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EFFECTS OF VARIOUS CULTURAL PRACTICES
ON YIELDS OF DOUBLE-CROPPED SOYBEANS
(GLYCINE MAX L.) FOLLOWING WINTER
GRAINS IN MICHIGAN

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# EFFECTS OF VARIOUS CULTURAL PRACTICES

# ON YIELDS OF DOUBLE-CROPPED SOYBEANS (*GLYCINE MAX* L.)

# FOLLOWING WINTER GRAINS IN MICHIGAN

By

Darell Lorne McIntyre

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ABSTRACT

EFFECTS OF VARIOUS CULTURAL PRACTICES
ON YIELDS OF DOUBLE-CROPPED SOYBEANS (GLYCINE MAX L.)
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Darell Lorne McIntyre

Effects of row spacing, seeding rate, and soybean variety on seed yield and other agronomic characteristics of double-cropped soybeans (*Glycine max* L. Merrill) after either winter barley (*Hordeum vulgare* L.) or winter wheat (*Triticum aestivum* L.) were studied at two locations in southern Michigan.

At Site 1, near Galien, Michigan, three well-adapted soybean varieties, 'Evans' from Group 0, 'Hodgson' from Group I, and 'Corsoy' from Group II, were no-till planted in winter barley stubble in 19 cm and 38 cm row spacings on July 6, 1977, on a Crozier loam (Aeric Ochraqualf) with a three percent slope.

Varietal effects were significant at the 0.05 level for seed yield, number of nodes per plant, seeds per plant, pods per node, seeds per pod, height of the first podded node above the soil line, and the number of the first podded node.

'Evans' showed the highest seed yield, pods per node, seeds per plant, seeds per pod, and lowest number of the first podded node. The

'Hodgson' variety set its first pods highest above the soil line, while 'Corsoy' had the highest number of pods per plant, and the most unpodded nodes below the lowest pods. No significant difference among varieties was found for plant height, pods per plant, and first internode diameter.

Response to row spacing was significant for seed yield, nodes per plant, height of the first podded node above the soil line, and the number of the first podded node, but all other agronomic characteristics measured were not significant. The 19 cm row spacing showed the highest seed yield, height of the first podded node, and number of the first podded node. Soybean plants in the 38 cm row spacing had the highest number of nodes per plant.

No statistically significant interactions occurred between variety and row spacing with regard to yield or any component of yield.

It is suggested that the observed differences were due to varietal responses to photoperiod, temperature, and available soil moisture conditions.

At Site 2, near Schoolcraft, Michigan, the same three soybean varieties used at Site 1 were seeded after winter wheat at two rates, 117.8 and 151.4 kg/ha in 25.4 cm row spacing on July 13, 1977, in a Volinia loam (Typic Arguidoll) with a zero percent slope.

Emergence at this site, which was unsatisfactory, may have been due to soil temperature effects upon hypocotyl elongation and/or soil borne diseases.

ACKNOWLEDGEMENT

To rejoice in a success is not the same as taking credit for it. To deny oneself the former is to cultivate indifference. To assume the latter is to preclude the attainment of wisdom.

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# INTRODUCTION

Traditionally, agricultural research has been primarily concerned with increasing the productivity of a given unit of land. In the temperate regions of the world this was accomplished first by the introduction of improved plant varieties, and more recently by the adoption of a broader approach in which high-yielding varieties are combined with an adequate fertility regime, disease, weed and insect control, and modern soil tillage practices. Initial dramatic yield increases have been obtained with the implementation of this total management concept. Over time, however, these yield increases have leveled off at a plateau, and further increases have been difficult to achieve. With improvement both in the efficacy of chemical weed control and in zero-tillage practices, double cropping has become a practical method of once again increasing crop production per unit of land. Along with the increase in yield per area of land, other benefits of double cropping include a more efficient utilization of machinery and labor, better control of soil erosion caused by wind and water, and a partial reduction in the risk associated with crop failure when only one crop per growing season is planted.

At present, double cropping is an accepted practice from the southern United States through the northern Ohio Valley. Success in the neighboring states of Ohio, Indiana, and Illinois has stimulated interest in the potential for double cropping in southern Michigan.

The present study was undertaken with two objectives in view. The first was to obtain some preliminary information on the feasibility of double cropping in southern Michigan which would be useful to persons interested in growing two crops per season. The second objective was to identify factors which merit further study.

# LITERATURE REVIEW

Double cropping, growing two crops in sequence during the same growing season, is a very old agricultural technique. Until recently it has been practiced most extensively in the tropical regions of the world where abundant precipitation combines with favorable temperatures to permit a growing season which may in some areas be year-round.

A comprehensive review of double-cropping practices, as well as other multiple-cropping systems, is included in the publication, *Multiple Cropping* (33). Many options are available in the selection of crops for use in a double-cropping sequence. The choice of a particular combination will be governed by the intended utilization of the crops, the type of farm where the crops are to be grown, and the length of the growing season. The interest of this study is the use of soybeans (*Glycine max* L. Merr.) after either winter barley (*Hordeum vulgare* L.) or winter wheat (*Triticum aestivum* L.), and the examination of the available literature will focus on these combinations in temperate regions.

## Seed Yields

Hinkle (19), at the Southeast Branch Station in Arkansas, compared double-cropped soybeans after wheat with growing these same crops by themselves and found that double-cropped soybeans yielded 1634 kg/ha, while soybeans alone averaged 2178 kg/ha when studied over a two-year period. The winter wheat produced 2669 kg/ha when averaged across both years and cropping systems. Stanford et al. (37) grew soybeans and grain sorghum after wheat harvested for grain in Mississippi for three years. The average yields for soybeans were 1909 kg/ha and 2243 kg/ha for no-tillage and conventional tillage, respectively, while the grain sorghum yields were 3857 kg/ha for the no-tillage system and 4023 kg/ha for conventional tillage. The reduction in yields under the no-tillage system was due to inadequate chemical weed control. In a four-year study conducted at two locations in North Carolina by Lewis and Phillips (23), soybean yields averaged 1982 kg/ha when planted in a no-till system after winter wheat. Camper, Jr. et al. (1) obtained double-cropped soybean yields of 1155 kg/ha in a two-year study in eastern Virginia at Warsaw. Triplett, Jr. et al (45) studied the potential of double-cropped soybeans in Ohio at two locations. At one location, Wooster, 'Chippewa 64' soybeans were planted in 38 cm rows following the harvest of winter wheat or barley. Soybean yields were 1426 and 1238 kg/ha for 1968 and 1970, respectively, when averaged across tillage techniques. At the Western Branch, near Springfield, double-cropped soybean yields were 1453, 2529, and 1251 kg/ha for 1968, 1969, 1970, respectively, when averaged across tillage practices. At two locations in Illinois, McKibben and Pendleton (30) studied the feasibility of double cropping soybeans after winter wheat. They reported that at Dixon Springs, 'Clark' soybean yields varied from 1083 to 2596 kg/ha, depending upon the herbicide used and the height of the winter wheat stubble. Yields obtained at Urbana were discouraging due to below-average rainfall. In 1972, however, McKibben and Oldham (31) reported soybean yields of 1944 kg/ha when averaged over cultural practices at the Urbana site, and yields of 2294 and 2603 kg/ha at Brownstown and Dixon Springs, respectively.

Management Considerations

First Crop. Research has demonstrated the importance of the proper first crop in order to obtain an adequate yield from the second crop in a double-cropping sequence. Winter grain cultivars must be selected which are early maturing in order to permit the earliest possible planting date for the double-cropped soybeans. Studies by various researchers have shown reductions in soybeans yields associated with delayed planting dates (9, 19, 21, 35).

