area (Figure 1), but the smallest decrease in seeds per panicle (Figure 2) with increases in seeding rate. Since seed weight remained constant, any change in either of the other two components had to be accompanied by a change in the third component in order to maintain a constant yield. The differences observed were likely due to the nature of the varieties.

Percentages of total variability contributed by components of variance for yield and yield components are given in Table 4 for the seeding rate experiment. Variations in seeding rate accounted for very little of the total variability in seed weight, sample yield and plot yield, but had a large effect on panicles per unit area (56.66%) and seeds per panicle (49.99%).

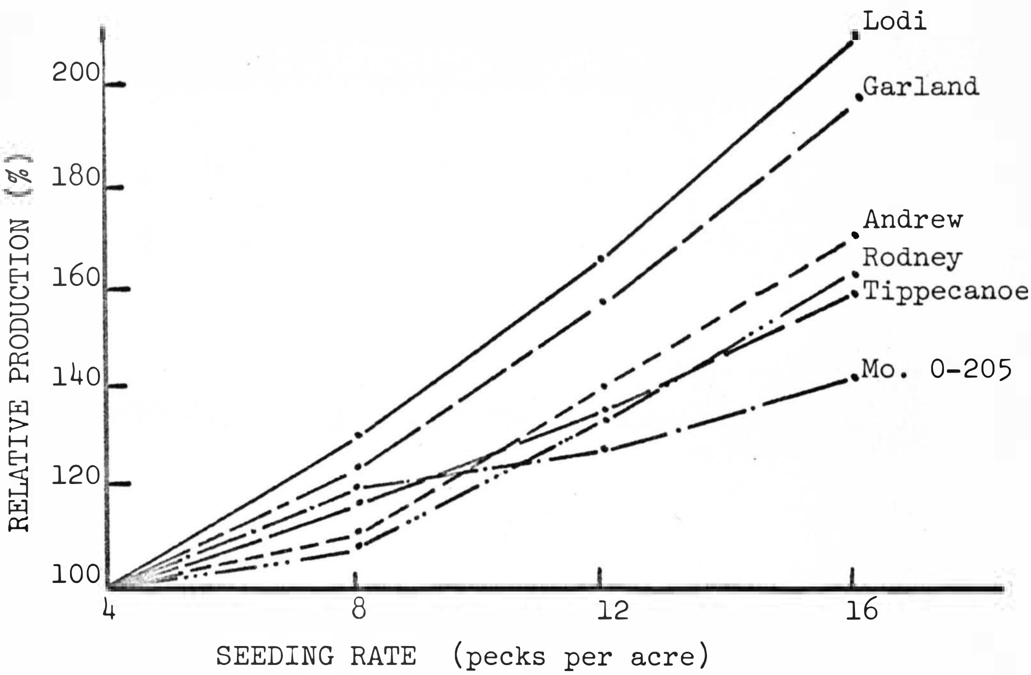

Figure 1. Mean relative panicles per unit area of six varieties as affected by seeding rate.

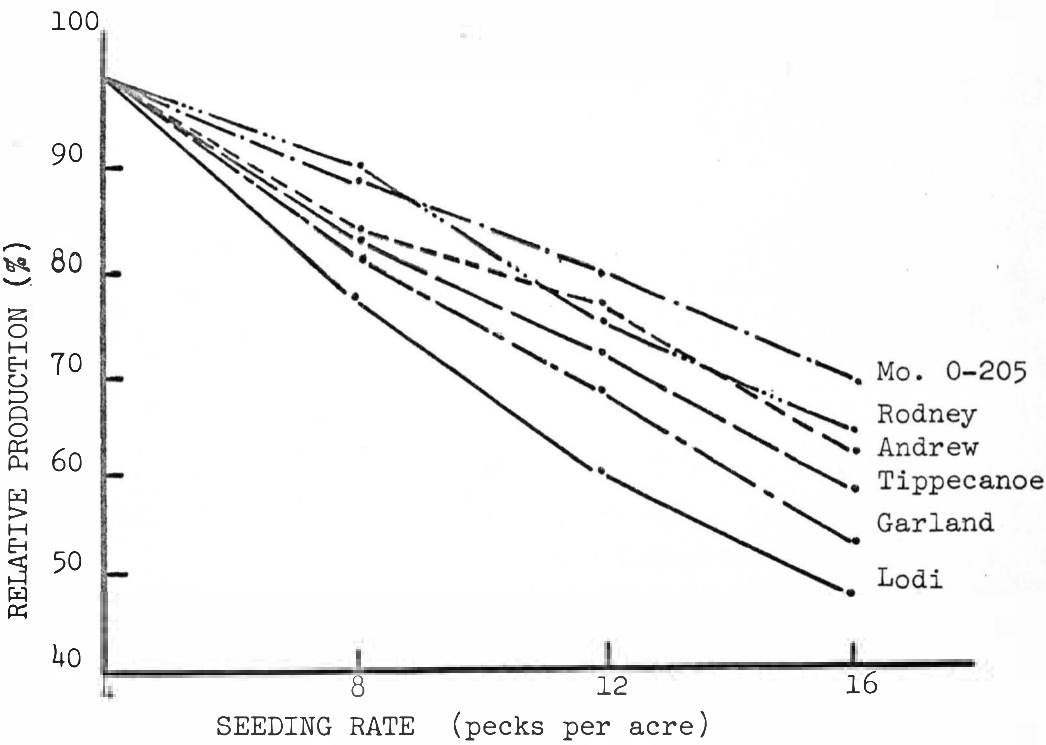

Figure 2. Mean relative seeds per panicle of six varieties as affected by seeding rate.

Table 4. Percentages of total variability in yield and yield components associated with different sources of variation in the seeding rate experiment.

Variance components	Yield and yield components: 200-seed weight	Seeds per panicle	Panicles per unit area	Sample yield	Plot yield
σ^2_{L}	5.47	15.35	6.43	29.00	47.95
$\sigma^2_{R/L}$	0.29	1.80	0.15	10.60	18.41
σ^2_{S}	0.02	49.99	56.66	0.01	1.29
σ^2_{LS}	0.53	1.99	0.73	1.44	- *
$\sigma^2_{RS/L}$	0.24	0.84	0.32	2.51	0.73
σ^2_{V}	71.79	11.70	12.28	4.80	5.32
σ^2_{LV}	3.72	0.88	1.57	1.84	1.26
$\sigma^2_{RV/L}$	2.12	0.84	0.31	4.06	-
σ^2_{SV}	0.24	2.96	2.14	0.04	-
σ^2_{LSV}	1.42	2.36	2.07	1.78	1.48
$\sigma^2_{RSV/L}$	2.83	2.46	1.42	13.40	23.56
σ^2_{e}	11.33	8.83	15.91	30.52	-- **

* Estimate of component was negative or very small.

** No residual component since determination was made on whole plot.

Variability in seed weight was dominated by varietal differences while sample yield and plot yield were influenced to a large extent by location. All variance components for yield and yield components in the seeding rate experiment are shown in Appendix Table A.

Yield and Yield Components

Treatment means for all characteristics studied in the seeding rate experiment are shown in Table 5. Mean sample yield varied from 95.9 bushels per acre at the 16-peck seeding rate to 98.6 bushels at the 12-peck rate. This difference was not statistically significant. Plot yield was highest at a seeding rate of 8 to 12 pecks per acre. Appendix Table B shows treatment means by individual location for all characteristics studied in the seeding rate experiment.

Mean relative production of seed weight, seeds per panicle and panicles per unit area for the six varieties are shown graphically in Figure 3. Both sample yield and plot yield increased slightly at the 8- and 12-peck rates but decreased slightly at the 16-peck rate. Panicles per unit area increased by 17, 42 and 71% with increases in seeding rate from 4 to 8, 12 and 16 pecks per acre, respectively. Seeds per panicle decreased approximately 15, 29 and 43% at the 8-, 12- and 16-peck rates, respectively, when compared to the 4-peck rate. This resulted in approximately a 15% decrease in seeds per panicle for each 4-peck increase in

Table 5. Treatment means for yield, yield components and other characteristics in the seeding rate experiment, (Average of six varieties).

Seeding rate, pecks/acre	Heading‡ date, June	Lodging‡, %	Maturity‡ date, July	Seed wt.†, g./200 seeds	Plant‡ height, inches	Seedlings‡ per unit area
4	29	3.8	30	5.24	42.0	30.2
8	28	2.7	28	5.26	41.0	54.5
12	27	4.3	27	5.28	40.1	76.4
16	27	4.8	26	5.25	39.1	98.7
Overall $\bar{x}$	28	3.9	28	5.26	40.6	65.0

† Average of three locations.
‡ Average of four locations.

Table 5. (continued) Treatment means for yield, yield components and other characteristics in the seeding rate experiment, (Average of six varieties).

Seeding rate, pecks/acre	Panicles† per unit area	Test wt.‡, lb./bu.	Seeds† per panicle	Panicles† per plant	Sample† yield, bu./acre	Plot† yield, bu./acre
4	54.0	34.6	47.2	1.94	96.4	90.8
8	63.4	35.5	40.3	1.18	97.5	94.1
12	76.5	36.0	33.3	1.02	98.6	95.1
16	92.2	36.5	27.1	0.94	95.9	92.8
Overall $\bar{x}$	71.5	35.7	37.0	1.27	97.1	93.2

† Average of three locations.
‡ Average of four locations.

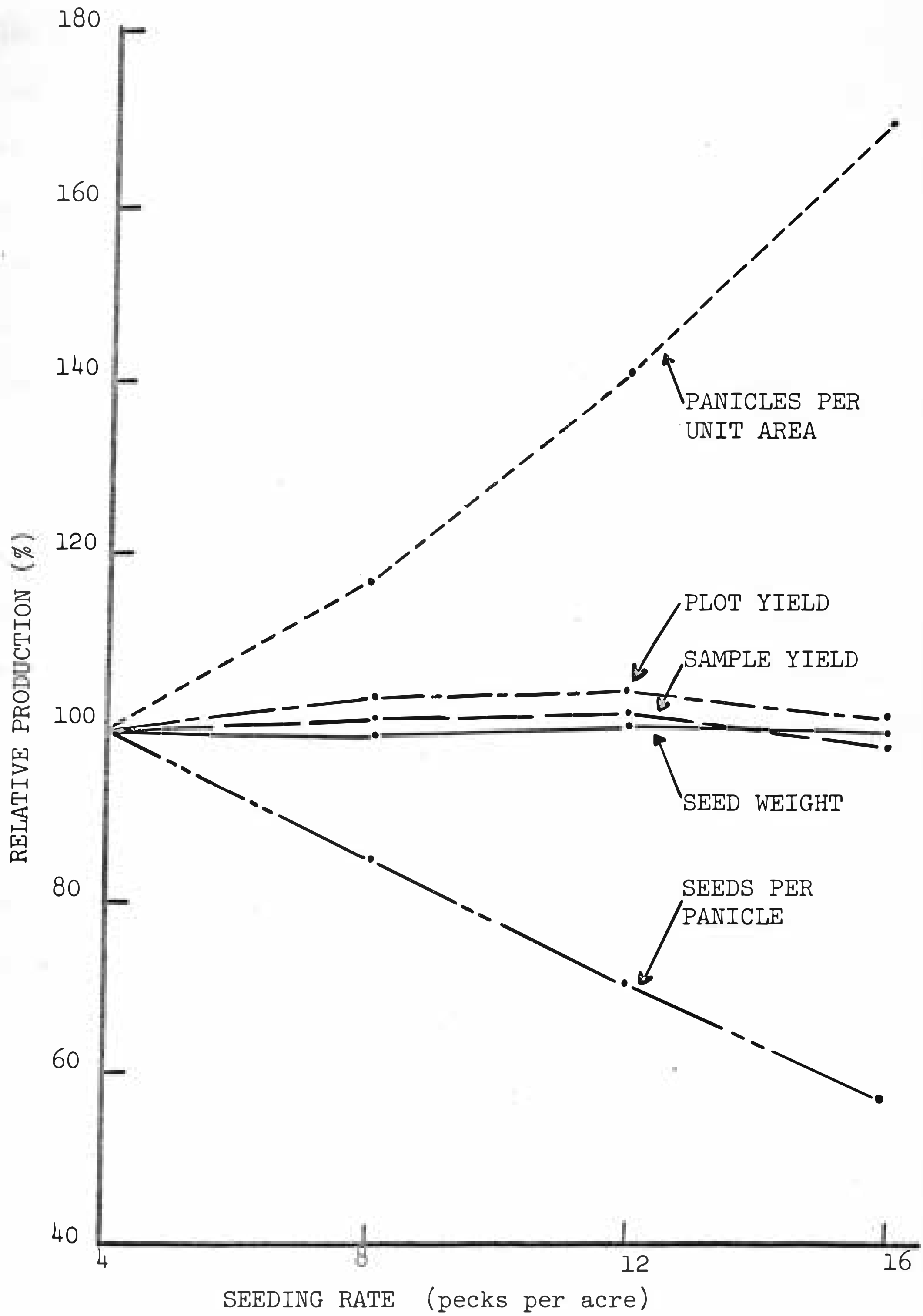

Figure 3. Mean relative yield and yield components as affected by seeding rate.

