# Row spacing and growth habit effects on soybean productivity under farming conditions

by

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# INTRODUCTION

The soybean (*Glycine max* (L) Merr.), in a relatively short time period, has become a major crop in the North Central United States. Expanded usefulness of the soybean and its products has caused increased demand. The greater demand has been followed by more hectarage under production. Improved cultivars, combined with better management and more efficient cultural practices, are helping to satisfy world demand by increasing yields per hectare.

In the North Central Soybean Production Area, large hectarages of indeterminate soybean genotypes have traditionally been grown in a crop rotation system with maize (*Zea mays* L.). This system is a complementary one for producers because, if they so choose, the same planting and interrow cultivation equipment can be used for both crops in the rotation.

The main advantages growers obtain are reduced equipment costs and the option for postemergence mechanical cultivation. A possible disadvantage of this system is that producers may be losing potential soybean yield by using a wider than optimum soybean row spacing. Wide rows are better suited for the maize crop.

Maize is grown largely in row widths of 70 cm or more in the North Central Production Area under present systems. Decreasing soybean row widths from this spacing is a cultural practice that generally results in greater yields in the northern United States soybean production areas. Producers have the option to choose either an arrangement of unit planters or a grain drill for seeding to achieve narrow row spacings.

Response to narrow rows is variable among soybean genotypes and environments. And, commercial soybean production systems may differ from some research environments in yield level and other factors.

The objectives of this study were to:

1) evaluate soybean row spacing systems in a situation intended to simulate farming conditions, and;
2) compare performance of determinate and indeterminate cultivars under these conditions to determine whether there is a growth habit by row spacing interaction.

# REVIEW OF LITERATURE

## Row Spacing

Many studies in the North Central Soybean Production Area have shown yield increases from soybeans as row widths are narrowed from 100 cm to 50 cm, and higher or unchanged yields as row widths decrease from 50 cm to about 20 cm. Benson and Shroyer (1978), based on a review of research performed in Iowa, concluded that 10, 17, and 22% increases could be expected from narrowing row widths from 102 cm to 76, 51, and 25 cm, respectively. Cooper (1977) found 10 to 20% yield increases from 17 cm row widths compared with 50 and 75 cm row widths under weed-free conditions in Illinois over a six-year period. In a 15-year summary of row spacing comparisons in Humboldt County, Iowa, Moklestad (1985) reported a 0.6 to 0.9 Mg/ha yield advantage for row widths 45 cm or less compared with spacings of 75 cm or more.

Walker and Fioritto (1984) found an 18% average yield increase from decreasing row widths from 76 to 19 cm when eleven soybean cultivars were tested in three environments over a two-year period. Costa et al. (1980) found a 21% seed yield advantage for 27 over 76 cm wide rows during three seasons of testing. Using ten cultivars and three intra-row plant spacings for each row width, Costa found that variations in intra-row plant spacing had little influence on yield.

Wilkens (1982) compared soybean performance in 18, 35, 51, and 71 cm row spacings subjected to tractor traffic treatment at differing times of development. Skip-row treatments (unplanted rows arranged to allow tractor wheel traffic to avoid plant damage) in the 18 and 35 cm spacings yielded 5 to 9% less than equivalent traffic treatments without skips. Tractor tire traffic during earlier stages of plant development caused little yield reduction of whole plots, but individual rows were affected greatly. On the average, row spacings of 18 and 35 cm yielded 8 to 9% more seed than the 71 cm spacings, which had no rows driven on but received equal compaction treatment.

Wiggans (1939) concluded that the closer to equidistant distribution of plants in a soybean stand, the greater would be its yield. Using near equidistant spacings and a wide range of population densities, Wilcox (1974) reported that there was a differential response of soybean genotypes to plant density.

For some tests, soybean response to reduced row width has been variable. Beaver and Johnson (1981) found a 5 to 9% seed yield increase as row spacings were narrowed from 80 to 50 cm, but yields in 50 and 20 cm widths did not differ. Hicks et al. (1969) tested four plant types in 76 and 25 cm row widths and found no seed yield difference between widths. Using equal plant populations in 25, 50, 75, and 100 cm row widths, Taylor (1980) found a significant yield response in only one of three years -- a 17% increase of 25 cm over 100 cm spacings during a year with a high moisture supply.

Shroyer (1980) used three population densities and found about an 8% yield increase from decreasing row widths from 69 to 34 cm, but no difference between 34- and 17-cm row spacings. Cooper (1971b) found yields in 17- and 50-cm row widths to be essentially equal unless planting date was delayed until early June during one season in Illinois. Lodging and yield varied with planting date, row width, and seeding rate in his study.

Theoretically, the more uniform distribution of soybean plants in narrower row widths implies reduced intra-plant competition for PAR, water, and nutrients, and therefore, potentially greater seed yield. Whether a narrow row yield advantage will be manifested enough to be statistically significant is influenced by environment, genotype, and population density of a soybean stand. These factors seem to interact and confound the ultimate results of row spacing research in many environments.

## Growth Habit

Three soybean growth habits have been described: determinate, semideterminate, and indeterminate. Differences between growth habits are observed as differences in timing of stem termination. The determinate types abruptly terminate stem elongation with the onset of flowering; some additional vegetative growth may occur as branching. Flowering is nearly simultaneous among nodes, and flowering duration is often somewhat shorter than that of indeterminate genotypes of similar seasonal duration. The main stem ends in a terminal raceme with numerous pods. In contrast to determinates, indeterminate types often double in height after flowering begins. Flowering progresses upward from the lower nodes, ultimately resulting in less lateral growth in the upper plant portions and a terminal node with one or two pods. The semideterminate growth habit has traits intermediate to determinates and indeterminates. Semideterminates typically terminate apical stem elongation somewhat earlier than indeterminates, and have less pods on the terminal raceme than determinates (Bernard, 1972).

Determinate soybean genotypes have primarily been grown in the Southern United States (south of about 38°N). Indeterminate genotypes predominate in the northern United States, and are thought to be more adaptable to the shorter cropping seasons of the most northern latitudes (Shibles, 1980). Within the past decade, determinate soybean genotypes adapted to the northern United States have been released. In northern latitudes, determinate cultivars are generally shorter and less lodging susceptible than indeterminate genotypes (Bernard, 1972). Because of this, researchers have suggested that the determinate or semideterminate growth habit may be a useful trait in varieties in the North Central Soybean Production Area (Shibles and Green, 1969; Hicks et al., 1969; Hartwig and Edwards, 1970; Cooper, 1981).

Some research in northern latitudes indicates a yield advantage for determinate cultivars in certain environments (Cooper, 1981; Fehr, 1978). Much of this work has been done under very high productivity (often including supplemental irrigation). In other tests, yield responses have been variable with the principal advantage being less lodging (Beaver and Johnson, 1981). Many studies have shown lodging to be an impediment to soybean yield under highly productive environments (Cooper, 1971a, 1971b; Wilcox and Sediyama, 1981). Cooper (1971a) found a 21 to 23% yield increase when natural lodging was prevented by use of artificial support.

Still other researchers have shown there to be no yield advantage for determinate cultivars at northern latitudes. Shroyer (1980) reported that determinate and semideterminate genotypes had no greater yield response to reduced row widths than indeterminates did, in agreement with the results of Beaver and Johnson (1981). Villalobos-Rodriguez et al. (1984) found there to be no difference between determinate, semi-determinate, and indeterminate genotypes in yield response to supplemental irrigation, which agrees with the results of Hartung et al. (1981).

Chang et al. (1982) and Green et al. (1977) found there to be no yield difference between indeterminate and semideterminate genotypes. In contrast, Wilcox (1980) recorded a 3 to 8% greater yield from indeterminates than semideterminates.

Some researchers have suggested that determinate soybean cultivars may not respond as well to environmental stress as indeterminate cultivars do in northern latitudes. Beaver and Johnson (1981) and Cooper (1981) suggested that determinate cultivars are less able to compensate for moisture stress during vegetative development than indeterminate genotypes. When subjected to defoliation, determinate and semideterminate genotypes have been shown to suffer greater yield reduction than indeterminates with similar genetic backgrounds (Fehr et al., 1977, 1981, 1984).

Green (1982) noted an apparent trend of determinate cultivars to yield well under more favorable environments, but their yields seemed to be equal to or lower than other genotypes when environments were less than favorable.

## Environmental Influences

Large environmental variability among seasons and locations is not unusual in the North Central Soybean Production Area. Environmental variability and variations in cultural practices have a strong influence on crop yields. Such differences should be taken into account when evaluating soybean yield responses.

A principal occurrence thought to account for a large portion of potential yield advantages from narrow row widths is the swifter accumulation of LAI, and subsequently greater PAR interception (Shaw and Weber, 1967; Shibles and Weber, 1966). Longer (1980) associated about 90% of the narrow row soybean yield increase with increased PAR interception.

Available moisture is a highly influential factor in soybean production. Water-use efficiency has been reported to increase as row widths decrease (Timmons et al., 1967; Peters and Johnson, 1960). Earlier canopy formation results in more rapid soil shading, and potentially, less evaporation loss. Taylor (1980) indicated that this benefit may be offset by canopy transpiration, however.