The most common double-cropping sequence in the more northern latitudes of the United States is barley or wheat harvested for grain followed by soybeans. Barley has been shown to mature up to two weeks earlier than wheat, and Herbek (17) reported that this two-week advantage resulted in a 22.8% (3403 vs. 2771 kg/ha) increase in soybean yields. Lewis (22) compared two barley varieties and four wheat varieties in North Carolina and found that a ten-day delay in wheat maturity resulted in a 269 kg/ha reduction in soybean yields. Further reductions of 202, 404, and 673 kg/ha were observed with the additional delays of six, eleven, and sixteen days associated with the later maturity of the wheat varieties. The harvesting of high-moisture grain and using supplemental drying has been suggested (22, 45) as a method of obtaining an earlier planting date for the soybeans.

Seedbed Preparation. Numerous studies have been undertaken to compare conventional-tillage planting with minimum-tillage planting of soybeans used as the second crop in a double-cropping sequence. Although conventional seedbed preparation results in a rapid loss of soil moisture in the upper level of the soil profile, Rogers, et al. (36) in Alabama, and Camper et al. (1) in Virginia, obtained satisfactory soybean yields

(1808 and 1155 kg/ha respectively) when planted in a conventionally-prepared seedbed after winter wheat. Collins and Cox (2) observed more severe moisture stress in double-cropped soybean plots in Arkansas where seedbed preparation was no-till than in adjacent plots which received some type of tillage in the seedbed preparation. It was suggested that this was due to the lower organic-matter content and lower water-holding capacity of the soils. Sanford et al. (37) obtained lower soybean yields when no-tillage seedbed preparation was compared with conventional tillage (1708 vs. 2250 kg/ha) in studies conducted in Mississippi. This was a result of ineffective control of nutsedge (*Cyprus* sp.) by herbicides alone. With adequate weed control, yields were similar.

Research in Illinois and Ohio (31, 45) has stressed the importance of no-till seedbed preparation in the conservation of soil moisture and in timeliness of planting. At least partial removal of the winter grain straw must be done, either by baling or incorporation into the soil, in order to obtain satisfactory results from the soybean planter (45). Cox et al. (5) found a higher incidence of diseased soybean seedlings when straw was incorporated rather than removed (23.6 vs. 4.6%). Collins and Cox (2) have reported that the straw contains substances which are phytotoxic to soybeans. Hayes (16) found that soil loss due to wind and water erosion was greatly reduced when no-till seedbed preparation was used. Several researchers have reported lower costs of producing a crop when minimum-tillage is practiced (22, 34, 37).

*Second Crop*. Proper selection of a soybean variety for use as a second crop is essential if adequate yields are to be obtained. Triplett, Jr. et al. (45) suggest the use of midseason varieties in

Ohio for securing the highest yields. McKibben (29) recommends the use of the same soybean variety which would be used for a full-season crop in Illinois. Research in Kentukcy (17) and in Mississippi (37) has shown higher yields when medium to medium-late varieties are used. Generally, early-season varieties have shown reduced yields, while very late-season varieties have not matured fully before the first killing frost in the fall. Camper et al. (1) and Collins and Cox (2) have suggested that breeding work be undertaken to develop varieties better adapted to double-cropped systems.

Population, Row Spacing, and Depth of Planting. Variety, planting date, germination, and row width should all be considered in determining the optimum plant population (3, 8, 22, 36). Lueschen and Hicks (26) measured soybean yields when populations were varied from 171,000 to 513,000 plants/ha, and concluded that soybeans can compensate for sparse populations by increased branching and number of pods per plant. However, as population decreased, lower podding occurred which could result in increased harvest losses. Present recommendations for double-cropped soybeans in Michigan are for seeding rates up to 10% higher than is normal for full-season crops (18). McKibben and Oldham (31) and Lewis (22) have suggested that higher planting rates for double-cropped soybeans are necessary for earlier shading of the soil to aid in weed control and for more sunlight interception. The most effective method of increasing plant populations is to use narrower rows rather than increase the number of plants within the row. Several researchers (4, 10) have reported significant increases in yields with narrower row-spacings, while increasing the plant populations within the row did not give a subsequent boost in yield.

The normal planting depth of from 2.5 to 5.0 cm is suggested for double-cropped soybeans. Recommendations vary concerning the advisability of planting in dry soil (18, 38). Erratic germination and emergence have been reported when planting depths have been increased; a practice often used with late plantings. Grabe and Metzer (14) have suggested that this is due to temperature-induced inhibition of hypocotyl elongation. Fehr _et al_. (12) have suggested that soil resistance is also important in soybean emergence. Stucky (43) obtained satisfactory field emergence from a 7.5 cm seeding depth.

_Fertilization_. There are three logical times of application of fertilizer for double-cropped soybeans. The most common practice is to apply some fertilizer at the planting time of each crop. A second approach is to apply sufficient potassium and phosphorous for both crops in the fall when the winter small grain is planted. McKibben and Oldham (31) have reported that double and triple the annual rates of phosphorous and potassium can be applied every two or three years with no consequent reduction in yields when compared with yearly fertilizer applications. They also emphasized the importance of a well-fertilized small grain crop for adequate weed control.

_Pest Control_. Specific pest control practices will vary in accordance with local conditions, however, researchers involved in double cropping all agree on the critical nature of adequate pest control. An excellent source of information on this subject is that reported by McKibben (28), who conducted extensive herbicide studies at Dixon Springs on an upland soil in Illinois in 1974 and 1975. Worsham (46) has shown that herbicide injury is influenced by the type of no-till planter used. The least damage occurred when the soil was slightly rounded in a ridge over the seeds, while a furrow resulted in the greatest crop injury.

No significant increases in disease or insect damage have been reported in the United States where double cropping is practiced. Cox et al. (5) have reported on the need for adequate disease control in seedbed preparation. They suggested that seedling disease was directly related to the quantity of straw incorporated into the soil, and they recommended the use of seed treatments. Litsinger and Moody (24) state that research in pest management must broaden in order to meet the needs of multiple cropping. They point out that research has traditionally been done on a single-crop basis, while in multiple cropping the pests of one crop may influence the pest situation of the following crop.

# MATERIALS AND METHODS

Field studies to evaluate the potential of double cropping in lower Michigan were conducted in 1977 at two locations in southwestern Michigan. Three well-adapted soybean varieties, one from each of the maturity groups 0, I, II, were planted after harvesting either winter barley or winter wheat. 'Evans' was selected from Group 0, 'Hodgson' from Group I, and 'Corsoy' from Group II.

## Site 1

The first site was at Galien, Michigan, on a Crozier loam (Aeric Ochraqualf) with a three percent slope. The soil had a pH of 7.2, and soil analysis showed 35 kg of Bray $P_1$ extractable P/ha and 239 kg of K/ha. The soybeans were planted using an Allis Chalmers model #600 no-till planter on July 6, after removing winter barley (*Hordeum vulgare* L. var. Norwind). The planter was modified to include an extra fluted coulter placed slightly ahead of and 15 cm to the side of each existing fluted coulter, and the double-disc furrow opener was adjusted to run behind and between these two cutting coulters. The straw from the barley crop was removed. Each of the three soybean varieties was evaluated for yield and other agronomic characteristics in two row spacings, 19 and 38 cm. Treatments were arranged in a randomized complete block design with eight replications.