seeding rate. Weight per seed remained constant over the four seeding rates. The relatively constant grain yield observed over the entire range of seeding rates resulted from an interaction among the yield components. An increase in panicles per unit area was largely counterbalanced by a sharp decrease in seeds per panicle. Seed weight was not affected by changes in seeding rate and had little compensatory effect in determining yield.

Figure 4 shows the relative production of seedlings per unit area, panicles per unit area and panicles per plant. The heavy seeding rate caused a large increase in seedlings per unit area and the accompanying increase in panicles per unit area. These increases were accompanied by a decrease in panicles per plant, as reported by Wiggans and Frey (29), and Thayer and Rather (27). Grafius (13) indicated that under a uniformly favorable field environment, panicles per unit area and kernels per panicle influenced yield, but kernel weight did not. The number of panicles per plant increased or decreased according to the density of stand. Therefore, around the optimum, a rather wide range in seeding rate resulted in only minor differences in yield.

Other Characteristics

As seeding rate was increased from 4 to 16 pecks per acre, heading date was hastened by two days and maturity date was hastened by four days. A late variety would likely have the benefit of the earlier maturity related to a heavy rate of seeding.

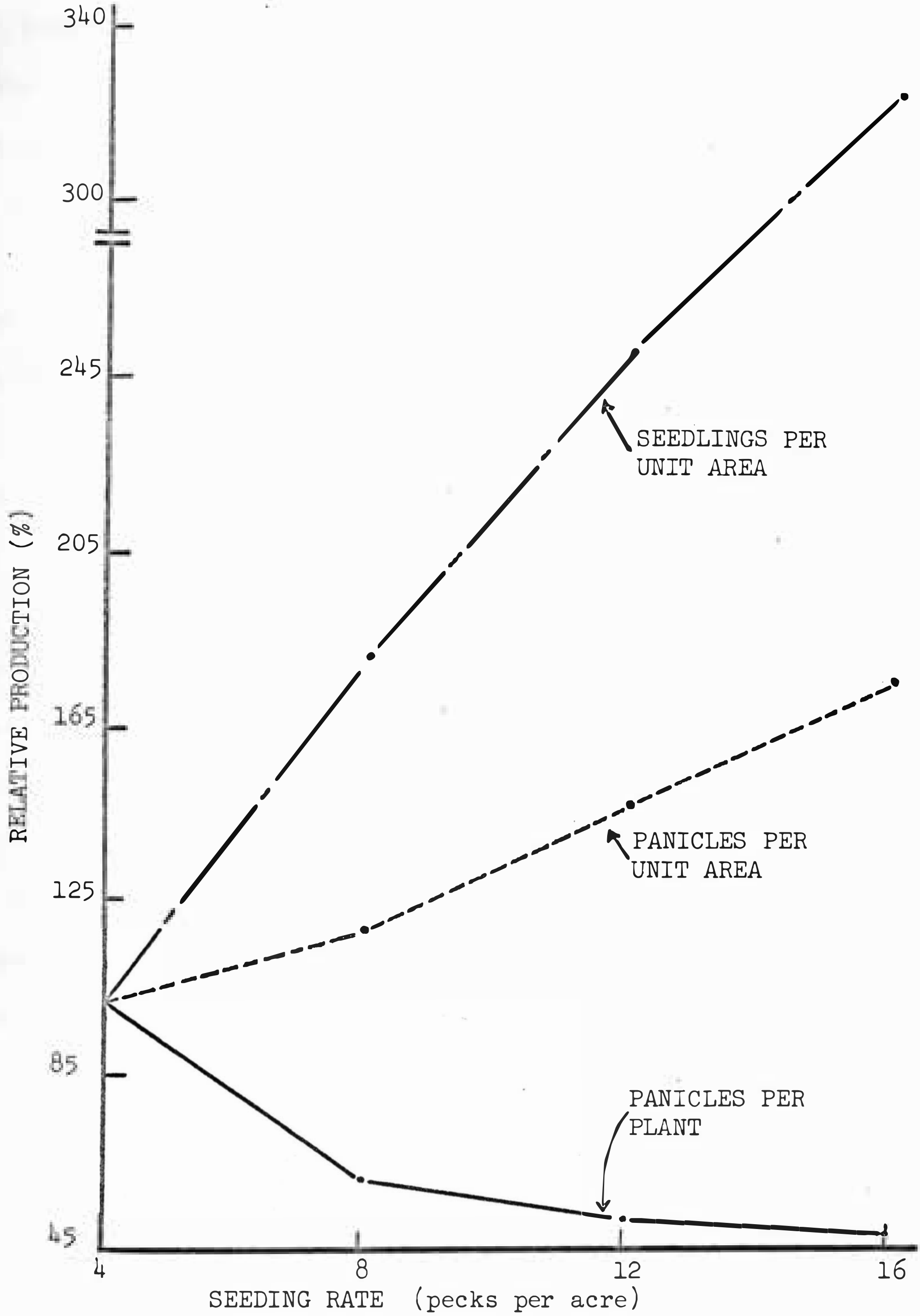

Figure 4. Mean relative production of seedlings per unit area, panicles per unit area and panicles per plant as affected by seeding rate.

Average plant height of the six varieties was reduced from 42.0 inches at the 4-peck seeding rate to 39.1 inches at the 16-peck rate. This decrease in plant height was likely due to increased competition for light, moisture and nutrients at the higher seeding rate.

High rate of seeding increased the amount of lodging. Greater competition for moisture, nutrition and light likely produced smaller and weaker stems which lodged more readily.

Test weight was increased at the high seeding rate. Oats are a cool weather crop and are often injured materially by a few hot days near maturity (4). Panicles on the main stem generally mature first and often escape the high temperature injury which later developing panicles may encounter. The earlier maturity caused by the high seeding rate could account for the accompanying increase in test weight. Significant negative correlations were found between test weight and either heading date or maturity date.

Table 6 shows variety means for all characteristics studied in the seeding rate experiment. Appendix Table C shows variety means by individual location for these characteristics.

Fertility Experiment

Analyses of Variance

Significance levels for all sources of variation including main effects and interactions are shown in Table 7 for the fertility experiment. Changes in fertility level caused highly significant

Table 6. Variety means for yield, yield components and other characteristics in the seeding rate experiment, (Average of four seeding rates).

Variety	Heading‡ date	Lodging,‡ %	Maturity‡ date	Seed wt.,† g./200 seeds	Plant‡ height, inches	Seedlings‡ per unit area
Andrew	6-24*	7.8	7-25*	5.58	39.4	66.5
Garland	6-26	4.2	7-26	5.22	36.3	61.3
Lodi	7-2	1.3	7-31	5.85	44.8	67.7
Mo. 0-205	6-26	4.5	7-26	4.36	42.8	66.9
Rodney	7-4	3.9	8-2	5.21	44.3	59.8
Tippecanoe	6-24	1.5	7-25	5.31	35.9	67.5
Overall $\bar{x}$	6-28	3.9	7-28	5.26	40.6	65.0

† Average of three locations.
‡ Average of four locations.
* 6 - June, 7 - July, 8 - August.

Table 6. (continued) Variety means for yield, yield components and other characteristics in the seeding rate experiment, (Average of four seeding rates).

Variety	Panicles† per unit area	Test wt.†, lb./bu.	Seeds† per panicle	Panicles† per plant	Sample† yield, bu./acre	Plot† yield, bu./acre
Andrew	72.2	35.5	33.9	1.24	96.7	91.3
Garland	63.5	36.9	41.7	1.19	96.1	92.2
Lodi	67.6	34.1	36.6	1.12	99.1	96.0
Mo. 0-205	84.2	35.8	37.8	1.47	101.1	94.8
Rodney	65.4	35.0	41.2	1.27	100.4	97.2
Tippecanoe	76.4	36.6	30.7	1.31	89.4	87.8
Overall $\bar{x}$	71.5	35.7	37.0	1.27	97.1	93.2

† Average of three locations.
‡ Average of four locations.
* 6 - June, 7 - July, 8 - August.

Table 7. Significance levels for all sources of variation in the fertility experiment.

Source ‡ of variation	Heading‡ date	Lodging‡	Maturity‡ date	Seed wt.†	Plant ‡ height	Seedlings ‡ per unit area
L	**	**	**	**	**	**
Ea	**	**	**	**	**	NS
F	NS	**	**	**	**	**
LF	NS	**	**	NS	*	*
Eb	**	**	NS	*	**	*
V	**	**	**	**	**	**
LV	**	**	**	*	**	NS
Ec	NS	**	NS	NS	NS	**
FV	NS	**	NS	NS	*	NS
LFV	NS	**	NS	**	**	NS
Ed	-	-	-	NS	-	*

* Significant at .05 level; ** Significant at .01 level; NS No significant difference.
\- No subsamples since determination was made on whole plot; therefore no test of significance. † Based on three locations; ‡ Based on four locations.
‡ Symbols: L, locations; F, fertility levels; V, varieties; E, error.

Table 7. (continued) Significance levels for all sources of variation in the fertility experiment.