Weed competition is affected by many factors, and may reduce soybean yields drastically (Burnside, 1979). Narrower row widths complete canopy closure earlier, aiding weed suppression. But, the loss of the option to cultivate means increased dependence on herbicides to control weeds. This means greater risk, particularly when the weather is unfavorable for good stand establishment and or herbicide activity. A uniform stand is a necessity for good weed control in narrow row widths. Wax (1972) recommended rows wide enough for cultivation if soybean land has a history of herbicide-resistant and or perennial weed problems. More recently, improved herbicides have made reliance on chemical weed control more practical.

In the North Central Soybean Production Area, soybean cropping system research involves a complex situation in which several factors can influence the main effects of a particular treatment. Environments often vary seasonally and among locations. Soybean genotypes may respond differently to the varying environments (Lehman and Lambert, 1960).

Row spacing studies may be influenced by plant population densities, plant distribution, crop genotype, and other factors. If the seeding equipment is different between spacings, caution must be used in separating the main effects of spacings from a response partially attributable to a differential effect between seeding implements. Compaction, herbicide treatment, interrow cultivation, disease and insect control, and weed competition are some of the other factors that may confound row spacing research.

# MATERIALS AND METHODS

## Location

An area with a maize-soybean cropping history was selected from grower's fields in the 1984 and 1985 growing seasons. The location was approximately 2 km east of Ankeny, in central Iowa (about 42°N).

The soil was a Webster silty clay loam (Typic Haplaqoul) with little slope (2-3%). Drainage was adequate, facilitated by underground clay tile. Iowa State University Soil Testing Laboratory results showed very high levels of phosphorus and high levels of potassium. The soil was slightly acidic (pH 5.9), and had a 3.7 to 3.8% organic matter content.

## Treatments

The experiment compared two cropping systems, conventional 75-cm rows versus grain-drill seeding. Six soybean cultivars were grown under each system.

The planting equipment for the 75-cm spacings was a 6-row 'John Deere' Model 1250 Plateless Planter. This model has single-runner seed furrow openers, and 17.5-cm wide press wheels with concave rubber tires.

An end-wheel grain drill was used: In 1984 it was an 'International Harvester' Model 5100 Soybean Special, in 1985 a 'John Deere' Model 8300. Both drills had 23 row openings, fluted seed metering mechanisms, double-disk seed furrowers, and narrow press wheels (approximately 2 to 4 cm wide) of about 25-cm diameter. Drill rows averaged to be 17 cm apart.

Three varieties each of determinate and indeterminate stem termination were selected, with the intention of matching three growth habit pairs of similar seasonal duration. The cultivars used in order of increasing seasonal duration were: Determinates 'Gnome', 'Sprite', and 'Elf'; indeterminates 'Asgrow 3127', 'Asgrow 3659', and 'Williams 82'.

The experimental design was a split-block with four replications. Cropping systems represented the main blocks. Cultivars were randomized within each row spacing.

## Plant Culture

The previous crop had been maize. The maize residue had been chisel-plowed in the fall after grain removal. In the spring the site was disked twice prior to planting. A preplant-incorporated herbicide was applied behind a 'Hiniker' field cultivator with a three-bar harrow attached to aid incorporation and level the seedbed. 'Dual' (metolachlor) was used each year at a rate of 3.3 kg ai/ha. Additionally, 'Amiben' (chloramben) was incorporated in 1984 at 4.5 kg ai/ha.

Because of their shorter plant stature and according to recommendations from previous research, the determinate cultivars were assumed to have a greater optimum plant density than the indeterminates. Therefore, the desired final populations were: For drilled plots 555,750 plants/ha for indeterminates and 741,000 plants/ha for determinates; for 75-cm plots 370,500 plants/ha for indeterminates and 555,750 plants/ha for determinates.

Seeding rates were adjusted according to germination (90%), and increased 10% to compensate for rotary hoeing of each spacing. Drilled seeding rates were increased an additional 10% to make up for possible poor coverage by the drill. Adjusted drilled plot seeding rates were 18.1 seeds/m row for determinates and 13.8 seeds/m row for indeterminates. Adjusted seeding rates in the 75-cm plots were 36.8 seeds/m row for determinates and 29.5 seeds/m row for the indeterminates.

Planting dates were 15 May 1984 and 17 May 1985. Dry conditions prevailed both years at seeding. Plots consisted of one drill width (3.9m) or one six-row pass (4.5m) of the row planter. Plot lengths were 91 m in 1984 and 76 m in 1985.

Plots were rotary-hoed at emergence. The 75-cm plots were mechanically cultivated once in 1984, twice in 1985.

Postemergence herbicide treatments were used both years. Spraying dates were 13 June 1984 and 21 June 1985, when the soybean plants were at the one to two trifoliolate leaf stage. 'Basagran' (bentazon) and 'Blazer' (aciflourfen) were tank-mixed and applied at a rate of 1.12 kg ai/ha bentazon plus 0.56 kg ai/ha aciflourfen. In 1984, both spacings received herbicide treatment. The plots were treated individually by spraying directly over the plot centers with a tractor-mounted sprayer. In 1985, only the drilled plots were sprayed. Treatments were applied to two plots simultaneously by straddling the plot borders with the tractor. Tractor traffic damage was confined mostly to a single row per wheel track (Figure 1), so the drilled plots had effectively two rows driven over in 1984, but only one row driven over in 1985.

## Data Collected

During the growing season, reproductive development was recorded as the number of days (after 30 April) to R1, R5, R7, and R8 as described by Fehr and Caviness (1977). Plant height was measured at maturity as the distance from the ground to the average plant stem tip in four areas per plot. Lodging was rated on a 1-5 scale (1 = erect, 5 = flat). Weediness was rated on a 1-5 scale, 1 corresponding to weed competition in 20% or less of the plot, 5 corresponding to 80% or more of the plot being weedy.

After physiological maturity, estimates of yield components were made by sampling two to four 1 $m^2$ areas per plot. Variables sampled included population densities, number of branches, number of pods borne on branches, and number of pods borne on main stems. Total pods per area were determined by addition. Yield was taken by combine harvest. A subsample of seed was taken at harvest for determining weight per 100

Figure 1. Drilled soybeans after herbicide treatment showing tractor tire damage

seed. Seed moisture was measured at harvest with a portable moisture meter. In 1984 it was a uniform 15.1%. In 1985 it varied by plot. Yield estimates were adjusted to 13.0% moisture.

## Harvest

A 'John Deere' Model 3300 combine was used in 1984, a 'Massey Ferguson' Model 760 was used in 1985. Both combines were equipped with 'Hiniker' floating cutter-bar gathering heads. Stubble height was short, about 4 to 5 cm, and harvest loss was considered negligible for all cultivars.

Plot ends were trimmed 1.6 m each year. The center rows of the plots were harvested and border rows left standing in 1984 by use of a combine with a 3.7 m wide gathering head. In 1985, the border rows were mowed two days prior to harvest with a walk-behind rotary cutter. Four rows of 75-cm plots and 19 rows of 17-cm plots were harvested.

Harvest dates were 14 October 1984, and 29 October 1985. Harvested seed was weighed from the combine by use of a scale wagon.

# RESULTS

## Growing Season Weather

A shortage of water is sometimes the most important factor limiting soybean growth and seed yield. During certain stages of development (particularly bloom and or seed-filling) moisture stress may have a significant effect on the yield component developing (Momen et al., 1979; Sionit and Kramer, 1977). After a period of stress, compensation for earlier stress effects may occur through later-developing yield components if the environment and seasonal duration permit. Because moisture stress effects are dependent upon the degree and the timing of the stress, daily observations of precipitation, maximum temperature, and minimum temperature were recorded. A table of these values can be found in the Appendix (Table A-1). Figure 2 shows a plot of mean monthly precipitation for the two seasons compared with the 25-year mean.

The 1984 growing season was characterized by above normal rainfall in April through July. In August, when the soybeans were in the seed-filling stage of reproductive development, little rainfall occurred and high temperatures prevailed. A killing frost on 26 September terminated the growth of some plots, affecting primarily Elf and Williams.