The 19 cm row spacing was obtained by making four passes over the field in such a manner as to plant equidistant between two previously planted rows. The planting rate was 134 kg/ha, and the planting depth was 5 cm. To assure an adequate fertility regime, 225 kg of 9-18-18/ha was applied at planting time, and the seeds were innoculated with the proper nitrogen-fixing bacteria. An herbicide mixture of 2.25 kg of metrabuzin/ha, 4.68 l of alachlor/ha and 4.68 l of glyphosate/ha was applied in 750 l of water/hectare.

When the plants were in the V1 stage of development, as described by Fehr and Caviness (11), the plots with the 38 cm row spacing were formed by hand elimination of alternate 19 cm rows within a given plot. Field plot size for each treatment consisted of either six 38 cm rows, or twelve 19 cm rows, each seven meters long, with 1.5 meter alleyways between each complete block. At the V2 growth stage, plant populations were hand thinned so as to be equal to those in the 38 cm row spacing. The final soybean plant populations were approximately 900,000 plants per hectare (17 plants/meter in 19 cm row spacing and 34 plants/meter in 38 cm row spacing).

Yield data were obtained by hand harvesting the center four rows in each 38 cm row plot, and the center eight rows in each 19 cm row plot on November 5, 1977. The harvested seed samples from each plot were dried to 9.9 percent moisture, weighed, and recorded as grams per plot. These weights were later converted to yields in kilograms per hectare at 13 percent seed moisture. Yields of the 'Hodgson' and 'Corsoy' varieties were statistically analyzed using the analysis of variance technique. Yields of 'Evans' could not be included in the analysis due to missing plots. Comparisons of all treatment means were made using the LSD method as described by Steel and Torrie (42) for cases with unequal number of entries. Data on number of seeds per plant, number of pods per plant, number of nodes per plant, number of seeds per pod, number of pods per node, number of the first podded node, plant height above the soil line, height of the first podded node above the soil line, and diamter of the first internode measured at its narrowest part were obtained from ten plants randomly selected from each plot for measurement. Statistical analyses of the data were performed, and treatment means were compared using the LSD method where significance was found (25, 42). A measurement of seed size was made by randomly selecting three lots of 100 seeds from each treatment and recording the weights in grams.

Site 2

The second site was near Schoolcraft, Michigan, on a Volinia loam (Typic Argiudoll) with a zero percent slope. Soil analysis showed 108 kg of Bray $P_1$ extractable P/ha, 440 kg of K/ha, and a pH of 6.0. The soybeans were planted on July 13, using a Tye no-till planter, after harvesting winter wheat (*Triticum aestivum* L.). The same three soybean varieties which were used at the Galien, Michigan location were each planted at two different rates, 117.8 and 151.4 kg/ha. Treatments were arranged in a randomized complete block design with seven replications. Plots were six meters long with 1.5 meter alleyways between each complete block. Each plot contained eight rows spaced 25.4 cm apart. Planting depth was 5 cm, and the seeds were innoculated just prior to planting.

Germination tests were conducted on July 24, on each of the three soybean varieties used. Four lots of 100 seeds each were obtained from each variety and germinated on moist paper toweling at ambient temperatures. Percent germination was noted but not recorded.

## RESULTS AND DISCUSSION

### Site 1

Rapid germination and emergence occurred after the July 6, planting date, and by July 18, all soybean varieties were in the V1 stage of development. Possible compaction effects were of interest because of the method involved in planting 19 and 38 cm row spacings. Using a planter with row spacing fixed at 76 cm required driving over previously planted rows with the tractor and planter wheels. Random checks, however, showed about 80% emergence of the seeds planted. The lack of compaction-related yield reduction was probably due to physical properties of the soil and the relative absence of soil moisture at planting. Sufficient physical support in the undisturbed areas between rows prevented excessive compaction of the soil directly over the seeds. The effect of compaction under slightly higher soil moisture conditions was evident in two areas, each approximately 30 cm wide and extending the entire length of the research area, where inadvertent vehicle traffic occurred after planting but before emergence, after some precipitation had fallen. In these areas emergence was often reduced by 50 percent.

Weed control, initially provided by herbicides and later by plant competition, was excellent throughout the growing period with no visible herbicide damage to the soybean plants. The herbicide mixture applied at planting gave almost 100% control of the weeds as compared to the field area surrounding the experimental plots. Only a few plants of curled dock (Rumex crispus) were found within the area sprayed.

The prolific emergence of volunteer barley within the soybean plots was initially of concern due to its competition with the soybean plants for available moisture and plant nutrients. Also, it has been reported that extracts from the straw of small grains will depress the growth of soybean plants (2). As the growing season advanced, however, the presence of volunteer barley was reduced, and by the time the soybean plants had reached their reproductive stages of growth, the barley was totally absent from within the plots. This was probably a result of a competitive soybean-barley interaction, as the alleys between plots consisted of solid barley stands.

The incidence of diseased soybean plants was minimal, consisting of a small amount of root rot (Phytophtora megasperma Drech. var. sojae A.A. Hildeb.), brown stem rot (Cephalosporium gregantum Allington and Chamberlain), sclerotinia stem rot (Sclerotinia sclerotiorum Lib Dby.), and downey mildew (Peronospora manshurica Naoum. Syd.), and was not considered a factor in soybean plant growth or final yield.

Insect damage was almost non-existant, with only a few green cloverworms (Plathypena scabra Fabricius) present.

The flowering dates for 'Corsoy' and 'Evans' were established by using the dates of various stages of development both before and after flower initiation, and correlating these observations with data presented by Fehr and Caviness (11) and Hanway and Thompson (15). The flowering date for 'Hodgson' was August 11. Maturity dates (R8 stage of development) were obtained by direct observation. Although they belong to different maturity groups, 'Evans' and 'Hodgson' both matured on October 14. This was probably a result of the unusually late date of planting. 'Corsoy' reached the R8 stage of development on November 5, the date all plots were harvested. Hand harvesting was necessary due to excessive soil moisture which prohibited the use of a mechanical combine.

Seed Yields

Varieties. Highly significant differences in yield (0.01) occurred among the three soybean varieties used in this field study (Table A1). 'Evans' (Group 0) yielded 6.4% more than 'Hodgson' (Group I), and 31.6% more than 'Corsoy' (Group II), when averaged across both row spacings (Table 1). This result was unexpected as previously published data (17, 28, 37, 45) indicated that varieties from medium to full-season in maturity for a given area of adaptation will give the highest yield when double-cropped after small grains. The implications of these results for making recommendations to growers are important enough to warrant a possible explanation. If the observed effects, which have

Table 1. Soybean yields (kg/ha) as influenced by variety and row spacing.

| Variety | Row Spacing | | | |
|---|---|---|---|---|
| | 19 cm | 38 cm | $\bar{X}$ | % Difference 19 cm > 38 cm |
| Corsoy | 1813.20 | 1580.69 | 1696.94 | 14.71 |
| Evans | 2381.57 | 2084.96 | 2233.26 | 14.23 |
| Hodgson | 2246.23 | 1949.87 | 2098.05 | 15.20 |
| $\bar{X}$ | 2147.00 | 1871.84 | | 14.70 |

$LSD_{.05}$ (Corsoy vs. Hodgson) - 202.81

$LSD_{.05}$ (Evans vs. Corsoy; Evans vs. Hodgson) - 219.06

not been evident in other studies of double-cropped soybeans after small grains are real, then relying entirely on previous data may result in erroneous recommendations. However, if the obtained results are an anomaly which is extremely situation-specific, then recommendations based on the results presented here will be in error. This is a strong possibility when only one-year's field data is available. Any explanation for the observations made in this study requires consideration of both environmental conditions and phenological development of the soybean plant.