Source ‡ of variation	Panicles † per unit area	Test wt.†	Seeds per† panicle	Panicles † per plant	Sample † yield	Plot † yield
L	**	**	**	**	NS	*
Ea	**	NS	**	**	**	**
F	**	**	**	**	**	**
LF	NS	**	NS	NS	NS	NS
Eb	**	NS	**	**	**	**
V	**	**	**	**	**	**
LV	**	**	NS	NS	NS	**
Ec	*	NS	**	**	**	NS
FV	**	NS	**	NS	NS	NS
LFV	NS	*	NS	NS	NS	*
Ed	NS	-	NS	**	*	-

* Significant at .05 level; ** Significant at .01 level; NS No significant difference.
\- No subsamples since determination was made on whole plot; therefore no test of significance. † Based on three locations; ‡ Based on four locations.
‡ Symbols: L, locations; F, fertility levels; V, varieties; E, error.

differences in all characteristics studied except heading date. Significant location X variety interactions (LV) for heading date, lodging, maturity date, seed weight, plant height, panicles per plant, test weight and plot yield indicated that varieties differed in their response to location. Fertility level X variety interactions (FV) were significant for lodging, plant height, panicles per unit area and seeds per panicle. Figures 5 and 6 show varietal response to changes in fertility level for the components, panicles per unit area and seeds per panicle, respectively. These components showed highly significant fertility X variety interactions. Mo. 0-205 and Rodney showed the greatest increase in panicles per unit area whereas Garland and Lodi showed the least response (Figure 5). These varieties showed an exact opposite response in seeds per panicle, with Garland and Lodi giving the greatest increase and Mo. 0-205 and Rodney responding least (Figure 6). Garland and Lodi showed a different response to fertility level than to seeding rate for panicles per unit area and seeds per panicle. Mo. 0-205 and Rodney showed the exact opposite response as that shown by Garland and Lodi in both experiments.

Percentages of total variability contributed by components of variance for yield and yield components are shown in Table 8. Variation in sample yield and plot yield in the fertility experiment was influenced primarily by changes in fertility level. The variety component contributed a large part (68.49%) of the total variability

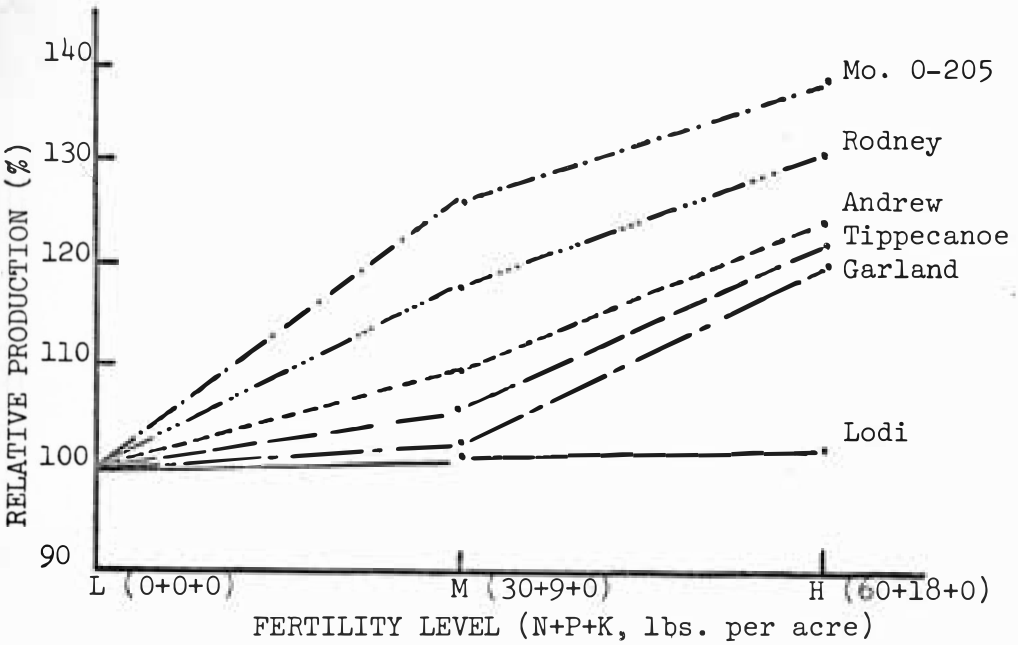

Figure 5. Mean relative panicles per unit area of six varieties as affected by fertility level.

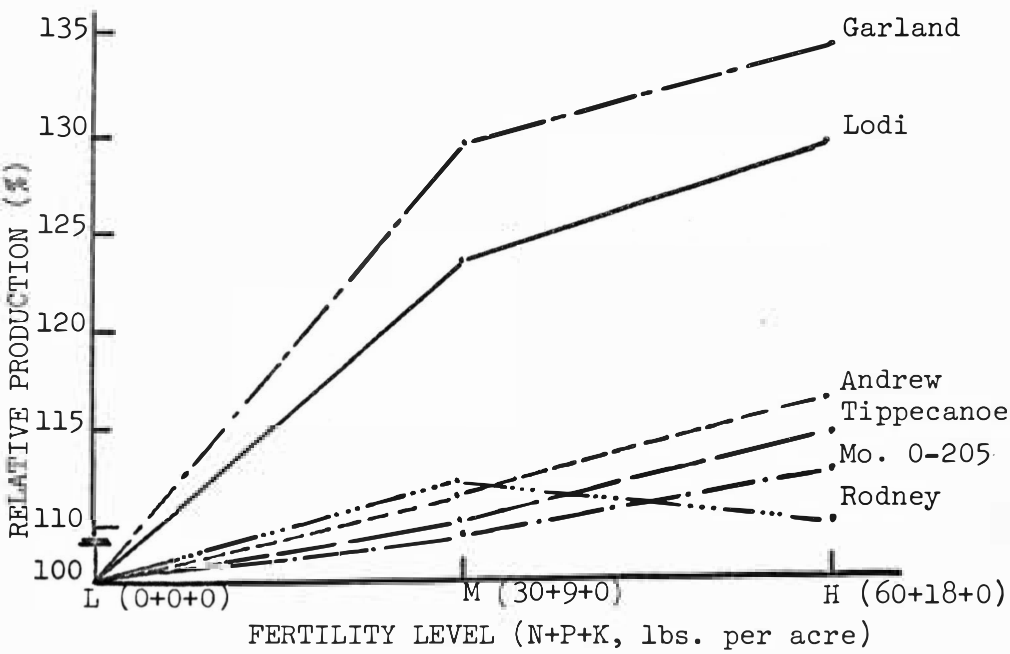

Figure 6. Mean relative seeds per panicle of six varieties as affected by fertility level.

Table 8. Percentages of total variability in yield-and yield components associated with different sources of variation in the fertility experiment.

Variance components	Yield and yield components				
	200-seed weight	Seeds per panicle	Panicles per unit area	Sample yield	Plot yield
σ^2_L	4.19	22.30	17.37	5.96	12.58
σ^2_{Ea}	1.64	5.92	1.11	9.71	8.46
σ^2_F	2.23	14.99	18.85	44.37	56.27
σ^2_{LF}	0.31	-	-	-	- *
σ^2_{Eb}	1.09	8.41	23.53	9.47	6.01
σ^2_V	68.49	20.89	3.16	2.49	3.60
σ^2_{LV}	1.37	1.78	3.92	1.23	1.84
σ^2_{Ec}	1.09	6.04	1.95	3.99	-
σ^2_{FV}	0.46	2.31	3.70	-	-
σ^2_{LFV}	2.73	0.16	1.31	0.68	1.99
σ^2_{Ed}	1.09	0.69	1.46	4.13	9.25
σ^2_e	15.31	16.51	23.63	18.07	-- **

* Estimate of component was negative or very small.
** No residual component since determination was made on whole plot.

in seed weight. Variability in panicles per unit area and seeds per panicle was influenced significantly by location, fertility level and variety. Most interaction components contributed little to the total variability for yield and the yield components. The large effect of varieties in controlling variation in seed weight in both experiments suggests this to be a highly heritable trait. Yield and the other components were influenced to a larger extent by the imposed environmental variations and their resulting interactions. Appendix Table D shows variance components for yield and its components in the fertility experiment.

Yield and Yield Components

Table 9 shows treatment means for all characteristics studied in the fertility experiment. Sample yield varied from 71.6 bushels at the low fertility level to 103.2 bushels at the high level, resulting in a 44% yield increase at the highest level. Plot yield closely paralleled sample yield, ranging from 68.5 bushels at the low level to 99.9 bushels at the high level, or a 46% yield increase at the highest level. Appendix Table E shows treatment means by individual location for all characteristics studied in the fertility experiment.

Figure 7 gives a graphic representation of the response of yield and its components to changes in fertility level. Panicles per unit area increased approximately 11 and 25% at the medium and high fertility levels, respectively. This component showed the greatest and most consistent response to additions of fertilizer. Seeds

Table 9. Treatment means for yield, yield components and other characteristics in the fertility experiment, (Average of six varieties).

Fertility level, (N+P+K)	Heading date, June ‡	Lodging, % ‡	Maturity date, July ‡	Seed wt., g./200 seeds †	Plant height, inches ‡	Seedlings per unit area ‡
L(0+0+0)	30	0.5	29	5.36	35.7	50.4
M(30+9+0)	27	2.7	27	5.30	39.5	54.3
H(60+18+0)	29	7.2	28	5.16	41.5	51.7
Overall $\bar{x}$	29	3.5	28	5.27	38.9	52.1

† Average of three locations.
‡ Average of four locations.

Table 9. (continued) Treatment means for yield, yield components and other characteristics in the fertility experiment, (Average of six varieties).

Fertility level, (N+P+K)	Panicles† per unit area	Test wt.,† lb./bu.	Seeds† per panicle	Panicles† per plant	Sample† yield, bu./acre	Plot† yield, bu./acre
L(0+0+0)	55.5	35.3	33.2	1.11	71.6	68.5
M(30+9+0)	61.6	35.5	39.2	1.17	93.0	88.2
H(60+18+0)	69.4	34.7	39.5	1.40	103.2	99.9
Overall $\bar{x}$	62.2	35.2	37.3	1.23	89.3	85.5

† Average of three locations.
‡ Average of four locations.

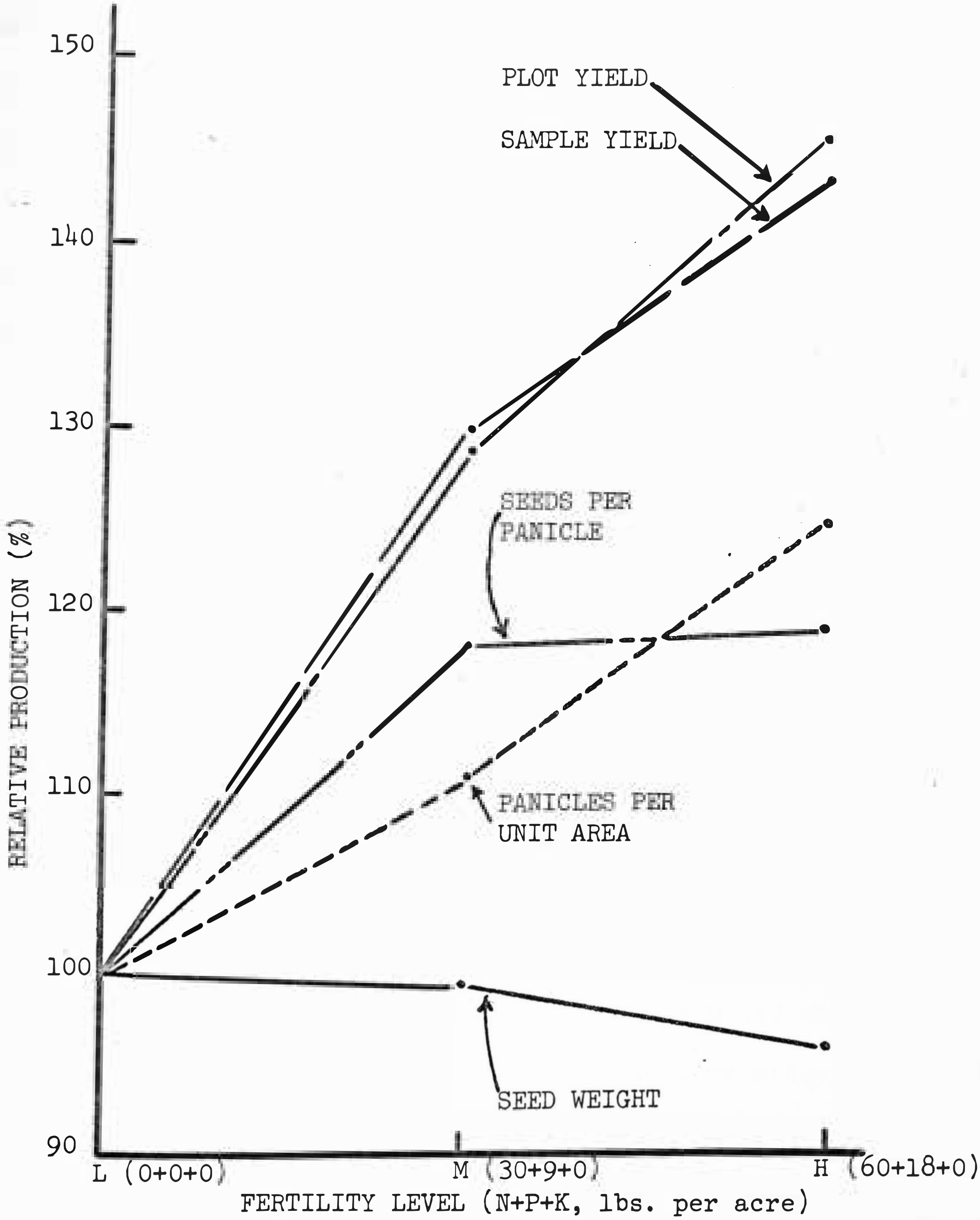

Figure 7. Mean relative yield and yield components as affected by fertility level.