The 1985 growing season had below average precipitation for the majority of the season. Rainfall was insufficient for

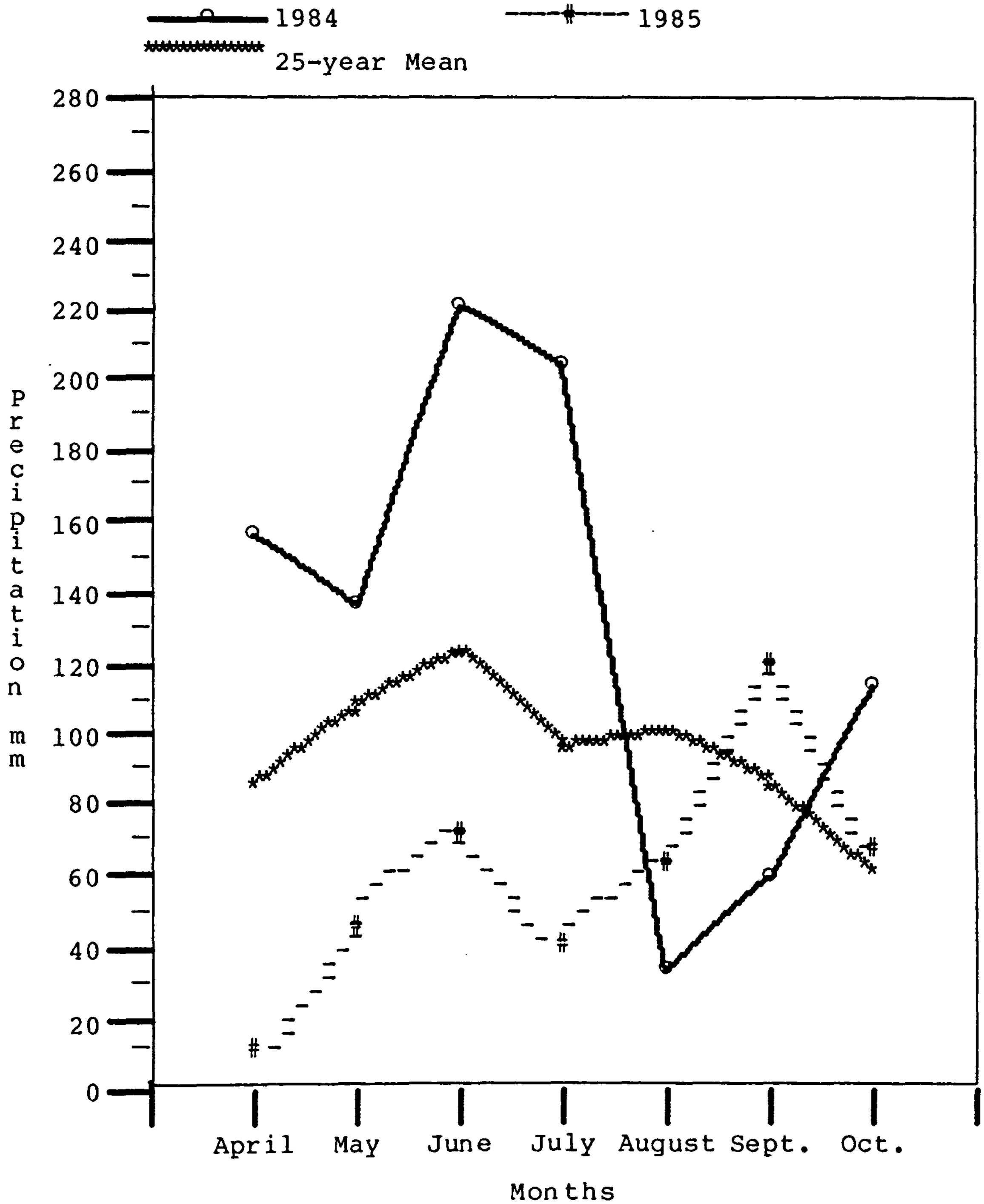


Figure 2. 1984 and 1985 Monthly precipitation and 25-year mean for Ankeny, Iowa

optimum emergence and abundant vegetative growth in the months of April through July. August had below normal precipitation during seed-filling, but some timely rains did occur before the first killing frosts.

The 1984 precipitation total for April through October was about 45% greater than the 25-year mean, which is 626 mm. In 1985, only 407 mm fell in the same period, which is about 35% less than the 25-year mean. These differences between the seasons had important effects on growth and yield as discussed in subsequent sections.

Another observation of possible importance was the occurrence of hail on 9 September 1984 and 23 June 1985. The hail was not large enough (< 2.5 cm diameter) to cause a stand reduction, but some leaf tearing, defoliation, and stem bruising did result. The determinate types may have been unable to recover from this damage as well as the indeterminate types (Fehr et al., 1977, 1981).

## Population Densities

Population density data are shown in Table 1. The difference between the growth habits was less than the 25% difference in seeding rates for the drilled plots, but the 75-cm row plots did show about a 25% difference in population density between the two growth habits. Population densities were much lower in 1985, primarily because of inadequate

Table 1. Population densities for cropping systems and growth habits

| | Plants/$m^2$ | | |
|---|---|---|---|
| | 1984 | 1985 | Seeding rate |
| Drilled | | | |
| Det. | 79 | 33 | 81 |
| Indet. | 70 | 31 | 62 |
| 75-cm rows | | | |
| Det. | 45 | 27 | 55 |
| Indet. | 38 | 21 | 44 |
| Cropping system main effects | | | |
| Drilled | 75 | 32 | |
| 75-cm rows | 42 | 24 | |

moisture for emergence. The drilled plots suffered a larger reduction than the wider spacing.

Since cropping season populations differed, and different population densities were used for the two row spacings, and because the determinate cultivars were seeded at greater rates than the indeterminates, most observations of plant characteristics will be discussed on a per-area rather than a per-plant basis.

## Seed Yield

There were highly significant interactions involving years in the analysis of variance of the combined data for seed yield (Table A-2). Consequently, results will be presented by years separately.

Cropping system and growth habit mean seed yields can be found in Table 2. Mean squares and F-ratios for the analysis of variance are in Appendix Tables A-3 and A-4. Cultivar means are shown in Appendix Tables A-5 and A-6. The 1984 results show drilled seed yields to be 0.07 Mg/ha greater, but this was not statistically significant. The yield response of drilled rows over the wider spacing was greater for the determinate cultivars, an average of 6% compared with 1% for the indeterminates.

Cultivar response varied considerably within the growth habits, but in general indeterminates were significantly superior in yield to determinates (Tables A-5 and A-6 of

Table 2. Soybean seed yield means for cropping systems, growth habits, and growing seasons

| | Seed yield (Mg/ha) | |
|---|---|---|
| | 1984 | 1985 |
| Drilled | | |
| Det. | 2.03 | 0.93 |
| Indet. | 2.52* | 1.52* |
| 75-cm rows | | |
| Det. | 2.07 | 2.23 |
| Indet. | 2.49* | 2.32 |
| Growth habit main effects | | |
| Det. | 2.05 | 1.58 |
| Indet. | 2.51* | 1.92* |
| Cropping systems main effects | | |
| Drilled | 2.31 | 1.22 |
| 75-cm rows | 2.24 | 2.27* |
| LSD (0.05) | 0.11 | 0.29 |

*Significant at 0.05 level.

Appendix). In 1984, the mean yield for the indeterminate cultivars was 0.42 Mg/ha greater for the 75-cm plots, and they yielded 0.49 Mg/ha greater than the determinate types did in the drilled plots.

In 1985, there was a cropping system by growth habit interaction (Pr > F = 0.08, Table A-4). The determinate genotypes again averaged to be lower in yield than the indeterminate genotypes (Table 2). This advantage in yield for the indeterminates was significant in the drilled plots, but not in the 75-cm row plots. The indeterminate cultivar yields averaged to be 0.09 Mg/ha greater for the 75-cm plots and 0.6 Mg/ha greater for the drilled plots.

Of interest is that the determinate cultivar Sprite was able to yield well in the wider row spacing (Tables A-5, A-6) compared with other determinates. This performance was part of the reason the growth habit mean yields did not differ significantly in the wider spacing in 1985. This will be elaborated upon in the discussion section.

## Plant Branching

Plant branching data are shown in Table 3. Large differences were observed in branch numbers between the two growth habits, with the determinate types typically showing about a three-fold greater branch number. Fewer branches were produced in 1985. Interestingly, the branch numbers per area were fairly similar for the two cropping systems each year,

Table 3. Plant branching for cropping systems, growth habits, and growing seasons

| | Branch number/$m^2$ | |
|---|---|---|
| | 1984 | 1985 |
| Drilled | | |
| Det. | 196 | 142 |
| Indet. | 52 | 36 |
| 75-cm rows | | |
| Det. | 183 | 148 |
| Indet. | 63 | 54 |
| Growth habit main effects | | |
| Det. | 189* | 145* |
| Indet. | 57 | 45 |
| Cropping system main effects | | |
| Drilled | 124 | 89 |
| 75-cm rows | 123 | 101 |
| LSD (0.05) | 11 | 14 |

*Significant at 0.01 level.

despite the population density differences between the cropping systems. There was a tendency for indeterminates to branch less in drilled plots while determinates were similar between cropping systems. However, this effect was statistically significant only in 1984 (Tables A-3, A-4). The branching data should be kept in mind when comparing the pod distribution results discussed next.

## Pod Distribution

Data for pod distribution, separated between pods borne on branches and pods borne on the main stems, are shown in Table 4. For the most part, pod distribution trends showed similarity in the two years. Pod numbers on branches were much greater for the determinate types, whereas main stem-borne pod numbers were higher for the indeterminate types. Fewer pods were branch-borne in drilled plots, although in 1985 the differences were not significant. The cropping system by growth habit interaction was significant for main-stem pods, but not for branches. Determinates had a greater difference in main stem pod number between cropping systems than indeterminates did. A pod number advantage was not observed for the indeterminate types, despite their greater yields. In fact, determinates had significantly greater total pod numbers both years. Within growth habits, Williams had fewer pods and larger weight per seed than the other varieties (Tables A-5, A-6).