Weather data was obtained from two area National Weather Service reporting stations (Niles, Michigan and South Bend, Indiana) (Tables A11-A12). As no data was available directly from the site of the field research, estimation was necessary. However, the two reporting stations used were close enough in physical proximity to the field site to minimize interpretive error.

Sufficient moisture during the growing season is often cited (38, 41, 45) as the critical factor influencing double-cropped soybean yields. Further research (7) has demonstrated that moisture stress in the soybean plant during the seed-filling period (R5 and R6 stages of development) shows the greatest effect upon yield. In the study presented here, this period would extend from August 31, the beginning of the R5 stage of development in 'Evans' through October 21, the end of the R6 stage of development in 'Corsoy'. Available data indicates that rainfall during this period was above average, that no more than five consecutive days occurred without measurable precipitation, and that these intervals were often associated with high relative humidity, indicated by the presence of fog (Table A11). These data, combined with the high water-holding capacity of the Crozier series soil, suggest that the soybean plants were not under moisture stress during the crucial R5 through R6 stages of development.

Mederski (32) has proposed that susceptibility to moisture stress is related to maturity group. He found that later maturing varieties were less affected by moisture stress than earlier ones. This may explain some of the yield differences between maturity groups of double-cropped soybeans which have been previously reported, because under average climatic conditions, moisture stress will occur in double-cropped soybean fields. However, if the plants are never subjected to moisture stress, as was the case in this study, then other factors would be more important in determining yield.

Flower induction in response to photoperiod in soybeans is well known (27). Maturity groupings are derived partially from a flowering date which insures adequate vegetative growth and allows sufficient time during the growing season for seed filling and maturity. It is agreed that for floral induction, soybean plants must not only have a critical photoperiod, but must also attain a certain physiological stage of development. This is evident in double-cropped soybeans since flower initiation occurs a considerable time after the critical photoperiod has occurred. Daylengths for the flowering dates of the soybeans used in this study were as follows (Table A13): August 8, the flowering date for 'Evans', had a daylength of 14 hours 9 minutes, and on August 11, the flowering date for 'Hodgson', the daylength was 14 hours 2 minutes. 'Corsoy' did not initiate flowering until August 26, which had a daylength of 13 hours 24 minutes. All three of these daylengths are considerably shorter than would be necessary if these varieties were planted at their usual time in May or early June.

The extremely late flowering date of 'Corsoy' is of particular interest. First, it provides a possible explanation for the yield differences obtained. From August 26, the flowering date of 'Corsoy', through October 21, the beginning of physiological maturity, there were 691 hours 20 minutes of possible sunlight. For 'Evans', the R1 - R6 stages of development, August 8, through October 1, had 714 hours 19 minutes of possible sunlight. This represents a 3.32% increase in total hours of possible sunlight over 'Corsoy'. The same reproductive phases in 'Hodgson' occurred between August 11, and October 1, and contained 672 hours of possible sunlight. Possible hours of sunlight were used, as no data was available on cloud cover to determine actual hours of sunlight. This calculated difference of only 23 hours 1 minute of solar radiation during the growing season cannot reasonably account for the 536.3 kg/ha yield difference between the 'Corsoy' and 'Evans' varieties. A further illustration of this is 'Hodgson's' outyielding 'Corsoy' by 401.11 kg/ha while receiving 19 hours 20 minutes less solar radiation during its reproductive growth phase. These differences may have been due to either varietal differences in total leaf area or to differences in photosynthetic efficiency per unit of leaf area or to both.

The second interesting aspect of the flowering date of 'Corsoy' is that it suggests a greater relative degree of day-neutrality than found in either 'Evans' or 'Hodgson'.

The angle at which the sun's radiation strikes the soybean canopy may influence its penetration into that canopy and thus alter the photosynthetic activity of the lower leaves on the plants. During the period between flower initiation and the beginning of maturity in 'Corsoy', the midday sun altitude went from $58.8^{o}$ to $37.7^{o}$ above the southern horizon. For 'Evans', the beginning of the R1 stage of development through the R6 stage of development encompassed a change in the midday sun altitude from $64.5^{o}$ to $45.2^{o}$ above the southern horizon. For 'Hodgson' the change during the R1 - R6 phase was from $63.6^{o}$ to $45.2^{o}$. Thus, the possibility exists that, although the total number of hours of sunlight received during the reproductive phase of each soybean variety did not vary by a large amount, the more direct solar radiation during the early reproductive period of 'Evans' and 'Hodgson', August 8, through August 22, penetrated the crop canopy to a greater extent and stimulated increased production of photosynthate, while the solar radiation received by the 'Corsoy' variety late in its reproductive cycle, after October 1, was less direct, more diffuse, and therefore less photosynthetically efficient (Table A14).

Temperature is another factor influencing yield variability. Although attempts to use heat-units for predicting soybean maturity have been generally unsuccessful, several researchers have noted a reduction in photosynthesis associated with lowering temperatures. Crookston et al. (6) found that photosynthesis was reduced only if the root temperature was reduced. Temperature data from South Bend, Indiana, approximately 20 km southeast of the research site, showed only slight departures from normal throughout the growing season from July 6, through November 5, (Table A12). The data also showed that the sum of the average daily temperatures from August 8, flower initiation in 'Evans', until August 23, the flowering date of 'Corsoy', to be 305.6°C. From October 2, through October 21, the period between the end of the R6 stage of development in 'Evans' and 'Hodgson' and the end of the R6 stage of development in 'Corsoy', the sum of the average daily temperatures was 187.2°C. Although soil temperature data were unavailable, it may be concluded that soil temperature, and corresponding root temperature, were lower later in the growing season during the reproductive phases of 'Corsoy' than during the reproductive phases of 'Evans' and 'Hodgson' earlier in the growing season. This would result in a lower rate of photosynthesis, which would be reflected in lower yields.

Shibles et al. (39) have hypothesized that both seed set efficiency and seed-fill would benefit by greater levels of photosynthate, as its availability limits both seed-fill and nitrogen fixation. Sinclair and de Wit (40) have proposed that photosynthetic activity is limited by the inability of the soybean plant to acquire nitrogen at a sufficient rate during seed-fill. The deficit in the nitrogen is satisfied by translocation from the leaves to the seeds, resulting in leaf senescence and a consequent reduction in overall photsynthetic ability. Thomas and Raper (44) have studied the cause of rapid seed-fill, and concluded that the photoperiodic conditions after floral induction are responsible for yield limits. They suggest that exposure to short days (9 hours) at the V1 stage of development will give the highest pod-production efficiency (number of pods set per total number of flowers initiated), and also that both decreasing thermoperiod and decreasing photoperiod increase the rate of seed fill.

The 18-day delay in flowering in 'Corsoy' after the onset of the R1 stage of development in 'Evans' provided a sufficient interval for the temperature and the daylength conditions to have a greater influence upon final seed yield, even though the R1 through R6 stages of development required almost the same number of days ('Corsoy', 56 days; 'Evans', 54 days; 'Hodgson', 51 days). The demand for photosynthate was increasing at a time when both solar radiation and soil temperature were decreasing. The inability of the plant to supply sufficient photosynthate for both seed-fill and nitrogen fixation caused translocation of nitrogen from leaves to seeds. This further reduced the photosynthetic activity of the leaves, which in turn increased the rate of nitrogen translocation. The resulting situation was one where an increasing demand for nitrogen for seed-fill was coupled with a decreasing ability to obtain nitrogen, and thus seed yields were limited.