per panicle was increased 18% at the medium level but only approximately 1% additional at the high level. There was a slight but continuous decrease in weight per seed from additions of fertilizer.

Different response of yield and yield components to fertility is likely a reflection of different patterns of growth and development of plant tissues. Panicles per plant and seeds per panicle are the result of vegetative growth while seed weight is a result of carbohydrate storage. Nitrogen and phosphorus are important for the synthesis of plant tissues and a high fertility level usually causes vigorous vegetative growth. Therefore, panicles per unit area and seeds per panicle were influenced more by high fertility level than was seed weight. Number of panicles per plant and seeds per panicle is determined at an earlier stage of plant growth than is seed weight. The number of panicles per plant is determined within two weeks after seedling emergence (8). Number of seeds per panicle is determined approximately 30 days after emergence (14). Seed weight is not determined until after anthesis, that is, approximately 60 days or more after emergence (10). Therefore, panicles per unit area and seeds per panicle showed a greater response to fertilizer application than did seed weight.

It has been reported that fertilization depresses seed weight slightly (10, 22). The decrease in seed weight at high fertility may be due to a change in the carbon-nitrogen ratio. The effectiveness of nitrogen fertilization depends largely upon changes in this ratio. During nitrogen metabolism, nitrate is reduced to ammonia which combines with organic acids derived from carbohydrates to form amino acids (precursors of protein) (25). Therefore, rapid nitrate reduction is accompanied by rapid utilization of carbohydrates. When the supplies of carbohydrates are inadequate in the plant to provide for nitrate reduction, large concentrations of the inorganic nitrate may build up. When the nitrogen supply is inadequate to keep pace with nitrate reduction, carbohydrates will accumulate and become available for storage in the seeds. Accordingly, seed weight was slightly heavier at the low fertility level than at the high level. Even though seed weight decreased slightly at the high fertility level, there was sufficient increase in tillers per plant and seeds per panicle to result in a higher grain yield.

The relative production of seedlings per unit area, panicles per unit area and panicles per plant is shown in Figure 8. Seedling emergence was stimulated at the medium fertility level. Panicles per plant was increased 5% at the medium fertility level and 26% at the high level compared to the check. Since seeding rate remained constant, there was a close relationship between panicles per plant and panicles per unit area.

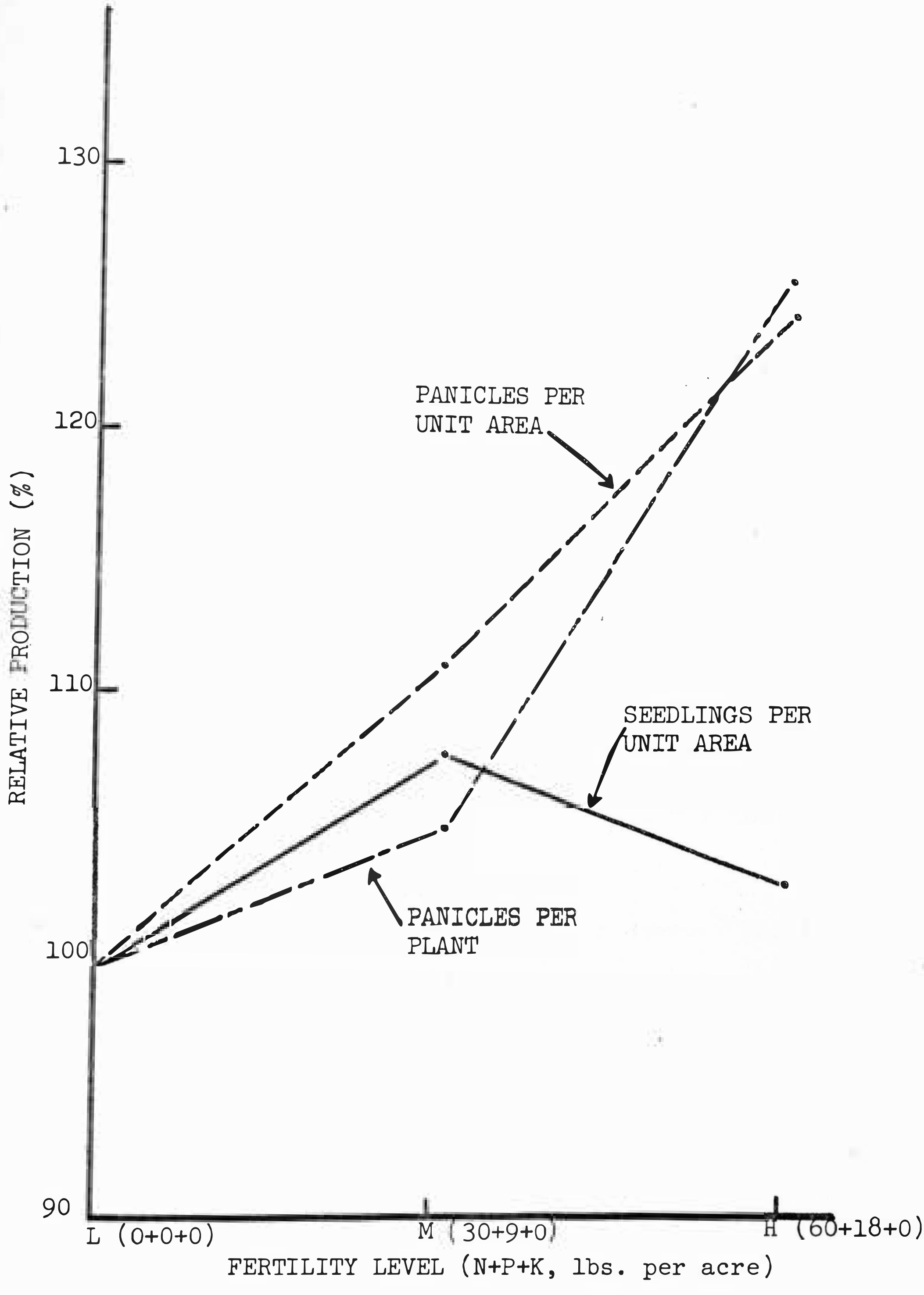

Figure 8. Mean relative production of seedlings per unit area, panicles per unit area and panicles per plant as affected by fertility level.

Other Characteristics

Heading date and maturity date were hastened by the addition of fertilizers. Plants grown at the medium fertility level headed and matured earlier than those grown at either of the other levels. This hastening of heading and maturity was likely due to a proper balance of available nitrogen and phosphorus in the soil. Williams (30) found that the time required for plants to attain a maximum rate of phosphorus absorption may be decreased by an increased concentration of phosphorus in the soil. This may explain why the high and medium fertility levels hastened maturity date as compared to the low level.

Average plant heights were 35.7, 39.5 and 41.5 inches at the low, medium and high fertility levels, respectively. It is known that an adequate supply of nutrients usually results in a vigorous growth, since nitrogen and phosphorus are important for the synthesis of plant tissue.

Lodging was increased at the high fertility level. This would be expected since nitrogen fertilization frequently increases plant height, weight, and leaf area, but does not increase diameter, wall thickness and weight per unit length of stem in proportion to the increase in weight of the plant (1). Miller et al. (20) reported that phosphorus had a direct effect on stem breaking-strength by reducing the lignin content and had an indirect effect in increasing the nitrogen content. As a result, lodging was increased at high fertility level.

Test weight was increased slightly as fertility level increased from low to medium, but dropped slightly at the high level.

Table 10 shows variety means for all characteristics studied in the fertility experiment. Appendix Table F shows variety means by individual location for these characteristics.

Simple Correlations

Correlation coefficients for all possible combinations of characteristics studied in the seeding rate and fertility experiments are shown in Tables 11 and 12, respectively. Panicles per unit area and seeds per panicle showed highly significant positive associations with sample yield in both experiments. Seed weight showed a non-significant but consistently negative association with yield. Sample yield and plot yield showed correlations of 0.534** and 0.824** in the seeding rate and fertility experiments, respectively. Seed weight was highly negatively correlated with panicles per unit area, panicles per plant and seeds per panicle in both experiments. Panicles per unit area and seeds per panicle showed a significant negative association. Panicles per plant was negatively correlated with panicles per unit area and seedlings per unit area.

Path Coefficient Analyses

Phenotypic correlation coefficients between sample yield and its components were partitioned into their direct and indirect effects by means of path coefficient analyses as shown in Figures 9

Table 10. Variety means for yield, yield components and other characteristics in the fertility experiment, (Average of three fertility levels).

Variety	Heading[‡] date	Lodging[‡] %	Maturity[‡] date	Seed wt.[†], g./200 seeds	Plant[‡] height, inches	Seedlings[‡] per unit area
Andrew	6-25[*]	9.5	7-27[*]	5.51	38.5	50.3
Garland	6-28	3.1	7-26	5.21	34.7	50.0
Lodi	7-2	0.6	7-31	6.01	42.8	54.2
Mo. 0-205	6-28	3.6	7-27	4.29	40.9	53.4
Rodney	7-4	2.8	8-2	5.31	42.4	49.1
Tippecanoe	6-25	1.2	7-25	5.31	34.0	53.6
Overall $\bar{x}$	6-29	3.5	7-28	5.27	38.9	52.1

† Average of three locations.
‡ Average of four locations.
* 6 - June, 7 - July, 8 - August.

Table 10. (continued) Variety means for yield, yield components and other characteristics in the fertility experiment, (Average of three fertility levels).

Variety	Panicles† per unit area	Test wt.†, lb./bu.	Seeds† per panicle	Panicles† per plant	Sample† yield, bu./acre	Plot† yield, bu./acre
Andrew	61.6	34.9	35.3	1.22	89.1	83.4
Garland	54.6	36.7	41.6	1.12	88.0	83.8
Lodi	56.3	33.7	36.2	1.09	90.4	89.4
Mo. 0-205	76.5	35.3	38.3	1.48	93.4	87.1
Rodney	56.6	34.7	41.7	1.16	92.9	90.2
Tippecanoe	67.3	36.0	30.7	1.31	81.8	79.4
Overall $\bar{x}$	62.2	35.2	37.3	1.23	89.3	85.6

† Average of three locations.
‡ Average of four locations.
* 6 - June, 7 - July, 8 - August.