Table 4. The distribution of pods between pods borne on branches and those borne on main stems for growth habits, cropping systems and growing seasons

| | Pod number/$m^2$ | | | | | |
|---|---|---|---|---|---|---|
| | 1984 | | | 1985 | | |
| | Branches | Main-Stems | Total | Branches | Main-Stems | Total |
| Drilled | | | | | | |
| Det. | 324 | 527 | 851 | 257 | 355 | 612 |
| Indet. | 51 | 686 | 737 | 47 | 492 | 539 |
| 75-cm rows | | | | | | |
| Det. | 418 | 340 | 759 | 327 | 297 | 624 |
| Indet. | 120 | 584 | 703 | 116 | 491 | 606 |
| Growth habit main effects | | | | | | |
| Det. | 371 | 434 | 805 | 292 | 326 | 618 |
| Indet. | 85 | 635 | 720 | 81 | 491 | 573 |
| Cropping system main effects | | | | | | |
| Drilled | 187 | 606 | 794 | 152 | 423 | 576 |
| 75-cm rows | 269 | 462 | 731 | 222 | 394 | 616 |
| LSD (0.05) | 32 | 37 | 54 | 30 | 31 | 39 |

## Plant Height

Plant height data are listed in Table 5. Because precipitation varied greatly between seasons so did the length of the main stems. In the wet year of 1984, the indeterminate types averaged to be twice as tall as the determinate cultivars, but in 1985 the indeterminate types were much shorter. They averaged only 30% taller than the determinate cultivars. The growth habit by cropping system interaction was not significant for plant height either year.

## Lodging

Very little lodging was observed for the determinate cultivars in all cases, as can be seen in Table 6. Across years, the determinate lodging ratings were less than those of the indeterminate types.

In 1984, there were greater differences in lodging than in 1985. The drilled plots lodged more on the average than the 75-cm row plots in 1984 (Table 6).

In the drier 1985 growing season, the indeterminate lodging ratings were reduced markedly, which was an expected response due to their relatively shorter stature under these conditions. Differences between the cropping systems were not significant in 1985 (Table A-4). The determinate lodging ratings suggest that they lodged more in 1985, but this is misleading because this measurement is a relative comparison within years, not an absolute comparison between years.

Table 5. Plant height data for cropping systems, growth habits and growing seasons

| | Main stem length (cm) | |
|---|---|---|
| | 1984 | 1985 |
| Drilled | | |
| Det. | 51 | 51 |
| Indet. | 96 | 67 |
| 75-cm rows | | |
| Det. | 42 | 56 |
| Indet. | 91 | 71 |
| Growth habit main effects | | |
| Det. | 47 | 53 |
| Indet. | 94 | 69 |
| Cropping system main effects | | |
| Drilled | 73 | 59 |
| 75-cm rows | 66 | 63 |
| LSD (0.05) | 3 | 3 |

Table 6. Lodging ratings for growth habits, cropping systems, and growing seasons

| | Lodging (1 to 5) | |
|---|---|---|
| | 1984 | 1985 |
| Drilled | | |
| Det. | 1.04 | 1.06 |
| Indet. | 2.75 | 1.57 |
| 75-cm rows | | |
| Det. | 1.00 | 1.42 |
| Indet. | 2.17 | 1.57 |
| Growth habit main effects | | |
| Det. | 1.02 | 1.24 |
| Indet. | 2.45 | 1.57 |
| Cropping system main effects | | |
| Drilled | 1.90 | 1.32 |
| 75-cm rows | 1.58 | 1.49 |
| LSD (0.05) | 0.15 | 0.12 |

## Weight Per 100 Seed

Seed weight results (Table 7) were inconsistent, and need to be examined on an individual cultivar basis (Appendix Tables A-5 and A-6) in addition to the main effects. In Table 7, the only finding of importance is a greater average weight per seed for the 75-cm row spacing in 1985 (Tables A-3 and A-4).

Evaluating seed weights by cultivar shows that the cultivars Sprite and Williams generally had greater weight per seed than their respective growth habit counterparts. As mentioned previously, Williams had the lowest pod numbers per area of all cultivars. The determinate types had lower or equal weights as the row widths were narrowed (Tables A-5, A-6). The indeterminate types tended (not significant) to have a seed weight decrease in narrow rows in 1985, but in 1984 the row spacing by growth habit interaction was significant and the response was reversed.

## Weediness

The ratings of weediness (Table 8) among the growth habits and cropping systems varied with the growing seasons. In 1984, a thorough job of weed control was achieved in the drilled plots, and the 75-cm row plots had higher weediness ratings. The indeterminate varieties with their larger plant stature apparently suppressed weed growth better in the wider spacing (Table 8).

Table 7. Weight per 100 soybean seed for growth habits cropping systems, and growing seasons

| | Seed weight (g/100 seed) | |
|---|---|---|
| | 1984 | 1985 |
| Drilled | | |
| Det. | 13.6 | 15.9 |
| Indet. | 14.5 | 16.0 |
| 75-cm rows | | |
| Det. | 13.8 | 17.7 |
| Indet. | 13.8 | 17.6 |
| Growth habit main effects | | |
| Det. | 13.7 | 16.8 |
| Indet. | 14.1 | 16.8 |
| Cropping system main effects | | |
| Drilled | 14.1 | 15.9 |
| 75-cm rows | 13.8 | 17.7* |
| LSD (0.05) | 0.42 | 0.52 |

*Significant at 0.05 level.

Table 8. Weediness ratings for cropping systems, growth habits, and growing seasons

| | Weediness (1 to 5 scale) | |
|---|---|---|
| | 1984 | 1985 |
| Drilled | | |
| Det. | 1.00 | 3.65 |
| Indet. | 1.00 | 3.25 |
| 75-cm rows | | |
| Det. | 2.29 | 1.90 |
| Indet. | 1.57 | 2.41 |
| Growth habit main effects | | |
| Det. | 1.65 | 2.83 |
| Indet. | 1.25 | 2.77 |
| Cropping system main effects | | |
| Drilled | 1.00 | 3.45 |
| 75-cm rows | 1.90 | 2.15 |
| LSD (0.05) | 0.24 | 0.51 |

In the 1985 season, poorer crop competition because of poor stands and reduced herbicide activity resulted in greater weed densities in the drilled plots than in the wider spacing. The growth habits showed a mixed response between the row spacings, with determinates having no greater weediness ratings than indeterminates (Tables A-4 and A-6).

# DISCUSSION

Because little moisture was available during seed-filling either year, and there was excessive (1984) or not enough moisture (1985) during early growth, neither season could be considered an optimum one for soybean seed yield. The moderate yield levels of the study (2.3 and 1.9 Mg/ha in 1984 and 1985, respectively) reflect these circumstances. As a generality, limiting moisture can reduce the yield response of soybeans to narrowing row widths (Taylor, 1980).

Cooper (1981) defined highly productive environments as those with yield levels of 3.3 Mg/ha or more. He claimed that short-statured lines were more responsive to narrow rows under these conditions. However, he also speculated that determinate soybean plants might be less able to compensate for early-season moisture stress than indeterminates at northern latitudes. Water stress, as I subsequently discuss, seemed to play a significant role in determining yield in these experiments.

## Growth Habits

Most research on population density reveals that the soybean, unlike many other crops, shows little yield response to a wide range in seeding rates (Hicks et al., 1969; Wilcox, 1974). Beaver and Johnson (1981) reported Elf, a determinate cultivar, performed well over densities ranging from 279,000 to 494,000 plants/ha. A seeding rate of 400,000 to 500,000 seeds/ha was suggested to be appropriate for determinates. Seeding rates for determinates were greater than this in my study (Table 1). Nevertheless, plant densities were too low in some cases. Because of early season dryness in 1985, population densities in drilled plots were low enough that wider than desirable gaps existed between plants in the stand. As a consequence, there was a strong weed infestation and reduced soybean yields, especially of the determinate types.

In most comparisons, seed yields of the indeterminates evaluated in the study were significantly greater than the determinate yields. The yield difference between the growth habits was not expressed as a difference in pod number favoring the indeterminates. In fact, the determinate types had somewhat higher total pod numbers. Because of this, the yield differences between the growth habits appears to be attributable to a difference in seed weight and or the number of normal-sized seeds per pod. This shows agreement with results from Steukerjuergen (1982) who found Gnome had significantly more pods and more branches per square meter, but its yields were no better than the indeterminate 'Century' because Gnome had lower weight per seed. Also, Shroyer (1980) found determinate pod numbers to be higher than indeterminate types, but their seed yields were less than or not different from the indeterminates.

Determinate cultivars have more branches and a greater percentage of their pods borne on branches. And, compared with indeterminates, they produce a greater proportion of their yield in the upper third of the plants (Shroyer, 1980). Conversely, indeterminate types have more pods on main stems, fewer branch-borne pods, and their branches are, for the most part, from nodes in the lower region of the canopy. Due to these aspects, the determinate types were similar in branch number between the two spacings both years, while the indeterminates had significantly fewer branches in the drilled plots in 1984, and fewer branch-borne pods in the drilled plots both years. Although the determinates had similar branch numbers between the cropping systems, like the indeterminates they did tend to have a greater percentage of pods on their main stems as the row width decreased.

As previously mentioned, neither growing season could be considered favorable, in terms of moisture, for soybean productivity. Because the determinates possessed no fewer pods than the indeterminates in my study, there is no reason to dispute reports of determinate cultivars yielding as well or better than indeterminates under favorable environments (Beaver and Johnson, 1981; Cooper, 1980; Green and Shibles, 1980; Schapaugh and Wilcox, 1980).