Row Spacing. The effect of row spacing upon yield was statistically significant at the 0.01 level (Table A1). Averaged across varieties, the 19 cm rows gave a 14.7% higher yield than the plants in the 38 cm rows (2147.00 vs. 1871.84 kg/ha). All three soybean varieties exhibited yield increases in the 19 cm row spacing when compared with the same variety in the 38 cm row spacing (Table 1). Yields for 'Corsoy', 'Evans', and 'Hodgson' in 19 cm rows were 14.7, 14.2, and 15.2% respectively, greater than yields in the 38 cm row spacing.

Several researchers have examined the effect of row spacing upon yield, and have concluded that increases in the narrower rows are due to a combination of more efficient use of available moisture (8, 32), earlier crop canopy formation which makes maximum use of available solar radiation (8, 22), and earlier ground cover which aids in weed control (8, 23). Since double-cropped soybeans form shorter and narrower plants than full-season plantings, the negative effects of lodging and early senescence of lower leaves often associated with narrow rows are avoided. No significant variety X spacing interaction was observed in this study (Tables A1 - A11). However, other researchers have reported that some varieties respond better to narrow rows than do others (3, 34). Research has also shown that yield increases in response to row spacing are more pronounced in the more northern latitudes of the United States (34).

Agronomic Characteristics

Yield Components. Differences in the number of nodes per plant were significant at the 0.01 level (Table A2). 'Corsoy' had 6.3% more nodes per plant than 'Evans', 11.56 vs. 10.87, and 7.8% more than 'Hodgson' (Table 2). It is important to note that although 'Corsoy' had the greatest number of potential reproductive sites (nodes), it had the lowest seed yield, suggesting that the environmental conditions during the reproductive phase of 'Corsoy' were more influential in

Table 2. Number of nodes per plant as influenced by variety and row spacing.

| Variety | Row Spacing | | | |
|---|---|---|---|---|
| | 19 cm | 38 cm | $\bar{X}$ | % Difference 19 cm > 38 cm |
| Corsoy | 11.12 | 12.00 | 11.56 | -7.33 |
| Evans | 10.90 | 10.84 | 10.87 | 0.55 |
| Hodgson | 10.49 | 10.94 | 10.72 | -4.11 |
| $\bar{X}$ | 10.84 | 11.26 | | -3.73 |

$LSD_{.05}$ - 0.64

limiting potential seed yield of that variety than were the growing conditions corresponding to the reproductive phases of 'Evans' and 'Hodgson'.

Variations in the number of pods per plant were not statistically significant among the three varieties (Table A3). However, 'Evans', with 20.80 pods per plant, had 5.2% and 10.6% more pods per plant than 'Corsoy' and 'Hodgson', respectively.

The variability in the number of pods per node among 'Corsoy', 'Evans', and 'Hodgson' was significant at the 0.05 level (Table A4). 'Evans' produced 9.2% and 11.8% more pods per node than 'Hodgson' and 'Corsoy', respectively, 1.90 vs. 1.74 and 1.70 (Table 4). Assuming that the three soybean varieties had the capabilities of producing equal numbers of pods per node, it is evident that 'Evans' is more efficient at setting pods under the environmental conditions encountered in this study than either 'Hodgson' or 'Corsoy'.

Table 3. Number of pods per plant as influenced by variety and row spacing.

| Variety | Row Spacing | | | |
|---|---|---|---|---|
| | 19 cm | 38 cm | $\bar{X}$ | % Difference 19 cm > 38 cm |
| Corsoy | 17.95 | 21.61 | 19.78 | -16.94 |
| Evans | 21.11 | 20.50 | 20.80 | 2.98 |
| Hodgson | 18.01 | 19.59 | 18.80 | - 8.06 |
| $\bar{X}$ | 19.02 | 20.57 | | - 7.54 |

Table 4. Number of pods per node as influenced by variety and row spacing.

| Variety | Row Spacing | | $\bar{X}$ | % Difference |
|---|---|---|---|---|
| | 19 cm | 38 cm | | 19 cm > 38 cm |
| Corsoy | 1.60 | 1.80 | 1.70 | -11.11 |
| Evans | 1.92 | 1.89 | 1.90 | 1.59 |
| Hodgson | 1.71 | 1.78 | 1.74 | - 3.93 |
| $\bar{X}$ | 1.74 | 1.82 | | - 4.40 |

$LSD_{.05}$ - 0.20

The total number of seeds per plant was highest in the 'Evans' variety, with an average of 21.8% more seeds per plant than 'Corsoy', 44.44 vs. 36.50, and 22.3% more than 'Hodgson', 44.44 vs. 36.34 (Table 5). These differences are statistically significant at the 0.01 level (Table A5).

Table 5. Number of seeds per plant as influenced by variety and row spacing.

| Variety | Row Spacing | | $\bar{X}$ | % Difference |
|---|---|---|---|---|
| | 19 cm | 38 cm | | 19 cm > 38 cm |
| Corsoy | 33.46 | 39.55 | 36.50 | -15.40 |
| Evans | 45.12 | 43.76 | 44.44 | 3.11 |
| Hodgson | 34.80 | 37.88 | 36.34 | - 8.13 |
| $\bar{X}$ | 37.79 | 40.40 | | - 6.46 |

$LSD_{.05}$ - 6.71

The number of seeds per pod was also highest in 'Evans' (2.13), with a 9.8% increase over 'Hodgson' (1.94), and a 15.8% increase over Corsoy (1.84) (Table 6). This difference was significant at the 0.01 level (Table A6). It is once again evident that, if all three varieties have an equal potential number of seeds per pod, then 'Evans' was able to interact with the environment in a manner which was more favorable to reproduction than were the other two varieties.

Table 6. Number of seeds per pod as influenced by variety and row spacing.

| Variety | Row Spacing | | | |
|---|---|---|---|---|
| | 19 cm | 38 cm | $\bar{X}$ | % Difference 19 cm > 38 cm |
| Corsoy | 1.86 | 1.83 | 1.84 | 1.64 |
| Evans | 2.12 | 2.14 | 2.13 | -0.93 |
| Hodgson | 1.94 | 1.94 | 1.94 | 0.00 |
| $\bar{X}$ | 1.97 | 1.97 | | 0.00 |

$LSD_{.05}$ - 0.11

Table 7. Seed size (g/100 seeds) as influenced by variety and row spacing.

| Variety | Row Spacing | | | |
|---|---|---|---|---|
| | 19 cm | 38 cm | $\bar{X}$ | % Difference 19 cm > 38 cm |
| Corsoy | 14.87 | 14.33 | 14.60 | 3.77 |
| Evans | 14.90 | 14.60 | 14.75 | 2.05 |
| Hodgson | 16.10 | 15.73 | 15.92 | 2.35 |
| $\bar{X}$ | 15.29 | 14.89 | | 2.69 |

Although statistical analysis of seed size was not performed, an insepection of available seed weights showed 'Hodgson' to be 7.9% heavier than 'Evans', 15.92 vs. 14.75, and 9.0% heavier than 'Corsoy', 15.92 vs. 14.60 (Table 7).

Of the six yield components studied, only the number of pods per node and the number of seeds per pod were indicators of the relative order of the final seed yields among 'Corsoy', 'Evans', and 'Hodgson'.

The overall effect of row spacing on yield components presents no definite trends. The effect of row spacing on the number of nodes per plant was significant at the 0.05 level when averaged across varieties (Table A2). The 38 cm row spacing showed a 3.9% increase in potential reproductive sites over the 19 cm row spacing, 11.26 vs. 10.84 pods per plant (Table 2). As was the case in the comparison of varieties when averaged across row spacing, the highest potential was not realized when final yields were measured.