Table 11. Simple correlation coefficients among agronomic characteristics in the seeding rate experiment.†

	Lodging	Maturity date	Seed wt.	Plant height	Seedlings per unit area	Panicles per unit area	Test wt.	Seeds per panicle	Panicles per plant	Sample yield	Plot yield
Heading date	-0.088*	0.912**	0.171**	0.708**	-0.241**	-0.329**	-0.446**	0.373**	0.089*	0.167**	0.273**
Lodging		-0.049	-0.012	0.126**	0.092*	0.105*	0.036	0.008	-0.033	0.198**	0.179**
Maturity date			0.159**	0.755**	-0.398**	-0.422**	-0.565**	0.474**	0.273**	0.183**	0.251**
Seed wt.				0.047	0.020	-0.224**	-0.149**	-0.149**	-0.240**	-0.053	-0.035
Plant height					-0.200**	-0.169**	-0.587**	0.313**	0.156**	0.298**	0.407**
Seedlings per unit area						0.864**	0.395**	-0.809**	-0.767**	0.071	0.073
Panicles per unit area							0.354**	-0.761**	-0.410**	0.247**	0.108*
Test wt.								-0.355**	-0.332**	-0.030	-0.023
Seeds per panicle									0.556**	0.261**	0.159**
Panicles per plant										0.097*	-0.041
Sample yield											0.534**

* Significant at .05 level.
** Significant at .01 level.
† Based on three locations.

Table 12. Simple correlation coefficients among agronomic characteristics in the fertility experiment.†

	Lodging	Maturity date	Seed wt.	Plant height	Seedlings per unit area	Panicles per unit area	Test wt.	Seeds per panicle	Panicles per plant	Sample yield	Plot yield
Heading date	-0.133**	0.382**	0.037	0.149**	-0.106*	-0.217**	-0.152**	0.065	-0.137**	-0.121*	-0.062
Lodging		-0.057	-0.081	0.153**	0.047	0.233**	-0.212**	0.102*	0.205**	0.273**	0.293**
Maturity date			0.220**	0.601**	-0.096*	-0.228**	-0.452**	0.198**	-0.155**	0.061	0.137**
Seed wt.				0.054	0.004	-0.444**	-0.253**	-0.222**	-0.431**	-0.078	-0.058
Plant height					0.007	0.189**	-0.538**	0.390**	0.204**	0.520**	0.615**
Seedlings per unit area						0.481**	0.012	-0.320**	-0.352**	0.185**	0.001
Panicles per unit area							-0.048	-0.107*	0.615**	0.580**	0.416**
Test wt.								0.013	-0.094	-0.164**	-0.094
Seeds per panicle									0.151**	0.602**	0.151**
Panicles per plant										0.452**	0.446**
Sample yield											0.824**

* Significant at .05 level.
** Significant at .01 level.
† Based on three locations.

through 12. A path coefficient is a standardized partial regression coefficient, and as such, measures the direct effect (P_{ij}) of an independent variable (yield component) upon the dependent variable (seed yield) after removal of the influence of all other independent variables in the analysis. Path coefficients are represented by single-headed arrows in the diagrams. The double-headed arrows indicate mutual association between characters included in the analysis as measured by their correlation coefficient, r_{ij}. The residual variation, or variation in yield not accounted for by variation in the independent variables, is represented as Z. Figure 9 diagramatically shows the interrelationships between yield and four of its components in the seeding rate experiment.

Table 13 shows a numerical breakdown of the correlations between sample yield and four yield components into their various direct and indirect effects in the seeding rate experiment. Seedlings per unit area had the largest direct effect (1.514) upon yield of the components included in the analysis. However, the observed correlation between seedlings per unit area and yield was reduced to a non-significant value (0.071) by the large negative indirect effects through seeds per panicle (-0.924) and panicles per plant (-0.524). These negative effects were a result of the large negative correlation between seedlings per unit area and the other two components. Seeds per panicle and panicles per plant had large positive direct effects but their observed correlations with yield were reduced significantly by the negative indirect effect of each

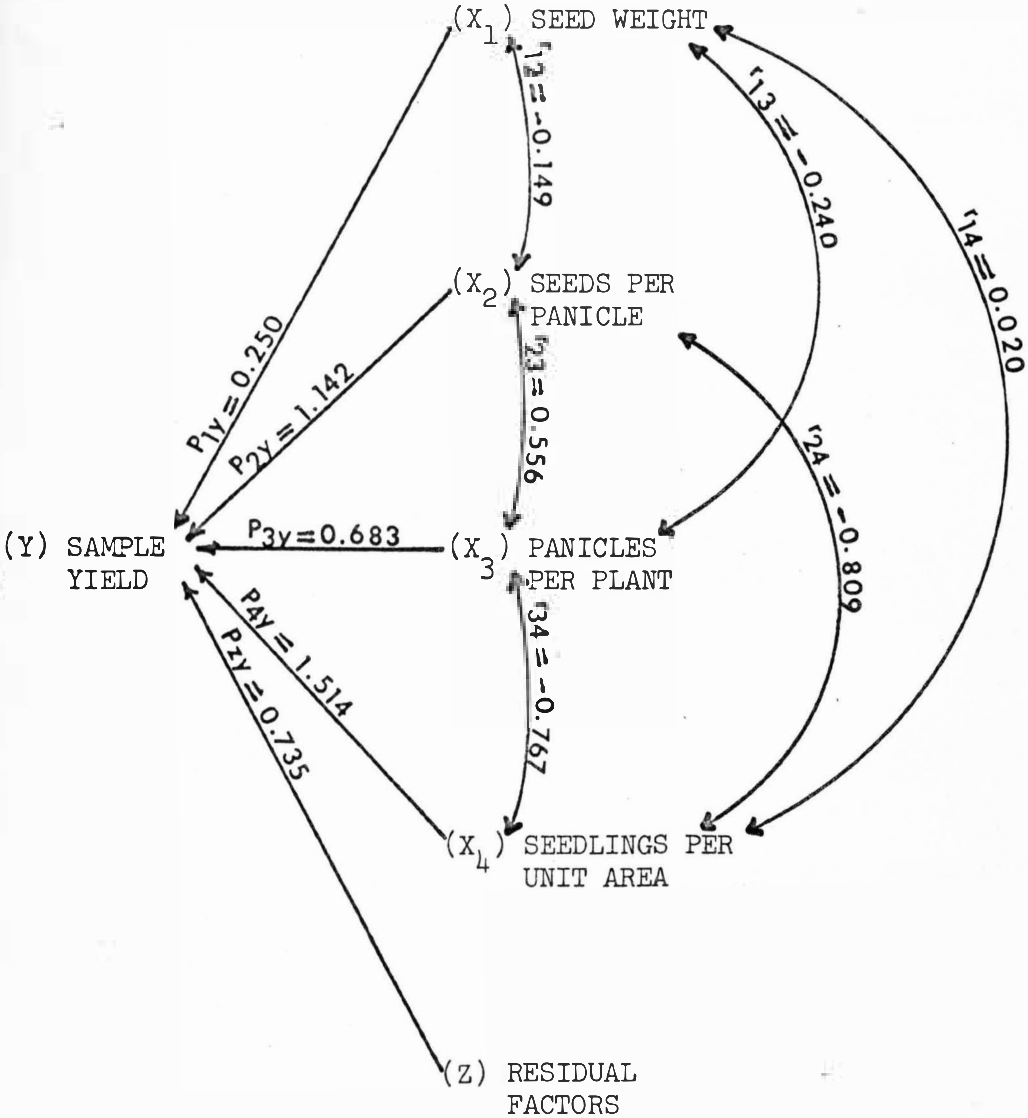

Figure 9. Diagramatic representation of the interrelationships between sample yield and four components in the seeding rate experiment.

Table 13. Path coefficient analysis of the influence of four components upon sample yield in the seeding rate experiment.

Type of influence and association		Phenotypic value
Seed weight; X_1:		
Direct effect	P_{1y}	0.250
Indirect, via seeds per panicle	$r_{12}P_{2y}$	-0.170
Indirect, via panicles per plant	$r_{13}P_{3y}$	-0.164
Indirect, via seedlings per unit area	$r_{14}P_{4y}$	0.030
Total correlation	r_{1y}	0.054
Seeds per panicle; X_2:		
Direct effect	P_{2y}	1.142
Indirect, via seed weight	$r_{12}P_{1y}$	-0.037
Indirect, via panicles per plant	$r_{23}P_{3y}$	0.380
Indirect, via seedlings per unit area	$r_{24}P_{4y}$	-1.224
Total correlation	r_{2y}	0.261**
Panicles per plant; X_3:		
Direct effect	P_{3y}	0.683
Indirect, via seed weight	$r_{13}P_{1y}$	-0.060
Indirect, via seeds per panicle	$r_{23}P_{2y}$	0.635
Indirect, via seedlings per unit area	$r_{34}P_{4y}$	-1.161
Total correlation	r_{3y}	0.097*
Seedlings per unit area; X_4:		
Direct effect	P_{4y}	1.514
Indirect, via seed weight	$r_{14}P_{1y}$	0.005
Indirect, via seeds per panicle	$r_{24}P_{2y}$	-0.924
Indirect, via panicles per plant	$r_{34}P_{3y}$	-0.524
Total correlation	r_{4y}	0.071
Coefficient of determination:		0.460

* Significant at .05 level.
** Significant at .01 level.

through seedlings per unit area. Seed weight had little effect upon yield either directly or indirectly through any of the other components. The coefficient of determination showed that 46% of the variation in seed yield could be accounted for by variation in the four components, seed weight, seeds per panicle, panicles per plant, and seedlings per unit area.

Figure 10 gives a diagramatic representation of the interrelationships between sample yield and three of its components in the seeding rate experiment. Table 14 shows a numerical breakdown of these relationships. Panicles per unit area and seeds per panicle were the two most important components in determining seed yield, giving values of 1.449 and 1.436, respectively, for their direct effects. Because of a large negative correlation (-0.761**) between panicles per unit area and seeds per panicle, the observed correlation between each of these components and yield was reduced significantly by large negative indirect effects through the opposing components. Seed weight showed a positive direct effect upon yield but negative indirect effects through the other two components. The coefficient of determination showed that variation in the three components accounted for 71% of the variation in sample yield, compared to a value of 46% in the previous analysis where four characters (two different than those in the present analysis) were used. Panicles per unit area was the most important component in accounting for variation in sample yield. It alone accounted for more variation than did the combination of seedlings per unit area and panicles per plant.