## Cropping Systems

The cropping system yield levels were affected by differences in cultural practices (mechanical versus herbicide weed control) and the environment (moisture availability for emergence and growth). As a result, no yield advantage was found from narrowing the rows as has often been reported (Benson and Shroyer, 1978; Cooper, 1977; Costa et al., 1980).

Relationships between pod number and seed weight were not always conclusive enough to explain the yield differences of the cultivars to changes in row width. Seed weights were apparently influenced by genotype as well as environment. Among their growth types, Williams and Sprite generally had greater weight per 100 seed, and Williams had the fewest pods of any variety tested. In 1984, Williams had a greater seed size increase from reducing the row spacing than the other cultivars, and correspondingly, this cultivar had only a small difference in pods per area between the two systems. In 1985, much of the yield difference between the cropping systems could be accounted for by the greater seed size from the 75-cm row plots. This effect was likely due in part to the greater weed competition in the 1985 drilled plots.

The two cropping systems were not significantly different in branch number. As row widths are narrowed, the usual response of the soybean is a decrease in the number of branches per plant. However, the narrower rows had more plants per area (Table 1), so branch numbers per area were similar.

## Lodging

As with most previous research with determinate cultivars at northern latitudes, their good standability compared with indeterminates was an obvious trait of a beneficial nature (Cooper, 1977, 1981; Hicks et al., 1969). However, under the dryland production conditions encountered in the study, lodging was not believed to be yield-limiting, except perhaps for some Williams plots. Williams was the tallest cultivar in the study, and consequently, it lodged more. But, only in the 1984 drilled plots did lodging of Williams appear to be bad enough to limit yield by altering the crop canopy. In the drier year of 1985, shorter plant stature and lower population density levels effectively prevented a lodging difference between the cropping systems.

## Weediness

In most plots, weed control was adequate, however, some of the 1985 drilled plots were an exception. Two weeds dominated weed populations during the study: Velvetleaf (*Abutilon theoprasti*) and giant foxtail (*Setaria faberii*). In the 1984 drilled plots, weed control was quite effective, demonstrating that good weed control by use of herbicides is possible.

For a positive seed yield response from a reduced row spacing, weeds must be controlled to prevent them from competing with the crop for PAR, water, and nutrients. For the preceding reason, the effectiveness and cost of weed control can make a difference in the profitability of a cropping system. The cost of most post-emergence herbicide materials currently on the market will raise their application expenses above the cost of mechanical cultivation on a per hectare basis. This, plus the more important role of management involved in chemical weed control, are likely reasons why drilled soybean production is not yet predominant in the North Central Soybean Production Area.

But, herbicides are available that have good selectivity for use on soybeans, and they control weeds well under proper conditions. Also, herbicide effectiveness and selectivity should continue to improve in the future, possibly making their use more cost-effective and reliable.

# SUMMARY AND CONCLUSIONS

For the cultivars studied, a significantly greater seed yield was found for indeterminates in most cases. However, sometimes the determinates yielded as well as the indeterminates. Therefore, a generalization about which stem termination type is best adapted to the North Central Soybean Production Area would be inappropriate. Because the determinates were at times not different in yield from the indeterminates, coupled with the facts that determinates had very good standability and as many or more pods as the indeterminates, no evidence was found to dispute the contention that determinates may yield as well as indeterminates in northern latitudes under favorable growing conditions.

The soybean yield levels were not high compared with yields normally achieved for this location. And, periods of low moisture were encountered both years. Thus, the determinates may have been at somewhat of a disadvantage if they are genuinely more susceptible to periods of moisture stress than indeterminate types. Contrary to reports from environments of high productivity, where the better standability of the determinate genotype may be advantageous, the determinate cultivars did not show a significantly greater yield response to reduced row widths than the indeterminates did.

The drilled cropping system did not yield significantly greater than the cultivated 75-cm rows. The reason the theoretical yield advantage of the narrower row widths was not observed was probably due more to cultural differences between the systems and environmental limitations, rather than the sole effect of narrowing the row widths. Weed control and adequate soybean population densities, both of which were problems in this study, and sufficient moisture are very important in allowing the potential advantage of narrow rows to be expressed.

The following conclusions can be elicited from these data:

1) The indeterminate cultivars in this study usually yielded more favorably under the conditions encountered, but this may not always happen because of the complexity of the genotype by environment interaction.
2) The determinate cultivars did not show a significantly greater yield response than the indeterminate cultivars as the row spacing narrowed from 75 cm to 17 cm in the environment encountered.
3) A yield advantage from growing soybeans in narrow, noncultivated rows may or may not be noticeable. Factors of the environment and cultural practices are highly influential.

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# APPENDIX

Table A-1. Weather observations for the 1984 and 1985 growing seasons by day

| Date | Temperature (°C) Max | Min | Precip. (mm) | Date | Temperature (°C) Max | Min | Precip. (mm) |
|---|---|---|---|---|---|---|---|
| 1984 | | | | 6 June | 28 | 19 | 0 |
| 1 May | 16 | 2 | 0 | 7 June | 25 | 17 | 42 |
| 2 May | 17 | 6 | 3 | 8 June | 28 | 18 | 0 |
| 3 May | 14 | 5 | 9 | 9 June | 26 | 17 | 62 |
| 4 May | 14 | 1 | 2 | 10 June | 23 | 14 | 8 |
| 5 May | 20 | 5 | 0 | 11 June | 27 | 13 | 19 |
| 6 May | 19 | 8 | T[a] | 12 June | 27 | 18 | 16 |
| 7 May | 16 | 7 | 1 | 13 June | 28 | 17 | 8 |
| 8 May | 13 | 2 | T | 14 June | 28 | 17 | 14 |
| 9 May | 18 | 4 | 0 | 15 June | 20 | 16 | 9 |
| 10 May | 23 | 7 | T | 16 June | 31 | 18 | 3 |
| 11 May | 22 | 13 | 0 | 17 June | 31 | 22 | 7 |
| 12 May | 23 | 7 | 0 | 18 June | 29 | 20 | 0 |
| 13 May | 26 | 14 | 1 | 19 June | 29 | 16 | 0 |
| 14 May | 23 | 7 | 0 | 20 June | 30 | 17 | 0 |
| 15 May | 19 | 11 | T | 21 June | 30 | 19 | 4 |
| 16 May | 22 | 9 | 0 | 22 June | 31 | 16 | T |
| 17 May | 31 | 11 | 0 | 23 June | 27 | 18 | 0 |
| 18 May | 29 | 18 | 8 | 24 June | 28 | 16 | 0 |
| 19 May | 18 | 16 | 23 | 25 June | 31 | 17 | 2 |
| 20 May | 26 | 12 | 0 | 26 June | 32 | 20 | 4 |
| 21 May | 27 | 12 | 0 | 27 June | 28 | 16 | 0 |
| 22 May | 23 | 14 | 10 | 28 June | 28 | 16 | T |
| 23 May | 24 | 8 | 0 | 29 June | 27 | 16 | 0 |
| 24 May | 26 | 13 | 1 | 30 June | 26 | 13 | 0 |
| 25 May | 19 | 9 | 45 | 1 July | 27 | 13 | 0 |
| 26 May | 18 | 6 | 0 | 2 July | 29 | 16 | 0 |
| 27 May | 16 | 9 | 9 | 3 July | 29 | 18 | 4 |
| 28 May | 16 | 6 | 23 | 4 July | 28 | 17 | T |
| 29 May | 12 | 6 | 0 | 5 July | 30 | 16 | 3 |
| 30 May | 23 | 7 | 0 | 6 July | 24 | 14 | 11 |
| 31 May | 27 | 9 | 0 | 7 July | 24 | 11 | 0 |
| 1 June | 28 | 16 | 0 | 8 July | 32 | 17 | 0 |
| 2 June | 25 | 11 | 2 | 9 July | 36 | 26 | T |
| 3 June | 27 | 11 | 0 | 10 July | 32 | 21 | 19 |
| 4 June | 28 | 16 | 15 | 11 July | 29 | 12 | 0 |
| 5 June | 30 | 17 | 5 | 12 July | 32 | 18 | 0 |

[a]T = trace.