Although not statistically significant (Tables A3, A4, A5, A6), the total number of pods per plant, pods per node, and seeds per plant showed slight increases in the 38 cm row spacing (Tables 3, 4, 5), while seeds per pod showed no increase in the 19 cm row spacing (Table 6). An increase of 2.7% in seed size was obtained in the 19 cm row spacing over the 38 cm row spacing, 15.29 vs. 14.89, when averaged across varieties (Table 7).

No statistically significant interactions between variety and row spacing occurred with regard to yield or any component of yield (Tables A1 - A6).

Morphological Components. No statistically significant differences in plant height occurred among the three soybean varieties or between

Table 8. Plant height (cm) as influenced by variety and row spacing.

| Variety | Row Spacing | | | % Difference |
|---|---|---|---|---|
| | 19 cm | 38 cm | $\bar{X}$ | 19 cm > 38 cm |
| Corsoy | 58.65 | 57.20 | 57.92 | 2.53 |
| Evans | 56.41 | 56.26 | 56.34 | 0.27 |
| Hodgson | 59.01 | 56.90 | 57.96 | 3.71 |
| $\bar{X}$ | 58.02 | 56.79 | | 2.16 |

the two row spacings (Table A7). However, the plants in the 19 cm row spacing were 2.2% taller, 58.02 cm vs. 56.79 cm (Table 8).

Variation in the number of the first podded node was statistically significant at the 0.01 level (Table A8). Averaged across row spacings, 'Corsoy' podded 0.48 nodes higher than 'Evans', and 0.38 nodes higher than 'Hodgson', 3.84 vs. 3.36 and 3.46, respectively (Table 9). The effect of row spacing on the number of the first podded node was significant at the 0.01 level (Table A8). Averaged across varieties, the first podded node of plants in 19 cm rows was 4.6% higher than that for plants in 38 cm rows, 3.63 vs. 3.47 (Table 9). The actual influence of the number of the first podded node upon final seed yield is not clearly evident. No data was gathered on the average number of seeds the lower podding of 'Evans' and 'Hodgson' represented, but it does suggest a loss of potential yield in the 'Corsoy' variety, as well as a reduction of potential in the 19 cm rows. A probable explanation is that this factor was not critical in determing yield.

The height of the first podded node above the soil line varied among the three soybean varieties at the 0.01 statistical level

Table 9. The number of the first podded node as influenced by variety and row spacing.

| Variety | Row Spacing | | | % Difference |
|---|---|---|---|---|
| | 19 cm | 38 cm | $\bar{X}$ | 19 cm > 38 cm |
| Corsoy | 3.92 | 3.76 | 3.84 | 4.26 |
| Evans | 3.39 | 3.32 | 3.36 | 2.11 |
| Hodgson | 3.59 | 3.32 | 3.46 | 8.13 |
| $\bar{X}$ | 3.63 | 3.47 | | 4.61 |

$LSD_{.-5}$ - 0.20

(Table A9). The height of the first podded node occurred 5.5% higher on 'Hodgson' than on 'Corsoy', 9.92 vs. 9.40 cm, and 16.0% higher than on 'Evans', 9.92 vs. 8.55 cm (Table 10). This measurement is an important factor when considering potential harvesting losses. If the plant is podded too low to the soil line, the cutter bar on the combine may either cut the pod at some point, and thus only partially harvest the pod, or it may cut above the lowest pod or pods entirely, resulting in a total loss of this portion of seed yield.

The effect of row spacing on the height of the first node was significant at the 0.01 level (Table A9). The narrower row spacing resulted in lowest pods being set 9.8% higher than in the wider rows, 9.73 vs. 8.86 cm (Table 10). This observation supports the conclusion that double-cropped soybeans will yield more if planted in the narrower row spacings. Greater yields have already been demonstrated for 19 cm rows in terms of possible production, and the higher location of the first podded node should minimize harvest losses, an additional advantage.

Table 10. The height of the first podded node (cm) as influenced by variety and row spacing.

| Variety | Row Spacing | | | |
|---|---|---|---|---|
| | 19 cm | 38 cm | $\bar{X}$ | % Difference 19 cm > 38 cm |
| Corsoy | 9.98 | 8.82 | 9.40 | 13.15 |
| Evans | 8.86 | 8.24 | 8.55 | 7.52 |
| Hodgson | 10.34 | 9.51 | 9.92 | 8.73 |
| $\bar{X}$ | 9.73 | 8.86 | | 9.82 |

$LSD_{.05}$ - 0.98

The diameter of the first internode was not statistically significant either among the soybean varieties, or between the two row spacings (Table A10). The diameter of 'Corsoy' was 2.8% greater than for 'Evans' and 'Hodgson', 0.37 vs. 0.36 and 0.36 respectively (Table 11).

Table 11. The diameter of the first internode (cm) as influenced by variety and row spacing.

| Variety | Row Spacing | | | |
|---|---|---|---|---|
| | 19 cm | 38 cm | $\bar{X}$ | % Difference 19 cm > 38 cm |
| Corsoy | 0.35 | 0.39 | 0.37 | -10.26 |
| Evans | 0.36 | 0.36 | 0.36 | 0.00 |
| Hodgson | 0.35 | 0.36 | 0.36 | - 2.78 |
| $\bar{X}$ | 0.35 | 0.37 | | - 5.40 |

Site 2

At the Schoolcraft, Michigan location, initial germination and emergence occurred within five days after planting. By July 23, approximately 10% of the seeds planted had emerged. No appreciable increase in soybean emergence was observed after that date. A marked varietal difference in emergence was noted, with 'Corsoy' having the best emergence, 'Evans' slightly less, and 'Hodgson' the poorest, with only an occasional plant in evidence. Although only slight differences in emergence were observed between the two seeding rates, the heavier seeding rate resulted in higher emergence for all varieties.

The failure of the expected normal emergence of 'Corsoy', 'Evans', and 'Hodgson' cannot be attributed to a lack of sufficient moisture. Precipitation measurements taken near the research site showed that 3.8 cm of rainfall occurred within four days after planting. This amount was spread over three dates, July 14, (2.0 cm), July 15, (0.5 cm), and July 17, (1.3 cm), and would have provided adequate soil moisture for germination.

No evidence of high resistance to emergence due to crusting of the soil surface was found. The wheat straw was cut twice with a disk after the grain was harvested, and this provided sufficient crop residue to avoid potential crusting problems. The depth of planting was rechecked and was approximately the desired 5 cm.

Using the original seed source for 'Evans' and 'Hodgson', four lots of 100 seeds each were selected from each variety for germination tests. In both varieties germination was between 85 and 95%. This was expected, as the seeds of the 'Evans' and 'Hodgson' varieties were from the same source as those planted near Galien, Michigan on July 6.

Although seeds of the 'Corsoy' variety were from a different source than the original seed source, it performed well in the germination test and had the highest relative emergence in the field. This suggests that an environmental factor was the cause of the low emergence obtained.

Grabe and Metzer (14) found that soybean varieties differed in emergence when planted 10 cm deep in sand and grown at 25°C, but emergence was normal at temperatures above and below this. They reported that the short hypocotyl length of some varieties was responsible for their poor emergence. Gilman _et al_. (13) showed that inhibition of hypocotyl elongation was determined by the length of exposure of the germinating seed to temperatures between 21° and 28°C. Fehr _et al_. (12) studied soybean emergence under field conditions and found that soil temperature did not consistently influence emergence. They suggested that soil resistance could mask the expression of temperature-dependent hypocotyl elongation. However, they did find that varieties which exhibit inhibited hypocotyl elongation at 25°C also show inferior field emergence. Studies at Iowa State University (20) have shown poor emergence in 'Corsoy', 'Hodgson', and 'Evans' varieties at 25°C.