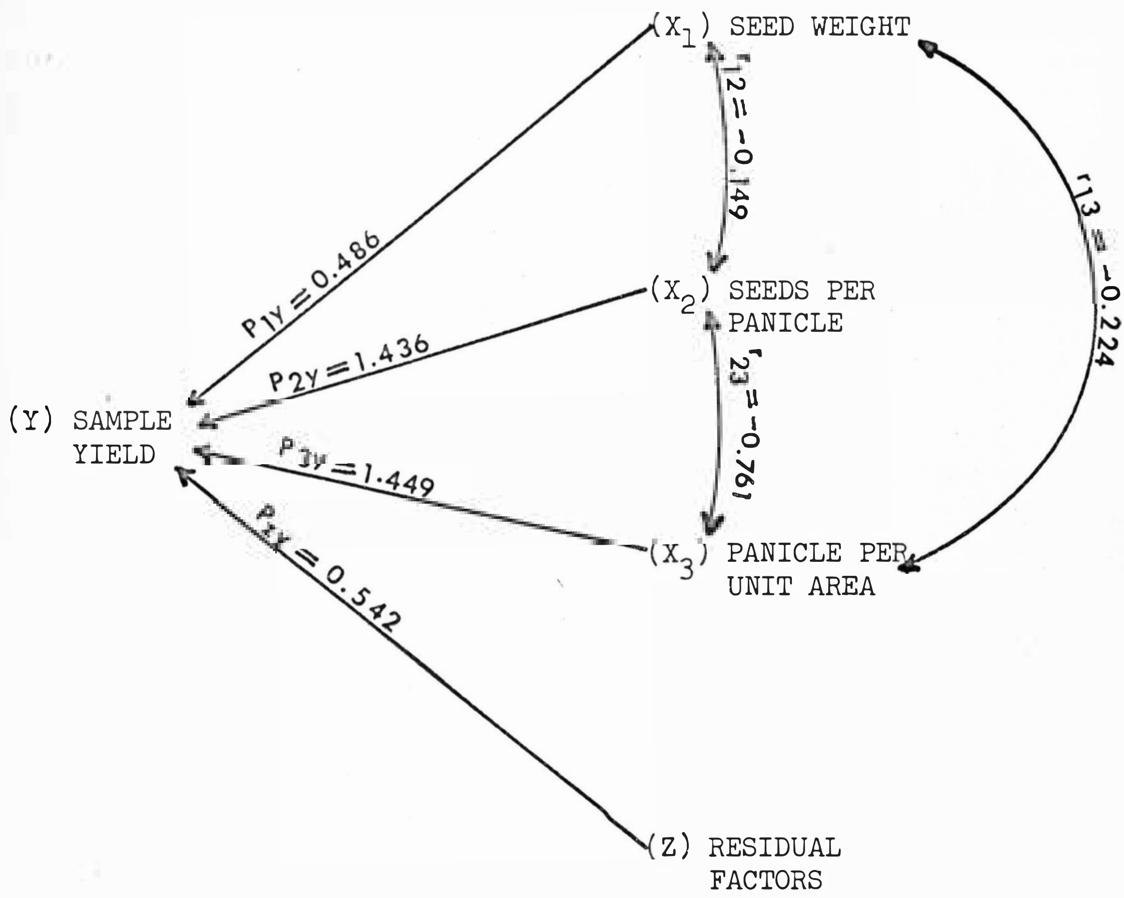

Figure 10. Diagramatic representation of the interrelationships between sample yield and three components in the seeding rate experiment.

Table 14. Path coefficient analysis of the influence of three components upon sample yield in the seeding rate experiment.

Type of influence and association		Phenotypic value
Seed weight; X_1:		
Direct effect	P_{1y}	0.486
Indirect, via seeds per panicle	$r_{12}P_{2y}$	-0.214
Indirect, via panicles per unit area	$r_{13}P_{3y}$	-0.325
Total correlation	r_{1y}	-0.053
Seeds per panicle; X_2:		
Direct effect	P_{2y}	1.436
Indirect, via seed weight	$r_{12}P_{1y}$	-0.072
Indirect, via panicles per unit area	$r_{23}P_{3y}$	-1.103
Total correlation	r_{2y}	0.261**
Panicles per unit area; X_3:		
Direct effect	P_{3y}	1.449
Indirect, via seed weight	$r_{13}P_{1y}$	-0.109
Indirect, via seeds per panicle	$r_{23}P_{2y}$	-1.093
Total correlation	r_{3y}	0.247**
Coefficient of determination:		0.706

* Significant at .05 level.
** Significant at .01 level.

Figure 11 gives a diagramatic representation of the interrelationships between sample yield and three components, seed weight, seeds per panicle and panicles per plant in the fertility experiment. Table 15 gives a numerical breakdown of these relationships. Figure 12 shows a diagram similar to Figure 11 except that panicles per unit area has been substituted in place of panicles per plant. Table 16 shows a numerical breakdown of the interrelationships between these characteristics.

Tables 15 and 16 both show seed weight to be the least important component in determining yield, both directly and indirectly. Seeds per panicle had the highest correlation with yield in both analyses, but panicles per unit area showed the largest direct effect of the components analyzed (0.885, Table 16). The coefficients of determination show that panicles per unit area was much more important in determining variation in yield (0.960, Table 16) than was panicles per plant (0.548, Table 15). Panicles per unit area and seeds per panicle, which were the important components in determining yield, were both increased significantly by the application of fertilizer.

The relative importance of the components in influencing yield and the interrelationships noted between characteristics in the fertility experiment were very similar to those reported for corresponding analyses in the seeding rate experiment.

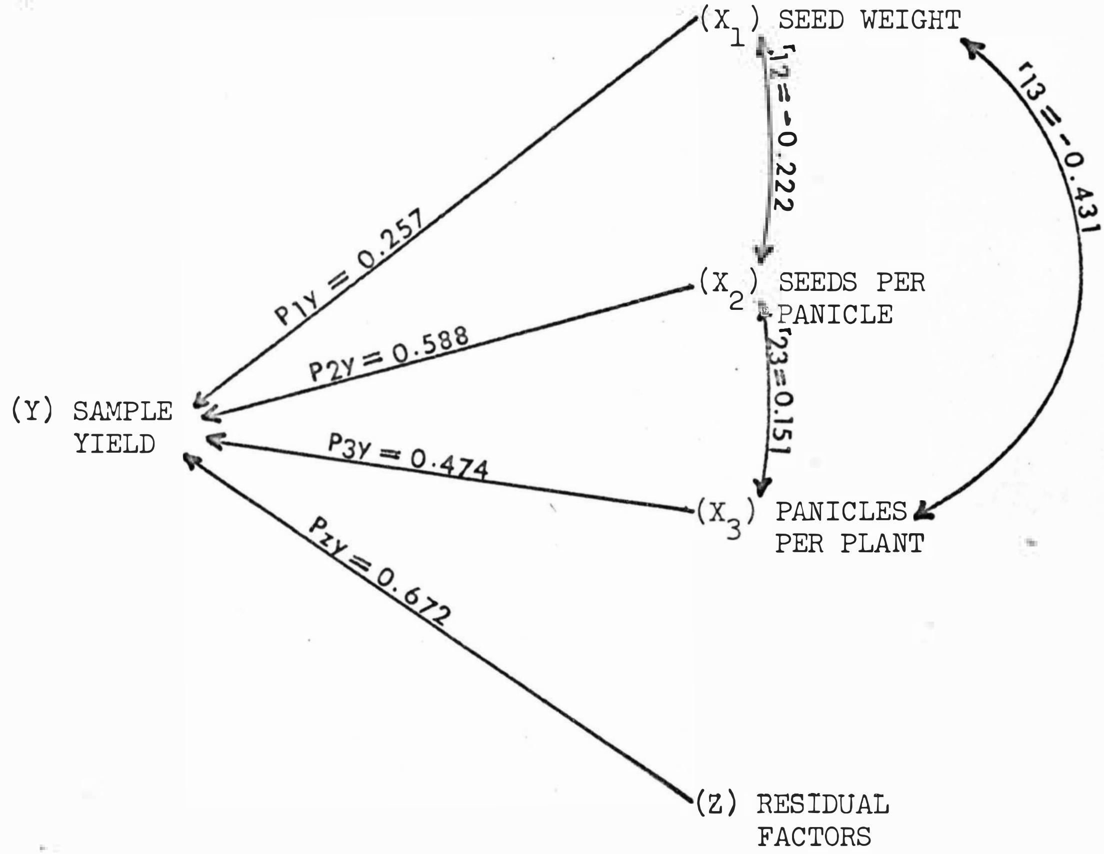

Figure 11. Diagramatic representation of the interrelationships between sample yield and three components in the fertility experiment.

Table 15. Path coefficient analysis of the influence of three components upon sample yield in the fertility experiment.

Type of influence and association		Phenotypic value
Seed weight; X_1:		
Direct effect	P_{1y}	0.257
Indirect, via seeds per panicle	$r_{12}P_{2y}$	-0.131
Indirect, via panicles per plant	$r_{13}P_{3y}$	-0.204
Total correlation	r_{1y}	-0.078
Seeds per panicle; X_2:		
Direct effect	P_{2y}	0.588
Indirect, via seed weight	$r_{12}P_{1y}$	-0.057
Indirect, via panicles per plant	$r_{23}P_{3y}$	0.071
Total correlation	r_{2y}	0.602**
Panicles per plant; X_3:		
Direct effect	P_{3y}	0.474
Indirect, via seed weight	$r_{13}P_{1y}$	-0.111
Indirect, via seeds per panicle	$r_{23}P_{2y}$	0.089
Total correlation	r_{3y}	0.452**
Coefficient of determination:		0.548

* Significant at .05 level.
** Significant at .01 level.

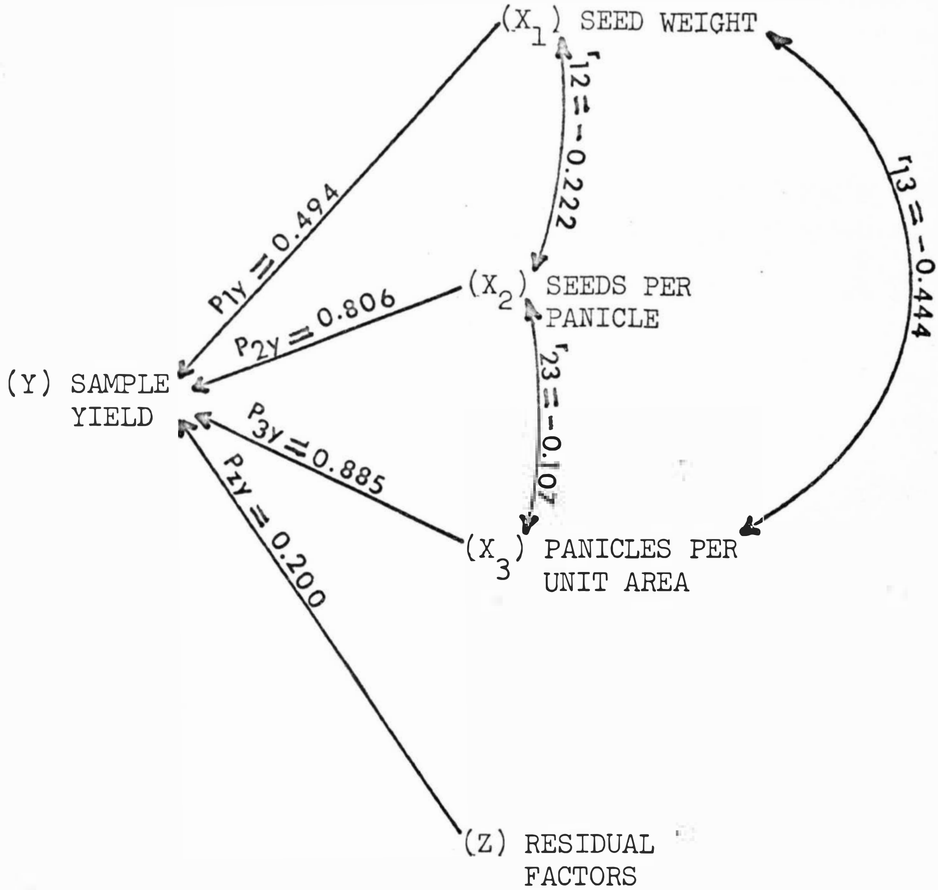

Figure 12. Diagramatic representation of the interrelationships between sample yield and three components in the fertility experiment.