Table A-1. Continued

| Date | Temperature (°C) Max | Min | Precip. (mm) | Date | Temperature (°C) Max | Min | Precip. (mm) |
|---|---|---|---|---|---|---|---|
| 13 July | 33 | 19 | 0 | 22 Aug. | 25 | 15 | 0 |
| 14 July | 36 | 19 | 92 | 23 Aug. | 24 | 9 | 0 |
| 15 July | 29 | 16 | 3 | 24 Aug. | 25 | 9 | 0 |
| 16 July | 31 | 16 | 0 | 25 Aug. | 29 | 19 | 0 |
| 17 July | 27 | 14 | 8 | 26 Aug. | 33 | 19 | 0 |
| 18 July | 26 | 12 | 0 | 27 Aug. | 36 | 22 | 0 |
| 19 July | 31 | 17 | 0 | 28 Aug. | 38 | 18 | 0 |
| 20 July | 30 | 20 | 1 | 29 Aug. | 37 | 18 | 0 |
| 21 July | 32 | 18 | 0 | 30 Aug. | 28 | 13 | T |
| 22 July | 34 | 22 | 0 | 31 Aug. | 32 | 9 | 1 |
| 23 July | 34 | 22 | 0 | 1 Sept. | 36 | 21 | T |
| 24 July | 31 | 18 | 0 | 2 Sept. | 27 | 17 | 3 |
| 25 July | 24 | 18 | 0 | 3 Sept. | 23 | 12 | 0 |
| 26 July | 24 | 16 | 55 | 4 Sept. | 27 | 12 | 2 |
| 27 July | 25 | 14 | 4 | 5 Sept. | 24 | 7 | 0 |
| 28 July | 26 | 13 | 0 | 6 Sept. | 24 | 12 | T |
| 29 July | 26 | 14 | 0 | 7 Sept. | 34 | 22 | 0 |
| 30 July | 28 | 16 | 0 | 8 Sept. | 28 | 13 | 10 |
| 31 July | 30 | 16 | 0 | 9 Sept. | 24 | 13 | 21 |
| 1 Aug. | 30 | 18 | 0 | 10 Sept. | 19 | 13 | 6 |
| 2 Aug. | 28 | 18 | 0 | 11 Sept. | 25 | 10 | 0 |
| 3 Aug. | 31 | 18 | 0 | 12 Sept. | 34 | 19 | 0 |
| 4 Aug. | 33 | 20 | 0 | 13 Sept. | 28 | 17 | 3 |
| 5 Aug. | 33 | 21 | 0 | 14 Sept. | 18 | 8 | 0 |
| 6 Aug. | 35 | 23 | 0 | 15 Sept. | 18 | 6 | 0 |
| 7 Aug. | 35 | 22 | 0 | 16 Sept. | 19 | 2 | 0 |
| 8 Aug. | 32 | 19 | 28 | 17 Sept. | 23 | 6 | 0 |
| 9 Aug. | 31 | 21 | 0 | 18 Sept. | 27 | 9 | 0 |
| 10 Aug. | 28 | 21 | 0 | 19 Sept. | 33 | 13 | 0 |
| 11 Aug. | 28 | 16 | 0 | 20 Sept. | 29 | 15 | 0 |
| 12 Aug. | 29 | 17 | 0 | 21 Sept. | 29 | 12 | 0 |
| 13 Aug. | 29 | 16 | 0 | 22 Sept. | 26 | 17 | T |
| 14 Aug. | 31 | 18 | 0 | 23 Sept. | 27 | 14 | 0 |
| 15 Aug. | 34 | 17 | 0 | 24 Sept. | 31 | 14 | 0 |
| 16 Aug. | 32 | 22 | T | 25 Sept. | 14 | 6 | 13 |
| 17 Aug. | 27 | 21 | 1 | 26 Sept. | 10 | -2 | 0 |
| 18 Aug. | 28 | 19 | T | 27 Sept. | 11 | 4 | T |
| 19 Aug. | 28 | 14 | 0 | 28 Sept. | 11 | 2 | T |
| 20 Aug. | 28 | 13 | 0 | 29 Sept. | 16 | -3 | 0 |
| 21 Aug. | 26 | 18 | 1 | 30 Sept. | 18 | 1 | 0 |

Table A-1. Continued

| Date | Temperature (°C) Max | Min | Precip. (mm) | Date | Temperature (°C) Max | Min | Precip. (mm) |
|---|---|---|---|---|---|---|---|
| 1 Oct. | 21 | 1 | 0 | 9 May | 30 | 14 | 0 |
| 2 Oct. | 22 | 4 | 0 | 10 May | 27 | 16 | 0 |
| 3 Oct. | 25 | 7 | 0 | 11 May | 26 | 14 | 9 |
| 4 Oct. | 24 | 7 | 22 | 12 May | 23 | 14 | T |
| 5 Oct. | 22 | 11 | T | 13 May | 18 | 8 | 1 |
| 6 Oct. | 18 | 13 | 1 | 14 May | 24 | 13 | 2 |
| 7 Oct. | 19 | 12 | 3 | 15 May | 16 | 10 | 0 |
| 8 Oct. | 21 | 11 | 1 | 16 May | 16 | 9 | 1 |
| 9 Oct. | 22 | 7 | 0 | 17 May | 22 | 8 | 0 |
| 10 Oct. | 23 | 11 | 0 | 18 May | 29 | 8 | 0 |
| 11 Oct. | 21 | 14 | 3 | 19 May | 29 | 13 | 0 |
| 12 Oct. | 24 | 14 | 1 | 20 May | 24 | 14 | 6 |
| 13 Oct. | 22 | 11 | 0 | 21 May | 23 | 7 | 0 |
| 14 Oct. | 21 | 13 | 6 | 22 May | 24 | 9 | 0 |
| 15 Oct. | 18 | 8 | 31 | 23 May | 27 | 9 | 0 |
| 16 Oct. | 12 | 6 | 21 | 24 May | 27 | 13 | 7 |
| 17 Oct. | 14 | 1 | T | 25 May | 30 | 12 | 0 |
| 18 Oct. | 13 | 7 | 11 | 26 May | 33 | 16 | 0 |
| 19 Oct. | 14 | 6 | 0 | 27 May | 26 | 13 | 12 |
| 20 Oct. | 15 | 6 | 0 | 28 May | 24 | 10 | 0 |
| 21 Oct. | 12 | 4 | T | 29 May | 29 | 11 | 0 |
| 22 Oct. | 12 | -1 | 0 | 30 May | 31 | 17 | 1 |
| 23 Oct. | 11 | -3 | 0 | 31 May | 27 | 14 | 0 |
| 24 Oct. | 16 | -1 | 0 | 1 June | 29 | 9 | 0 |
| 25 Oct. | 11 | 5 | 8 | 2 June | 23 | 9 | 0 |
| 26 Oct. | 21 | 5 | 0 | 3 June | 23 | 7 | 0 |
| 27 Oct. | 20 | 11 | 5 | 4 June | 22 | 12 | 1 |
| 28 Oct. | 12 | 0 | 0 | 5 June | 27 | 9 | 0 |
| 29 Oct. | 17 | -4 | 0 | 6 June | 27 | 11 | 0 |
| 30 Oct. | 11 | -1 | 0 | 7 June | 32 | 11 | 0 |
| 31 Oct. | 16 | -1 | 1 | 8 June | 39 | 20 | 0 |
| | | | | 9 June | 34 | 18 | 0 |
| 1985 | | | | 10 June | 24 | 13 | 3 |
| 1 May | 22 | 18 | T | 11 June | 19 | 11 | 7 |
| 2 May | 24 | 5 | 0 | 12 June | 20 | 9 | 3 |
| 3 May | 27 | 6 | 0 | 13 June | 24 | 8 | 0 |
| 4 May | 28 | 13 | 0 | 14 June | 24 | 13 | 8 |
| 5 May | 24 | 15 | 4 | 15 June | 27 | 14 | 1 |
| 6 May | 23 | 9 | 0 | 16 June | 28 | 13 | 21 |
| 7 May | 26 | 10 | 2 | 17 June | 26 | 16 | 1 |
| 8 May | 29 | 9 | 0 | 18 June | 24 | 14 | T |

Table A-1. Continued

| Date | Temperature (°C) Max | Min | Precip. (mm) | Date | Temperature (°C) Max | Min | Precip. (mm) |
|---|---|---|---|---|---|---|---|
| 19 June | 24 | 12 | 0 | 30 July | 24 | 17 | 12 |
| 20 June | 29 | 10 | 0 | 31 July | 22 | 17 | 0 |
| 21 June | 31 | 22 | T | 1 Aug. | 26 | 12 | 0 |
| 22 June | 29 | 17 | 0 | 2 Aug. | 27 | 11 | 0 |
| 23 June | 28 | 18 | 13 | 3 Aug. | 25 | 16 | T |
| 24 June | 31 | 16 | 0 | 4 Aug. | 27 | 17 | 0 |
| 25 June | 33 | 21 | 0 | 5 Aug. | 33 | 20 | 0 |
| 26 June | 33 | 21 | 10 | 6 Aug. | 34 | 20 | 0 |
| 27 June | 23 | 18 | 1 | 7 Aug. | 32 | 17 | 0 |
| 28 June | 23 | 11 | 0 | 8 Aug. | 31 | 14 | 0 |
| 29 June | 26 | 15 | 0 | 9 Aug. | 36 | 19 | 10 |
| 30 June | 29 | 14 | 0 | 10 Aug. | 23 | 13 | 4 |
| 1 July | 29 | 17 | 0 | 11 Aug. | 27 | 9 | 0 |
| 2 July | 29 | 19 | 0 | 12 Aug. | 33 | 19 | 0 |
| 3 July | 33 | 13 | 0 | 13 Aug. | 31 | 14 | 0 |
| 4 July | 33 | 13 | 0 | 14 Aug. | 25 | 15 | 0 |
| 5 July | 29 | 17 | 0 | 15 Aug. | 27 | 12 | T |
| 6 July | 33 | 15 | 0 | 16 Aug. | 29 | 18 | 0 |
| 7 July | 34 | 23 | 0 | 17 Aug. | 29 | 19 | 2 |
| 8 July | 32 | 21 | 0 | 18 Aug. | 25 | 11 | 0 |
| 9 July | 35 | 24 | 0 | 19 Aug. | 26 | 15 | 1 |
| 10 July | 32 | 15 | 0 | 20 Aug. | 24 | 9 | T |
| 11 July | 32 | 16 | 0 | 21 Aug. | 26 | 14 | T |
| 12 July | 28 | 20 | 1 | 22 Aug. | 26 | 17 | 44 |
| 13 July | 33 | 18 | T | 23 Aug. | 26 | 18 | T |
| 14 July | 34 | 19 | 2 | 24 Aug. | 24 | 15 | 1 |
| 15 July | 28 | 16 | 0 | 25 Aug. | 23 | 15 | 0 |
| 16 July | 29 | 17 | 0 | 26 Aug. | 23 | 16 | 0 |
| 17 July | 33 | 14 | 0 | 27 Aug. | 28 | 12 | 0 |
| 18 July | 33 | 19 | 0 | 28 Aug. | 29 | 14 | 0 |
| 19 July | 29 | 21 | 10 | 29 Aug. | 29 | 19 | 0 |
| 20 July | 29 | 14 | 0 | 30 Aug. | 26 | 18 | 0 |
| 21 July | 31 | 16 | 0 | 31 Aug. | 31 | 16 | 0 |
| 22 July | 28 | 14 | 0 | 1 Sept. | 30 | 21 | 0 |
| 23 July | 30 | 13 | 0 | 2 Sept. | 34 | 18 | T |
| 24 July | 33 | 18 | 1 | 3 Sept. | 32 | 22 | 0 |
| 25 July | 28 | 20 | 13 | 4 Sept. | 30 | 19 | 0 |
| 26 July | 29 | 14 | 0 | 5 Sept. | 33 | 21 | T |
| 27 July | 31 | 15 | 0 | 6 Sept. | 36 | 23 | 0 |
| 28 July | 32 | 16 | 0 | 7 Sept. | 36 | 23 | 0 |
| 29 July | 27 | 21 | 0 | 8 Sept. | 35 | 21 | 0 |