In the present study the effect of temperature was probably more of a factor in emergence than was soil resistance. It is reasonable to assume that the soil temperature at a depth of 5 cm during the July 13, to July 23, period was in the 20° to 30°C range most of the time. The presence of the double-cut wheat straw in the upper 10 cm of the soil profile would greatly reduce the potential resistance to hypocotyl elongation associated with a fine loam such as the Volinia series.

Cox *et al.* (5) has reported that the incorporation of wheat straw increases the incidence of diseased soybean seedlings. He also reported that substances in the wheat straw were phytotoxic to soybeans.

A probable explanation for the results obtained at Site 2 would include any or all of these aforementioned causes.

## SUMMARY AND CONCLUSIONS

The effects of row spacing, planting rate, and soybean variety on double-cropped soybeans were studied at two locations in southern Michigan.

At Site 1, near Galien, Michigan, it was found that with adequate moisture, sufficient length of growing season, and proper weed control, double-cropped soybeans were highly productive. 'Evans', 'Hodgson', and 'Corsoy' had seed yields of 2233.26, 2098.05, and 1696.94 kg/ha, respectively. When averaged across varieties the effect of row spacing was clearly evident, with plants in the 19 cm rows yielding 14.7% more than the plants in the 38 cm rows, 2147 kg/ha vs. 1871.84 kg/ha. The 19 cm rows also podded higher, which is a benefit in harvesting. The data from this study show that a favorable climate, minimum seedbed tillage, adequate weed control and narrow row spacing can result in highly productive soybean yields.

At the second site, near Schoolcraft, Michigan, the insufficient germination and emergence precluded an intended study of varieties and seeding rates.

Future research should focus on factors such as the best varieties and plant populations for use in the double-cropping system as the potential for double-cropped soybeans has been amply demonstrated in this study.

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LITERATURE CITED


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# APPENDIX

Table A1. Analysis of variance of soybean yields (kg/ha) as influenced by variety and row spacing.

| Source | df | Mean square | F |
|---|---|---|---|
| Variety | 1 | 1287104.00 | 33.847 ** |
| Spacing | 1 | 559416.08 | 14.711 ** |
| Variety X Spacing | 1 | 8154.32 | 0.214 |
| Error | 21 | 38027.39 | |

**Denotes significance at the 0.01 probability level.

Table A2. Analysis of variance of the number of nodes per plant as influenced by variety and row spacing.

| Source | df | Mean square | F |
|---|---|---|---|
| Variety | 2 | 3.275208 | 8.231 ** |
| Spacing | 1 | 2.125208 | 5.341 * |
| Variety X Spacing | 2 | 0.881458 | 2.215 |
| Error | 35 | 0.397899 | |

**Denotes significance at the 0.01 probability level.
*Denotes significance at the 0.05 probability level.

Table A3. Analysis of variance of the number of pods per plant as influenced by variety and row spacing.

| Source | df | Mean square | F |
|---|---|---|---|
| Variety | 2 | 16.102708 | 1.777 |
| Spacing | 1 | 28.520833 | 3.148 |
| Variety X Spacing | 2 | 18.278958 | 2.018 |
| Error | 35 | 9.059405 | |

Table A4. Analysis of variance of the number of pods per node as influenced by variety and row spacing.

| Source | df | Mean square | F |
|---|---|---|---|
| Variety | 2 | 0.1748396 | 4.350 * |
| Spacing | 1 | 0.0776021 | 1.931 |
| Variety X Spacing | 2 | 0.0513771 | 1.278 |
| Error | 35 | 0.0401956 | |

*Denotes significance at the 0.05 probability level.

Table A5. Analysis of variance of the number of seeds per plant as influenced by variety and row spacing.

| Source | df | Mean square | F |
|---|---|---|---|
| Variety | 2 | 343.31650 | 7.858 ** |
| Spacing | 1 | 81.12000 | 1.857 |
| Variety X Spacing | 2 | 56.17938 | 1.286 |
| Error | 35 | 43.68976 | |

**Denotes significance at the 0.01 probability level.

Table A6. Analysis of variance of the number of seeds per pod as influenced by variety and row spacing.

| Source | df | Mean square | F |
|---|---|---|---|
| Variety | 2 | 0.3331521 | 29.833 ** |
| Spacing | 1 | 0.0004688 | 0.042 |
| Variety X Spacing | 2 | 0.0021812 | 0.195 |
| Error | 35 | 0.0111671 | |

**Denotes significance at the 0.01 probability level.

Table A7. Analysis of variance of plant height (cm) influenced by variety and row spacing.

| Source | df | Mean square | F |
|---|---|---|---|
| Variety | 2 | 13.710625 | 0.728 |
| Spacing | 1 | 18.376875 | 0.976 |
| Variety X Spacing | 2 | 3.986875 | 0.212 |
| Error | 35 | 18.831899 | |

Table A8. Analysis of variance of the number of the first podded node as influenced by variety and row spacing.

| Source | df | Mean square | F |
|---|---|---|---|
| Variety | 2 | 1.0608330 | 26.588 ** |
| Spacing | 1 | 0.3168750 | 7.942 ** |
| Variety X Spacing | 2 | 0.0400000 | 1.002 |
| Error | 35 | 0.0398988 | |

**Denotes significance at the 0.01 probability level.

Table A9. Analysis of variance of the height of the first podded node as influenced by variety and row spacing.

| Source | df | Mean square | F |
|---|---|---|---|
| Variety | 2 | 7.7033330 | 8.175 ** |
| Spacing | 1 | 9.0133330 | 9.565 ** |
| Variety X Spacing | 2 | 0.2808333 | 0.298 |
| Error | 35 | 0.9423333 | |

**Denotes significance at the 0.01 probability level.

Table A10. Analysis of variance of the diameter of the first internode (cm) as influenced by variety and row spacing.

| Source | df | Mean square | F |
|---|---|---|---|
| Variety | 2 | 0.0007852 | 0.795 |
| Spacing | 1 | 0.0027755 | 2.810 |
| Variety X Spacing | 2 | 0.0015406 | 1.560 |
| Error | 35 | 0.0009876 | |

Table A11. Daily precipitation (mm).