Table 16. Path coefficient analysis of the influence of three components upon sample yield in the fertility experiment.

Type of influence and association		Phenotypic value
Seed weight; X_1:		
Direct effect	P_{1y}	0.494
Indirect, via seeds per panicle	$r_{12}P_{2y}$	-0.179
Indirect, via panicles per unit area	$r_{13}P_{3y}$	-0.393
Total correlation	r_{1y}	-0.078
Seeds per panicle; X_2:		
Direct effect	P_{2y}	0.806
Indirect, via seed weight	$r_{12}P_{1y}$	-0.110
Indirect, via panicles per unit area	$r_{23}P_{3y}$	-0.094
Total correlation	r_{2y}	0.602**
Panicles per unit area; X_3:		
Direct effect	P_{3y}	0.885
Indirect, via seed weight	$r_{13}P_{1y}$	-0.219
Indirect, via seeds per panicle	$r_{23}P_{2y}$	-0.086
Total correlation	r_{3y}	0.580**
Coefficient of determination:		0.960

** Significant at .01 level.

SUMMARY AND CONCLUSIONS

Six spring oat varieties were grown at four locations to study the effects of four seeding rates and three fertility levels on yield, yield components and other agronomic characteristics and to determine the relationships among these characteristics.

Increase in seeding rate did not significantly affect sample yield, but significantly hastened heading and maturity dates, increased panicles per unit area and test weight, decreased panicles per plant and seeds per panicle, and reduced plant height. The constancy of grain yields for different seeding rates was due primarily to the counterbalance of two components, namely, increase in panicles per unit area and decrease in seeds per panicle. The other component, seed weight, was unaffected. The high compensation between panicles per unit area and seeds per panicle demonstrates the need for a uniform stand if selection is to be made for either of these components. Varieties differed in their response to changes in seeding rate, especially for the two components, panicles per unit area and seeds per panicle.

Fertilization increased yield significantly, primarily through increases in panicles per unit area and seeds per panicle. Other significant effects were hastening of maturity, increased panicles per plant, plant height and lodging, and decreased seed weight and test weight. Varieties showed large differences in their response to fertilization for the components panicles per unit area and seeds per panicle. The response of yield and its components were related physiologically to the treatment variables.

Simple correlation and path coefficient analyses were used to study the associations among characteristics. Panicles per unit area, and seeds per panicle had the greatest direct effects upon yield. These components also showed significant effects indirectly through the other components. Seed weight had little effect upon yield either directly or indirectly through the other components.

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Appendix Table A. Variance components of yield and yield components for the seeding rate experiment.

Component estimated	Seed wt.	Panicles per unit area	Seeds per panicle	Panicles per plant	Sample yield	Plot yield
σ^2_{L}	0.01932	31.186	23.233	0.005	97.920	99.539
$\sigma^2_{R/L}$	0.00104	0.734	2.720	0.003	35.812	38.214
σ^2_{S}	0.00007	274.780	75.658	0.206	0.042	2.686
σ^2_{LS}	0.00188	3.540	3.011	0.006	4.856	- *
$\sigma^2_{RS/L}$	0.00083	1.543	1.276	0.002	8.493	1.515
σ^2_{V}	0.25344	59.570	17.709	0.014	16.194	11.049
σ^2_{LV}	0.01313	7.619	1.330	0.002	6.208	2.608
$\sigma^2_{RV/L}$	0.00750	1.500	1.265	0.001	13.721	–
σ^2_{SV}	0.00083	10.348	4.482	0.010	0.124	–
σ^2_{LSV}	0.00500	10.064	3.575	0.003	6.019	3.065
$\sigma^2_{RSV/L}$	0.01000	6.905	3.720	0.001	45.250	48.910
σ^2_{e}	0.04000	77.140	13.370	0.023	103.060	-- **

* Estimate of component was negative or very small.
** No residual component since determination was made on whole plot.

Appendix Table B. Treatment means for yield, yield components and other characteristics in the seeding rate experiment, (Average of six varieties).

Seeding rate, pecks/acre	Heading date	Lodging, %	Maturity date	Seed wt., g./200 seeds	Plant height, inches	Seedlings per unit area
			Brookings			
4	* 7-2	6.9	* 8-5	5.30	47.2	29.4
8	7-1	2.1	8-3	5.35	45.7	52.7
12	7-30	3.8	8-2	5.31	44.6	78.2
16	6-30	4.0	8-1	5.32	44.0	100.2
Overall $\bar{x}$	7-1	4.2	8-3	5.32	45.3	65.1
			Davis			
4	6-19	4.2	7-19	5.26	41.6	24.9
8	6-17	6.0	7-17	5.36	40.8	49.6
12	6-17	4.6	7-16	5.43	39.8	70.2
16	6-16	5.8	7-15	5.38	39.3	95.5
Overall $\bar{x}$	6-17	5.2	7-17	5.36	40.4	60.1

* 6 - June, 7 - July, 8 - August.

Appendix Table B. (continued) Treatment means for yield, yield components and other characteristics in the seeding rate experiment, (Average of six varieties).

Seeding rate, pecks/acre	Heading date	Lodging, %	Maturity date	Seed wt., g./200 seeds	Plant height, inches	Seedlings per unit area
			Garden City			
	*		*			
4	7-6	0.0	8-4	5.15	41.8	30.4
8	7-4	0.8	8-2	5.08	41.5	59.4
12	7-4	2.7	8-1	5.11	40.8	78.5
16	7-4	5.6	7-31	5.06	39.9	100.8
Overall $\bar{x}$	7-5	2.3	8-2	5.10	41.0	67.3
			Ipswich			
4	6-30	4.0	7-28	**	37.4	36.0
8	6-29	1.9	7-27		36.1	56.3
12	6-29	6.0	7-27		35.3	78.8
16	6-29	3.7	7-27		33.3	98.2
Overall $\bar{x}$	6-29	3.9	7-27		35.5	67.3

* 6 - June, 7 - July, 8 - August.

** No data available.

Appendix Table B. (continued) Treatment means for yield, yield components and other characteristics in the seeding rate experiment, (Average of six varieties).

Seeding rate, pecks/acre	Panicles per unit area	Test wt., lb./bu.	Seeds per panicle	Panicles per plant	Sample yield, bu./acre	Plot yield, bu./acre
			Brookings			
4	49.3	34.6	54.1	1.70	103.3	101.4
8	59.4	35.5	47.6	1.13	110.0	105.4
12	75.7	35.9	37.8	0.98	112.0	108.0
16	90.3	36.4	30.9	0.90	108.0	106.4
Overall $\bar{x}$	68.7	35.6	42.6	1.18	108.3	105.3
			Davis			
4	50.1	35.0	45.6	2.03	87.5	85.6
8	58.7	36.6	37.6	1.19	87.1	88.4
12	72.6	37.0	31.3	1.04	90.1	88.2
16	90.3	37.3	24.4	0.95	86.7	84.2
Overall $\bar{x}$	67.9	36.5	34.7	1.30	87.9	86.6

* 6 - June, 7 - July, 8 - August.

Appendix Table B. (continued) Treatment means for yield, yield components and other characteristics in the seeding rate experiment, (Average of six varieties).

Seeding rate, pecks/acre	Panicles per unit area	Test wt. lb./bu.	Seeds per panicle	Panicles per plant	Sample yield, bu./acre	Plot yield, bu./acre
			Garden City			
4	62.6	34.2	42.0	2.08	98.5	85.3
8	72.2	34.4	35.6	1.22	95.6	88.5
12	81.3	35.2	30.9	1.05	93.7	89.3
16	96.1	35.7	26.0	0.96	92.9	87.8
Overall $\bar{x}$	78.1	34.9	33.4	1.33	95.2	87.7
			Ipswich			
4	**	**	**	**	**	**
8						
12						
16						
Overall $\bar{x}$						

* 6 - June, 7 - July, 8 - August.

** No data available.

Appendix Table C. Variety means for yield, yield components and other characteristics in the seeding rate experiment, (Average of four seeding rates).

Variety	Heading date	Lodging, %	Maturity date	Seed wt., g./200 seeds	Plant height, inches	Seedlings per unit area
			Brookings			
	*		*			
Andrew	6-27	8.4	8-1	5.62	43.3	69.9
Garland	6-29	2.8	7-31	5.27	40.3	62.1
Lodi	7-4	0.6	8-6	5.99	50.4	68.9
Mo. 0-205	6-30	6.9	8-2	4.45	49.1	67.6
Rodney	7-7	6.3	8-8	5.30	50.1	57.1
Tippecanoe	6-27	0.0	7-30	5.29	39.1	65.1
Overall $\bar{x}$	7-1	4.2	8-3	5.32	45.3	65.1
			Davis			
Andrew	6-13	14.1	7-14	5.59	39.6	62.9
Garland	6-16	2.8	7-15	5.24	35.9	55.1
Lodi	6-21	2.2	7-20	6.06	44.6	62.0
Mo. 0-205	6-15	3.8	7-15	4.41	40.9	61.2
Rodney	6-25	7.5	7-22	5.44	44.8	57.2
Tippecanoe	6-14	0.6	7-14	5.40	36.4	61.9
Overall $\bar{x}$	6-17	5.2	7-17	5.36	40.4	60.1

* 6 - June, 7 - July, 8 - August.

Appendix Table C. (continued) Variety means for yield, yield components and other characteristics in the seeding rate experiment, (Average of four seeding rates).

Variety	Heading date	Lodging, %	Maturity date	Seed wt., g./200 seeds	Plant height, inches	Seedlings per unit area
			Garden City			
	*		*			
Andrew	7-2	4.4	7-30	5.54	41.3	68.6
Garland	7-3	3.1	7-31	5.15	36.7	61.0
Lodi	7-8	1.6	8-5	5.50	44.9	68.7
Mo. 0-205	7-3	2.2	7-31	4.22	42.8	70.2
Rodney	7-10	0.0	8-7	4.90	43.6	61.8
Tippecanoe	7-1	2.5	7-30	5.28	36.6	73.5
Overall $\bar{x}$	7-5	2.3	8-2	5.10	41.0	67.3
			Ipswich			
Andrew	6-26	4.1	7-25	**	33.4	64.7
Garland	6-27	9.7	7-26		32.2	66.8
Lodi	7-4	0.3	7-30		39.1	71.2
Mo. 0-205	6-28	5.0	7-26		38.4	68.6
Rodney	7-6	1.6	7-31		38.6	63.1
Tippecanoe	6-25	2.8	7-26		31.5	69.6
Overall $\bar{x}$	6-29	3.9	7-27		35.5	67.3

* 6 - June, 7 - July, 8 - August.

** No data available.

Appendix Table C. (continued) Variety means for yield, yield components and other characteristics in the seeding rate experiment, (Average of four seeding rates).

Variety	Panicles per unit area	Test wt., lb./bu.	Seeds per panicle	Panicles per plant	Sample yield, bu./acre	Plot yield, bu./acre
			Brookings			
Andrew	70.8	36.1	38.8	1.15	109.1	105.9
Garland	61.8	36.5	48.5	1.07	107.3	104.8
Lodi	66.4	33.7	40.3	1.06	108.9	106.3
Mo. 0-205	80.1	36.3	43.9	1.35	114.6	107.7
Rodney	61.6	34.5	47.7	1.22	112.3	109.0
Tippecanoe	71.3	36.7	36.4	1.23	97.7	98.0
Overall $\bar{x}$	68.7	35.6	42.6	1.18	108.3	105.3
			Davis			
Andrew	71.0	35.6	31.4	1.33	86.9	82.3
Garland	61.1	37.3	40.0	1.26	89.5	86.9
Lodi	63.2	35.8	33.5	1.13	85.8	90.1
Mo. 0-205	76.0	36.4	35.9	1.46	88.3	85.1
Rodney	63.1	36.7	38.8	1.24	94.8	92.7
Tippecanoe	63.2	36.9	28.7	1.39	82.0	82.5
Overall $\bar{x}$	67.9	36.5	34.7	1.30	87.9	86.6

* 6 - June, 7 - July, 8 - August.