Table A-1. Continued

| Date | Temperature (°C) Max | Min | Precip. (mm) |
|---|---|---|---|
| 9 Sept. | 28 | 16 | 0 |
| 10 Sept. | 21 | 16 | T |
| 11 Sept. | 24 | 16 | T |
| 12 Sept. | 18 | 12 | 2 |
| 13 Sept. | 18 | 11 | 0 |
| 14 Sept. | 22 | 10 | 0 |
| 15 Sept. | 25 | 6 | 0 |
| 16 Sept. | 26 | 14 | T |
| 17 Sept. | 31 | 18 | 0 |
| 18 Sept. | 33 | 21 | 0 |
| 19 Sept. | 33 | 21 | 0 |
| 20 Sept. | 27 | 12 | 4 |
| 21 Sept. | 13 | 9 | 12 |
| 22 Sept. | 20 | 12 | 9 |
| 23 Sept. | 15 | 8 | 38 |
| 24 Sept. | 13 | 4 | T |
| 25 Sept. | 16 | 7 | 11 |
| 26 Sept. | 15 | 4 | 0 |
| 27 Sept. | 22 | 3 | 0 |
| 28 Sept. | 14 | 6 | 2 |
| 29 Sept. | 6 | 4 | 43 |
| 30 Sept. | 10 | 5 | 2 |
| 1 Oct. | 14 | -2 | 0 |
| 2 Oct. | 18 | 3 | 0 |
| 3 Oct. | 18 | 9 | T |
| 4 Oct. | 16 | 7 | 3 |
| 5 Oct. | 12 | 5 | 0 |
| 6 Oct. | 21 | 2 | 0 |
| 7 Oct. | 18 | 7 | T |
| 8 Oct. | 17 | 9 | T |
| 9 Oct. | 10 | 2 | 28 |
| 10 Oct. | 9 | 2 | 1 |
| 11 Oct. | 10 | 4 | 1 |
| 12 Oct. | 17 | 9 | 13 |
| 13 Oct. | 21 | 3 | 0 |
| 14 Oct. | 13 | 8 | 1 |
| 15 Oct. | 21 | 3 | 0 |
| 16 Oct. | 19 | 2 | 0 |
| 17 Oct. | 20 | 12 | 1 |
| 18 Oct. | 18 | 13 | 14 |
| 19 Oct. | 13 | 9 | 1 |
| 20 Oct. | 12 | 10 | 0 |
| 21 Oct. | 15 | 10 | T |
| 22 Oct. | 20 | 9 | 0 |
| 23 Oct. | 21 | 14 | 1 |
| 24 Oct. | 19 | 10 | 0 |
| 25 Oct. | 23 | 3 | 0 |
| 26 Oct. | 25 | 12 | 0 |
| 27 Oct. | 18 | 5 | 0 |
| 28 Oct. | 16 | 3 | 0 |
| 29 Oct. | 14 | 4 | 0 |
| 30 Oct. | 16 | 7 | 0 |
| 31 Oct. | 10 | 2 | 3 |

Table A-2. The mean squares for seed yield from the combined analysis of data

| Source | df | | Mean Squares | Pr > F |
|---|---|---|---|---|
| Year | 1 | | 1501. | .0001 |
| Rep (Year) error a | 6 | | 115. | .0029 |
| Spacing | 1 | | 1271. | .0001 |
| Spacing X Year error b | 1 | | 1700. | .0001 |
| Spacing X Rep (Year) error c | 6 | | 83. | .0209 |
| Variety | 5 | | | |
| Growth habit | | 1 | 850. | .0001 |
| Variety (Growth habit) | | 4 | 76. | .0512 |
| Variety X Spacing | 5 | | | |
| GH X Spacing | | 1 | 54. | .1867 |
| Spacing X Variety (GH) | | 4 | 35. | .3469 |
| Variety X Year | 5 | | 34. | .3575 |
| Variety X Spacing X Year | 5 | | 82. | .0296 |
| Residual | 60 | | 30. | |
| Total | 95 | | | |

Table A-3. The mean squares for plant characters for the 1984 growing season

| | d.f. | | Population density Mean Square | Pr > F |
|---|---|---|---|---|
| Rep | 3 | | 68. | .0007 |
| Row spacing | 1 | | 5753. | .0015 |
| Rep X row spacing error a | 3 | | 45. | .0065 |
| Variety | 5 | | | |
| GH[a] | | 1 | 435. | .0001 |
| Variety (GH) | | 4 | 68. | .0003 |
| Variety X row spacing | 5 | | | |
| Spacing X GH | | 1 | 4. | .5234 |
| Spacing X variety (GH) | | 4 | 3. | .85 |
| Residual | 30 | | 9. | |
| Total | 47 | | | |

| | d.f. | | Total pod number Mean Square | Pr > F |
|---|---|---|---|---|
| Rep | 3 | | 4666. | .65 |
| Row spacing | 1 | | 46875. | .151 |
| Rep X row spacing error a | 3 | | 12744. | .232 |
| Variety | 5 | | | |
| GH | | 1 | 86360. | .0033 |
| Variety (GH) | | 4 | 59506. | .0004 |
| Variety X row spacing | 5 | | | |
| Spacing X GH | | 1 | 10325. | .2776 |
| Spacing X variety (GH) | | 4 | 2552. | .8741 |
| Residual | 30 | | 8445. | |
| Total | 47 | | | |

[a]GH = growth habit.

| Seed yield Mean Square | Pr > F | Plant branching Mean Square | Pr > F | Branch-borne pods Mean Square | Pr > F | Main-stem pods Mean Square | Pr > F |
|---|---|---|---|---|---|---|---|
| 4. | .68 | 192. | .66 | 1823. | .61 | 11201. | .051 |
| 16. | .31 | 13. | .775 | 80401. | .013 | 250507. | .012 |
| 11. | .308 | 133. | .774 | 2819. | .43 | 8484. | .109 |
| 560. | .0001 | 208692. | .0001 | 981409. | .0001 | 485515. | .0001 |
| 85. | .0001 | 448. | .31 | 12334. | .0088 | 51364. | .0001 |
| 7. | .37 | 1764. | .034 | 1957. | .425 | 21273. | .026 |
| 4. | .73 | 99. | .991 | 2684. | .48 | 4926. | .302 |
| 8. | | 358. | | 2991. | | 3846. | |

| Plant height Mean Square | Pr > F | Lodging Mean Square | Pr > F | Weight per seed Mean Square | Pr > F | Weediness Mean Square | Pr > F |
|---|---|---|---|---|---|---|---|
| 3. | .89 | 0.03 | .67 | 0.54 | .247 | 0.16 | .418 |
| 75. | .076 | 1.2 | .022 | 0.59 | .334 | 9.6 | .0044 |
| 10. | .137 | 0.07 | .426 | 0.37 | .378 | 0.16 | .418 |
| 4105. | .0001 | 24.8 | .0001 | 1.44 | .06 | 1.88 | .0019 |
| 88. | .0001 | 1.4 | .0001 | 5.7 | .0001 | .24 | .234 |
| 7. | .245 | 0.88 | .0008 | 1.87 | .034 | 1.88 | .0019 |
| 5. | .424 | 0.07 | .35 | 0.11 | .863 | .96 | .234 |
| 5. | | 0.06 | | 0.36 | | .16 | |