| | Jul | | Aug | | Sept | | Oct | |
|---|---|---|---|---|---|---|---|---|
| Day | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 1 | | | | | 38.6 | 76.2 | 16.5 | 19.6 |
| 2 | | | 2.0 | 17.3 | 0.8 | F | 0.2 | 0.2 |
| 3 | T | | 1.8 | 1.0 | | | | |
| 4 | T | F | 5.6 | 2.0 | 2.5 | 4.1 | F | F |
| 5 | | | 3.3 | 2.0 | 2.0 | T | 0.2 | 1.3 |
| 6 | | | 2.0 | 8.9 | | F | | |
| 7 | T | T | 5.8 | 1.3 | | F | 7.1 | 13.7 |
| 8 | 0.8 | 0.8 | 35.0 | 35.0 | 0.2 | F | 7.1 | 2.3 |
| 9 | | F | 1.8 | 0.2 | | | 0.5 | 0.8 |
| 10 | | | 16.5 | 9.9 | | | T | T |
| 11 | 4.1 | 4.8 | 2.8 | 3.0 | | F | 3.6 | 4.3 |
| 12 | 6.1 | 27.9 | F | F | 8.6 | 10.2 | T | |
| 13 | | | | F | 30.5 | 32.2 | | F |
| 14 | | | | F | F | F | | F |
| 15 | | T | | | 18.3 | 26.4 | T | 0.5 |
| 16 | 0.5 | 11.9 | 1.3 | 4.1 | 0.2 | T | 3.3 | 7.1 |
| 17 | 4.3 | 4.6 | | | 4.6 | 0.5 | 0.2 | |
| 18 | T | | | F | 9.4 | 25.4 | 5.1 | 18.3 |
| 19 | | F | | | T | F | 2.8 | 1.3 |
| 20 | | F | T | T | 1.3 | 3.8 | F | F |
| 21 | T | T | 3.0 | 2.8 | 0.2 | F | | |
| 22 | | | | F | 0.2 | T | 3.8 | 0.5 |
| 23 | | | 3.3 | | 0.2 | F | 1.0 | 1.5 |
| 24 | 9.6 | 17.8 | 1.3 | F | 19.0 | 14.7 | | |
| 25 | F | F | | | | 2.5 | 0.5 | 1.0 |
| 26 | | | T | | 14.5 | 25.6 | T | T |
| 27 | | | | F | | | F | T |
| 28 | | | 6.6 | 54.5 | | | F | F |
| 29 | 0.5 | 0.2 | 7.4 | 7.4 | 0.2 | T | F | F |
| 30 | F | F | F | F | 6.4 | 7.1 | F | F |
| 31 | T | T | | | | | 3.0 | 5.8 |
| Total | 25.9 | 68.0 | 99.5 | 150.3 | 157.7 | 228.7 | 54.9 | 78.2 |

1 - Niles, Michigan
2 - South Bend, Indiana
F - Fog
T - Trace amounts

Table A12. Monthly temperatures at South Bend, Indiana ($^{o}C$).

| | Jul | Aug | Sept | Oct |
|---|---|---|---|---|
| Average | 24.6 | 21.0 | 18.0 | 10.3 |
| Departure from normal | 2.2 | - 0.7 | 0.8 | - 1.6 |

Table A13. Daylength at 41°48' N Lat.

| | Jul | | Aug | | Sept | | Oct | |
|---|---|---|---|---|---|---|---|---|
| Day | hr | mi | hr | mi | hr | mi | hr | mi |
| 1 | 15 | 10 | 14 | 25 | 13 | 09 | 11 | 46 |
| 2 | 15 | 09 | 14 | 23 | 13 | 05 | 11 | 43 |
| 3 | 15 | 08 | 14 | 21 | 13 | 03 | 11 | 40 |
| 4 | 15 | 08 | 14 | 19 | 13 | 01 | 11 | 37 |
| 5 | 15 | 07 | 14 | 17 | 12 | 58 | 11 | 34 |
| 6 | 15 | 06 | 14 | 14 | 12 | 54 | 11 | 31 |
| 7 | 15 | 05 | 14 | 11 | 12 | 52 | 11 | 28 |
| 8 | 15 | 04 | 14 | 09 | 12 | 49 | 11 | 26 |
| 9 | 15 | 03 | 14 | 06 | 12 | 46 | 11 | 23 |
| 10 | 15 | 02 | 14 | 04 | 12 | 44 | 11 | 20 |
| 11 | 15 | 01 | 14 | 02 | 12 | 41 | 11 | 18 |
| 12 | 15 | 00 | 14 | 00 | 12 | 39 | 11 | 15 |
| 13 | 14 | 58 | 13 | 57 | 12 | 36 | 11 | 12 |
| 14 | 14 | 57 | 13 | 55 | 12 | 33 | 11 | 10 |
| 15 | 14 | 56 | 13 | 52 | 12 | 30 | 11 | 07 |
| 16 | 14 | 54 | 13 | 50 | 12 | 27 | 11 | 04 |
| 17 | 14 | 53 | 13 | 47 | 12 | 24 | 11 | 02 |
| 18 | 14 | 51 | 13 | 45 | 12 | 22 | 10 | 59 |
| 19 | 14 | 49 | 13 | 43 | 12 | 20 | 10 | 56 |
| 20 | 14 | 48 | 13 | 39 | 12 | 16 | 10 | 53 |
| 21 | 14 | 47 | 13 | 37 | 12 | 14 | 10 | 51 |
| 22 | 14 | 45 | 13 | 34 | 12 | 11 | 10 | 48 |
| 23 | 14 | 43 | 13 | 32 | 12 | 08 | 10 | 46 |
| 24 | 14 | 41 | 13 | 29 | 12 | 05 | 10 | 43 |
| 25 | 14 | 39 | 13 | 27 | 12 | 02 | 10 | 41 |
| 26 | 14 | 37 | 13 | 24 | 12 | 00 | 10 | 38 |
| 27 | 14 | 35 | 13 | 21 | 11 | 57 | 10 | 36 |
| 28 | 14 | 33 | 13 | 19 | 11 | 53 | 10 | 32 |
| 29 | 14 | 31 | 13 | 17 | 11 | 51 | 10 | 30 |
| 30 | 14 | 29 | 13 | 14 | 11 | 48 | 10 | 28 |
| 31 | 14 | 27 | 13 | 12 | | | 10 | 25 |

Table A14. Midday sun altitude above the southern horizon at 41$^{o}$ 48' N Lat (degrees).

| Day | Jul | Aug | Sept | Oct |
|---|---|---|---|---|
| 1 | 71.32 | 60.96 | 56.68 | 45.24 |
| 2 | 71.28 | 66.11 | 56.32 | 44.85 |
| 3 | 71.20 | 65.85 | 55.96 | 44.46 |
| 4 | 71.12 | 65.60 | 55.60 | 44.07 |
| 5 | 71.04 | 65.33 | 55.23 | 43.68 |
| 6 | 70.94 | 65.06 | 54.86 | 43.30 |
| 7 | 70.84 | 64.78 | 54.49 | 42.92 |
| 8 | 70.74 | 64.50 | 54.11 | 42.54 |
| 9 | 70.62 | 64.21 | 53.74 | 42.16 |
| 10 | 70.50 | 63.93 | 53.36 | 41.78 |
| 11 | 70.38 | 63.63 | 52.98 | 41.40 |
| 12 | 70.24 | 63.33 | 52.60 | 41.02 |
| 13 | 70.10 | 63.04 | 52.22 | 40.65 |
| 14 | 69.97 | 62.73 | 51.84 | 40.27 |
| 15 | 69.82 | 62.42 | 51.65 | 39.90 |
| 16 | 69.66 | 62.12 | 51.06 | 39.53 |
| 17 | 69.50 | 61.80 | 50.67 | 39.16 |
| 18 | 69.32 | 61.48 | 50.29 | 38.80 |
| 19 | 69.15 | 61.16 | 49.90 | 38.44 |
| 20 | 68.97 | 60.83 | 49.61 | 38.07 |
| 21 | 68.78 | 60.50 | 49.13 | 37.71 |
| 22 | 68.58 | 60.18 | 48.66 | 37.37 |
| 23 | 69.39 | 59.84 | 48.20 | 37.00 |
| 24 | 68.18 | 59.50 | 47.96 | 36.65 |
| 25 | 67.97 | 59.16 | 47.57 | 36.31 |
| 26 | 67.76 | 58.81 | 47.18 | 35.96 |
| 27 | 67.54 | 58.46 | 46.80 | 35.62 |
| 28 | 67.31 | 58.12 | 46.41 | 35.28 |
| 29 | 67.09 | 57.76 | 46.02 | 34.94 |
| 30 | 66.85 | 57.40 | 45.63 | 34.61 |
| 31 | 66.60 | 57.05 | | 34.29 |