Appendix Table C. (continued) Variety means for yield, yield components and other characteristics in the seeding rate experiment, (Average of four seeding rates).

Variety	Panicles per unit area	Test wt., lb./bu.	Seeds per panicle	Panicles per plant	Sample yield, bu./acre	Plot yield, bu./acre
			Garden City			
Andrew	74.7	34.7	31.4	1.25	94.1	85.7
Garland	67.7	36.8	36.6	1.24	91.5	85.0
Lodi	73.2	32.8	36.0	1.18	102.6	91.5
Mo. 0-205	96.5	34.8	33.5	1.61	100.4	91.5
Rodney	71.4	33.9	37.2	1.35	94.1	89.8
Tippecanoe	84.8	36.2	27.1	1.32	88.4	83.0
Overall $\bar{x}$	78.1	34.9	33.4	1.33	95.2	87.7
			Ipswich			
Andrew	**	**	**	**	**	**
Garland						
Lodi						
Mo. 0-205						
Rodney						
Tippecanoe						
Overall $\bar{x}$						

* 6 - June, 7 - July, 8 - August.
** No data available.

Appendix Table D. Variance components of yield and yield components for the fertility experiment.

Component estimated	Seed wt.	Panicles per unit area	Seeds per panicle	Panicles per plant	Sample yield	Plot yield
σ^2_{L}	0.01917	43.742	18.098	0.009	34.228	55.812
σ^2_{Ea}	0.00750	2.801	4.804	0.003	55.835	37.517
σ^2_{F}	0.01020	47.466	12.164	0.024	255.028	249.537
σ^2_{LF}	0.00140	-	-	-	-	- *
σ^2_{Eb}	0.00500	8.889	6.823	0.009	54.416	26.628
σ^2_{V}	0.31329	58.312	16.950	0.020	14.308	15.982
σ^2_{LV}	0.00625	9.866	1.447	-	6.492	8.159
σ^2_{Ec}	0.00500	4.898	4.898	0.007	22.962	-
σ^2_{FV}	0.00208	9.316	1.871	0.002	-	-
σ^2_{LFV}	0.01250	3.309	0.133	-	3.929	8.835
σ^2_{Ed}	0.00500	3.675	0.563	0.015	23.745	41.030
σ^2_{e}	0.07000	59.500	13.400	0.014	103.870	-- **

* Estimate of component was negative or very small.
** No residual component since determination was made on whole plot.

Appendix Table E. Treatment means for yield, yield components and other characteristics in the fertility experiment, (Average of six varieties).

Fertility level, (N+P+K)	Heading date	Lodging, %	Maturity date	Seed wt., g./200 seeds	Plant height, inches	Seedlings per unit area
			Brookings			
	*		*			
L(0+0+0)	7-1	0.6	8-4	5.33	40.9	49.3
M(30+9+0)	6-29	1.3	8-2	5.35	43.9	54.6
H(60+18+0)	7-1	2.3	8-3	5.24	46.5	52.2
Overall $\bar{x}$	6-30	1.4	8-3	5.31	43.8	52.0
			Davis			
L(0+0+0)	6-23	0.4	7-17	5.48	37.0	49.4
M(30+9+0)	6-17	5.0	7-17	5.43	40.5	47.8
H(60+18+0)	6-22	20.8	7-18	5.29	41.8	47.7
Overall $\bar{x}$	6-21	8.7	7-17	5.40	39.8	48.3
			Garden City			
L(0+0+0)	7-5	0.2	8-3	5.28	35.7	52.4
M(30+9+0)	7-4	1.3	8-2	5.11	39.2	56.7
H(60+18+0)	7-4	2.5	8-2	4.95	40.6	50.9
Overall $\bar{x}$	7-4	1.3	8-2	5.11	38.5	53.3
			Ipswich			
L(0+0+0)	6-30	0.6	7-29	**	29.2	50.6
M(30+9+0)	6-29	3.1	7-27		34.3	58.1
H(60+18+0)	6-29	3.3	7-27		37.1	56.1
Overall $\bar{x}$	6-29	2.3	7-28		33.5	54.9

* 6 - June, 7 - July, 8 - August.

** No data available.

Appendix Table E. (continued) Treatment means for yield, yield components and other characteristics in the fertility experiment, (Average of six varieties).

Fertility level, (N+P+K)	Panicles per unit area	Test wt., lb./bu.	Seeds per panicle	Panicles per plant	Sample yield, bu./acre	Plot yield, bu./acre
			Brookings			
L(0+0+0)	50.3	35.3	39.0	1.03	77.0	75.9
M(30+9+0)	59.0	35.9	43.8	1.09	101.2	98.3
H(60+18+0)	66.1	34.6	44.0	1.28	112.1	110.6
Overall $\bar{x}$	58.4	35.3	42.3	1.13	96.8	94.9
			Davis			
L(0+0+0)	51.8	36.7	31.2	1.06	65.5	63.6
M(30+9+0)	56.1	36.3	38.3	1.19	85.3	83.3
H(60+18+0)	66.4	35.2	38.1	1.40	98.0	96.9
Overall $\bar{x}$	58.1	36.1	35.9	1.22	82.9	81.3
			Garden City			
L(0+0+0)	64.3	33.9	29.4	1.23	72.2	66.0
M(30+9+0)	69.8	34.3	35.6	1.24	92.5	83.1
H(60+18+0)	75.6	34.3	36.4	1.52	99.6	92.2
Overall $\bar{x}$	69.9	34.2	33.8	1.33	88.1	80.4
			Ipswich			
L(0+0+0)	**	**	**	**	**	**
M(30+9+0)						
H(60+18+0)						
Overall $\bar{x}$						

* 6 - June, 7 - July, 8 - August.
** No data available.

Appendix Table F. Variety means for yield, yield components and other characteristics in the fertility experiment, (Average of three fertility levels).

Variety	Heading date*	Lodging, %	Maturity date*	Seed wt., g./200 seeds	Plant height, inches	Seedlings per unit area
			Brookings			
Andrew	6-27	2.5	8-1	5.57	43.0	50.7
Garland	6-29	0.0	7-31	5.11	38.8	51.4
Lodi	7-4	0.0	8-6	6.07	48.4	54.6
Mo. 0-205	6-30	4.2	8-3	4.34	46.4	51.2
Rodney	7-4	1.7	8-8	5.38	48.3	50.8
Tippecanoe	6-28	0.0	7-30	5.38	37.6	53.5
Overall $\bar{x}$	6-30	1.4	8-3	5.31	43.8	52.0
			Davis			
Andrew	6-18	26.7	7-14	5.51	38.6	51.4
Garland	6-25	6.7	7-15	5.34	35.2	45.1
Lodi	6-20	1.7	7-20	6.21	44.5	51.8
Mo. 0-205	6-21	6.7	7-16	4.41	41.2	49.9
Rodney	6-26	8.3	7-24	5.51	44.0	45.0
Tippecanoe	6-17	2.5	7-15	5.41	35.2	46.6
Overall $\bar{x}$	6-21	8.7	7-17	5.40	39.8	48.3

* 6 - June, 7 - July, 8 - August.

Appendix Table F. (continued) Variety means for yield, yield components and other characteristics in the fertility experiment, (Average of three fertility levels).

Variety	Heading date	Lodging, %	Maturity date	Seed wt., g./200 seeds	Plant height, inches	Seedlings per unit area
			Garden City			
	*		*			
Andrew	7-1	2.9	7-31	5.46	39.3	54.5
Garland	7-2	2.5	7-31	5.18	34.6	50.7
Lodi	7-9	0.0	8-6	5.74	42.3	51.1
Mo. 0-205	7-2	1.3	8-1	4.12	40.5	55.5
Rodney	7-10	0.8	8-7	5.03	40.7	52.2
Tippecanoe	7-1	0.4	7-31	5.14	33.5	56.0
Overall $\bar{x}$	7-4	1.3	8-2	5.11	38.5	53.3
			Ipswich			
Andrew	6-25	5.8	7-26	**	33.1	54.5
Garland	6-27	3.3	7-27		30.3	52.6
Lodi	7-4	0.8	7-29		35.9	59.3
Mo. 0-205	6-28	2.1	7-27		35.5	56.8
Rodney	7-7	0.4	7-31		36.5	48.3
Tippecanoe	6-25	1.7	7-26		29.8	58.2
Overall $\bar{x}$	6-29	2.3	7-28		33.5	55.0

* 6 - June, 7 - July, 8 - August.
** No data available.

Appendix Table F. (continued) Variety means for yield, yield components and other characteristics in the fertility experiment, (Average of three fertility levels).

Variety	Panicles per unit area	Test wt., lb./bu.	Seeds per panicle	Panicles per plant	Sample yield, bu./acre	Plot yield, bu./acre
			Brookings			
Andrew	55.9	35.8	40.1	1.11	94.0	93.3
Garland	52.3	37.0	48.0	1.02	95.5	92.0
Lodi	54.7	33.3	38.4	1.02	95.3	95.3
Mo. 0-205	68.9	35.6	43.5	1.36	97.6	94.3
Rodney	55.5	33.8	46.9	1.11	104.5	103.5
Tippecanoe	63.3	36.2	36.6	1.19	93.7	90.9
Overall $\bar{x}$	58.4	35.3	42.3	1.13	96.8	94.9
			Davis			
Andrew	60.1	35.3	32.8	1.19	81.2	76.8
Garland	52.8	37.5	40.1	1.18	84.9	83.1
Lodi	54.0	35.1	34.0	1.05	83.5	84.0
Mo. 0-205	69.6	36.5	37.5	1.42	86.6	85.1
Rodney	50.0	36.2	40.9	1.12	84.8	83.1
Tippecanoe	62.3	36.8	30.1	1.35	76.6	75.7
Overall $\bar{x}$	58.1	36.2	35.9	1.22	82.9	81.3

* 6 - June, 7 - July, 8 - August.

Appendix Table F. (continued) Variety means for yield, yield components and other characteristics in the fertility experiment, (Average of three fertility levels).

Variety	Panicles per unit area	Test wt., lb./bu.	Seeds per panicle	Panicles per plant	Sample yield, bu./acre	Plot yield, bu./acre
			Garden City			
Andrew	68.8	33.7	32.9	1.35	92.1	80.1
Garland	58.8	35.6	36.8	1.17	83.5	76.4
Lodi	60.3	32.8	36.1	1.19	92.4	88.9
Mo. 0-205	91.0	33.9	34.0	1.66	95.9	81.9
Rodney	64.3	34.0	37.4	1.24	89.5	83.9
Tippecanoe	76.2	35.0	25.5	1.38	75.2	71.5
Overall $\bar{x}$	69.9	34.2	33.8	1.33	88.1	80.5
			Ipswich			
Andrew	**	**	**	**	**	**
Garland						
Lodi						
Mo. 0-205						
Rodney						
Tippecanoe						
Overall $\bar{x}$						

* 6 - June, 7 - July, 8 - August.
** No data available.