Table A-4. The mean squares for plant characters for the 1985 growing season

| | d.f. | | Population density Mean Square | Pr > F |
|---|---|---|---|---|
| Rep | 3 | | 113. | .0012 |
| Row spacing | 1 | | 862. | .071 |
| Rep X row spacing error a | 3 | | 115. | .001 |
| Variety | 5 | | | |
| GH[a] | | 1 | 174. | .003 |
| Variety (GH) | | 4 | 18. | .368 |
| Variety X row spacing | 5 | | | |
| Spacing X GH | | 1 | 43. | .117 |
| Spacing X variety (GH) | | 4 | 14. | .49 |
| Residual | 30 | | 16. | |
| Total | 47 | | | |

| | d.f. | | Total pod number Mean Square | Pr > F |
|---|---|---|---|---|
| Rep | 3 | | 55672. | .0001 |
| Row spacing | 1 | | 19240. | .619 |
| Rep x row spacing error a | 3 | | 69931. | .0001 |
| Variety | 5 | | | |
| Gh | | 1 | 24480. | .026 |
| Variety (GH) | | 4 | 44189. | .0001 |
| Variety x row spacing | 5 | | | |
| Spacing x GH | | 1 | 9324. | .159 |
| Spacing x variety (GH) | | 4 | 6614. | .233 |
| Residual | 30 | | 4472. | |
| Total | 47 | | | |

[a]GH = growth habit.

| Seed yield Mean Square | Pr > F | Plant branching Mean Square | Pr > F | Branch-borne pods Mean Square | Pr > F | Main-stem pods Mean Square | Pr > F |
|---|---|---|---|---|---|---|---|
| 227. | .012 | 3089. | .003 | 7373. | .051 | 32615. | .0001 |
| 2956. | .022 | 1645. | .405 | 58032. | .16 | 10443. | .549 |
| 155. | .048 | 1763. | .036 | 17432. | .001 | 23008. | .0004 |
| 308. | .021 | 121605. | .0001 | 532354. | .0001 | 328517. | .0001 |
| 30. | .69 | 496. | .47 | 10044. | .011 | 27651. | .0001 |
| 171. | .08 | 408. | .39 | 5. | .97 | 9747. | .075 |
| 101. | .13 | 209. | .82 | 3147. | .31 | 2808. | .433 |
| 52. | | 547. | | 2539. | | 2862. | |

| Plant height Mean Square | Pr > F | Lodging Mean Square | Pr > F | Weight per seed Mean Square | Pr > F | Weediness Mean Square | Pr > F |
|---|---|---|---|---|---|---|---|
| 4.6 | .22 | 0.51 | .0001 | 2.15 | .062 | 1.33 | .17 |
| 38.7 | .135 | 0.37 | .412 | 35.3 | .0029 | 20.3 | .0005 |
| 9.3 | .039 | 0.41 | .0001 | 0.43 | .65 | 0.07 | .96 |
| 463.0 | .0001 | 1.33 | .0001 | 0.01 | .90 | 0.04 | .82 |
| 121.0 | .0001 | 0.24 | .0001 | 3.4 | .007 | 0.07 | .98 |
| 0.9 | .58 | 0.40 | .004 | 0.12 | .70 | 2.52 | .07 |
| 0.5 | .96 | 0.03 | .524 | 0.4 | .73 | 0.67 | .48 |
| 2.9 | | 0.04 | | 0.79 | | 0.74 | |

Table A-5. Means for plant characters listed by cultivar for the 1984 growing season

| | Seed yield Mg/ha | | Pod number pods/$m^2$ | | Branch-borne pods pods/$m^2$ | | Main-stem pods pods/$m^2$ | |
|---|---|---|---|---|---|---|---|---|
| | 75-cm rows | drilled | 75-cm rows | drilled | 75-cm rows | drilled | 75-cm rows | drilled |
| Det. | | | | | | | | |
| Elf | 2.11 | 2.12 | 1202 | 1252 | 578 | 375 | 624 | 877 |
| Gnome | 1.71 | 1.84 | 1114 | 1269 | 692 | 506 | 422 | 763 |
| Sprite | 2.38 | 2.14 | 1148 | 1333 | 630 | 564 | 518 | 768 |
| Mean | 2.07 | 2.03 | 1155 | 1285 | 633 | 482 | 521 | 803 |
| Indet. | | | | | | | | |
| A3127 | 2.45 | 2.52 | 1215 | 1255 | 218 | 59 | 997 | 1197 |
| A3659 | 2.66 | 2.74 | 1110 | 1137 | 214 | 98 | 896 | 1038 |
| Williams | 2.37 | 2.31 | 898 | 902 | 122 | 67 | 776 | 835 |
| Mean | 2.49 | 2.52 | 1074 | 1098 | 185 | 75 | 890 | 1023 |
| LSD 0.05 | 0.11 | | 87. | | 56. | | 54. | |
| MEAN | 2.24 | 2.31 | 1114 | 1191 | 409 | 278 | 705 | 913 |

| Seed weight | | Plant height | | Lodging | | Weediness | |
|---|---|---|---|---|---|---|---|
| g/100 seed | | cm | | 1 to 5 scale | | 1 to 5 scale | |
| 75-cm rows | drilled | 75-cm rows | drilled | 75-cm rows | drilled | 75-cm rows | drilled |
| 13.9 | 13.7 | 50 | 53 | 1.0 | 1.0 | 1.7 | 1.0 |
| 13.5 | 13.0 | 31 | 45 | 1.0 | 1.0 | 2.5 | 1.0 |
| 14.2 | 14.2 | 47 | 54 | 1.0 | 1.1 | 2.6 | 1.0 |
| 13.9 | 13.6 | 42 | 51 | 1.0 | 1.0 | 2.3 | 1.0 |
| 12.8 | 13.5 | 83 | 89 | 2.0 | 2.9 | 1.5 | 1.0 |
| 13.5 | 13.9 | 89 | 93 | 1.6 | 2.1 | 1.6 | 1.0 |
| 15.1 | 16.1 | 102 | 106 | 2.9 | 3.2 | 1.4 | 1.0 |
| 13.8 | 14.5 | 91 | 96 | 2.2 | 2.7 | 1.5 | 1.0 |
| 0.42 | | 0.05 | | .15 | | .24 | |
| 13.8 | 14.1 | 67 | 73 | 1.6 | 1.9 | 1.9 | 1.0 |

Table A-6. Means for plant characters listed by cultivar for the 1985 growing season

| | Seed yield Mg/ha | | Pod number pods/m$^2$ | | Branch-borne pods pods/m$^2$ | | Main-stem pods pods/m$^2$ | |
|---|---|---|---|---|---|---|---|---|
| | 75-cm rows | drilled | 75-cm rows | drilled | 75-cm rows | drilled | 75-cm rows | drilled |
| Det. | | | | | | | | |
| Elf | 2.08 | 1.05 | 609 | 597 | 286 | 205 | 323 | 392 |
| Gnome | 2.00 | 0.95 | 613 | 615 | 355 | 289 | 258 | 325 |
| Sprite | 2.62 | 0.78 | 650 | 623 | 341 | 276 | 309 | 347 |
| Mean | 2.23 | 0.93 | 624 | 612 | 327 | 247 | 297 | 355 |
| Indet. | | | | | | | | |
| A3127 | 2.70 | 1.45 | 688 | 576 | 153 | 26 | 535 | 551 |
| A3659 | 2.28 | 1.38 | 621 | 645 | 114 | 97 | 506 | 549 |
| Williams | 1.97 | 1.71 | 511 | 395 | 80 | 19 | 431 | 376 |
| Mean | 2.32 | 1.52 | 606 | 539 | 116 | 47 | 491 | 492 |
| LSD 0.05 | 0.29 | | 39. | | 30. | | 31. | |
| MEAN | 2.27 | 1.22 | 616 | 576 | 222 | 152 | 394 | 423 |

| Seed weight g/100 seed | | Plant height cm | | Lodging 1 to 5 scale | | Weediness 1 to 5 scale | |
|---|---|---|---|---|---|---|---|
| 75-cm rows | drilled | 75-cm rows | drilled | 75-cm rows | drilled | 75-cm rows | drilled |
| 17.4 | 15.7 | 58 | 53 | 1.5 | 1.0 | 2.2 | 3.1 |
| 17.2 | 15.5 | 55 | 49 | 1.3 | 1.1 | 1.7 | 4.0 |
| 18.4 | 16.3 | 55 | 50 | 1.4 | 1.1 | 1.7 | 3.9 |
| 17.7 | 15.9 | 56 | 51 | 1.4 | 1.1 | 1.9 | 3.6 |
| 17.8 | 16.9 | 68 | 66 | 1.4 | 1.4 | 2.2 | 3.4 |
| 16.9 | 15.0 | 66 | 61 | 1.4 | 1.4 | 2.6 | 3.2 |
| 18.2 | 16.1 | 79 | 74 | 1.9 | 1.8 | 2.4 | 3.1 |
| 17.6 | 16.0 | 71 | 67 | 1.6 | 1.6 | 2.4 | 3.2 |
| 0.50 | | 2.6 | | .12 | | .51 | |
| 17.7 | 15.9 | 63 | 59 | 1.5 | 1.3 | 2.1 | 3.4 |