POLYMER SEED COATING EFFECTS ON FEASIBILITY OF EARLY PLANTING IN CORN

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ABSTRACT

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This research was conducted to investigate the effects of temperature-sensitive polymer seed coatings on corn (*Zea mays* L.) growth and development. Field experiments were established in 2000 and 2001 on a poorly drained, dark prairie soil (mesic Typic Haplaquolls) on fields previously in soybeans (*Glycine max* L.) in west central Indiana. Two corn Hybrids (Fielder's Choice 9307 and 8509) were no-till planted on three dates representing early (28 March 2000, 2 April 2001), intermediate (14 April 2000, 19 April 2001) and late (16 May 2000, 11 May 2001) planting times. Each Hybrid was treated as follows in 2000: the untreated control (UTC), seed coating A (2 % of seed weight), seed coating B (3 % of seed weight), and in 2001: the untreated control (UTC), seed coating C (slightly different polymer than in 2000, 2 % of seed weight), seed coating D (same polymer as in 2000, 2.5 % of seed weight).

Polymer coatings resulted in emergence delays ranging from 1 to 6 days for early, intermediate and late planting dates for both Hybrids and in both years. For early-planted corn, coated seed only improved emergence uniformity relative to uncoated seed for one season (2000) and one Hybrid (8509). In fact, in 2001 coated treatments of both Hybrids decreased emergence uniformity. Polymer coatings never increased total number of

seedlings emerged in either year, but improved final established stands following the initial planting date in 2001, when mid-April frosts reduced the stand of uncoated seed of 9307 more than 8509, and coated seed treatments of both Hybrids were less affected than uncoated seed treatments because of the former's later emergence.

One consequence of delayed emergence during early vegetative growth was that coated treatments generally resulted in shorter and less developed plants than the uncoated treatment. In general, within-row variability in plant height or vegetative stages was not more pronounced with coated versus uncoated treatments. Grain yields were affected by Hybrid and planting dates, but not by polymer seed coatings except for the early planting date in 2001, when corn with coated seed of Hybrid 9307 resulted in yield gains of from 15 to 18% due to the larger frost damage experienced by the uncoated seed treatment.

Individual plant grain yields were affected more by plant-to-plant variability in development later in the season than by variability in emergence, and emergence differences appeared to exert only a minor influence on variability in later season growth. After early planting, even when some coating treatments resulted in a more variable emergence, individual grain yields were never affected by relative emergence time as much as they were by subsequent developmental differences among plants in a corn row.

Corn growth and yield advantages with polymer coatings may have been more apparent if cooler and wetter soil conditions had prevailed after the first 2 planting dates in both years. Overall polymer effects on emergence were Hybrid dependent, and less evident with later planting dates. Main effects of Hybrid and planting date impacted corn response more than polymer treatments.

LITERATURE REVIEW

Planting Date and Corn Productivity

Corn grain yield is related to light interception, to radiation use efficiency and to photoassimilate partitioning (Gifford et al. 1984). Planting date, planting pattern and density, as well as genotype, are factors that can influence these variables and, therefore, affect grain yield.

Variation in planting date in maize modifies the radiative and thermal conditions during growth. The amount of incident radiation and the proportion of this radiation that is intercepted by the crop directly determine crop growth rate (Tollenaar and Brulsema, 1988; Muchow *et al*., 1990). On the other hand, temperature affects the duration of crop growth (Warrington and Kanemasu, 1983) and, consequently the time during which incident radiation can be intercepted and transformed to dry matter. Temperature also affects final leaf number (Hesketh *et al*., 1969; Tollenaar and Hunter, 1983; Stevenson and Goodman, 1972) and leaf canopy development (Hesketh and Warrington, 1989), which influence crop leaf area index.

Bollero *et al*. (1996) found grain yield to decrease linearly with decreasing soil temperature. They found that increased grain yield with increasing soil temperature early in the season was due to larger leaf surfaces in the upper portion of the canopy. It has been also documented that low air temperatures reduce radiation use efficiency (RUE) in maize (Andrade *et al*., 1993).

Grain yield in maize is mostly dependent on variation in the number of kernels harvested (Claasen and Shaw, 1970; Hall *et al*., 1981). However, growth conditions during grain filling could also affect grain yield by affecting dry matter allocation to kernels (Tollenaar and Daynard, 1978; Uhart and Andrade, 1991). Filling duration is often influenced by temperature (Derieux and Bonhomme, 1982). Tollenaar (1977) reported that decreased assimilate supply during the period after 2 to 3 week post-silking in maize had little effect on kernel growth rate, but reduced kernel weight at maturity because of shorter filling duration. Similar conclusions have been reached with *in vitro* cultured (Afuakwa et al., 1984) and field-grown (Tollenaar and Daynard, 1978) kernels.

Dry matter accumulation in kernels depends, among other factors, on the rate and duration of crop growth, and on the availability of assimilates reserves from other plant parts (Tollenaar, 1977). The potential sink strength for assimilates of the kernel is established during the lag phase of kernel development, when endosperm cell division occurs (Capitanio et al., 1983; Reddy and Daynard, 1983). A shortage in assimilate supply or unfavorable thermal environment during this phase affects the potential kernel size (Frey, 1981; Jones *et al*., 1984). In turn, increased temperature during grain filling increases the metabolic rate and sink strength of maize kernels (Ou-Lee and Setter, 1985a, b) and thus, the rate of grain filling (Jones *et al*., 1981; Jones *et al*., 1984). Moreover, several authors have suggested that the reduction in assimilate supply to maize kernels induces early black layer formation affecting filling duration and kernel size (Tollenaar and Daynard, 1978; Afuakwa *et al*., 1984).

Thus, important effects of temperature and radiation on growth and development could be expected when planting date is modified. Maximum corn yields are generally obtained with corn Hybrids and planting dates that enables corn plants to utilize the entire available growing season, while avoiding severe stress during critical growth stages.

Late planting effect on grain yield

Cirilo and Andrade (1994a) studied the effect of planting date on growth and dry matter partitioning of maize crops grown without water and nutrient limitations. Delayed planting decreased the number of calendar days as well as the thermal time from planting to grain maturation (Nielsen *et al*. 2002). Delays in planting date hastened development between seedling emergence and silking, decreasing cumulative incident radiation on the crop during the vegetative period. Cirilo and Andrade (1994a, b), however, observed that late planting increased crop growth rate during the vegetative period because of high radiation use efficiency and higher percent radiation interception. Conversely, late planting decreased crop growth rate during the grain filling period because of low RUE and low incident radiation. Late planting affected grain yield by decreasing kernel weight and kernel number per unit area. Moreover, maize subjected to late planting accumulated more dry matter before silking than from silking to physiological maturity compared to early planting. However, no differences in the number of endosperm cells formed among planting dates were observed; thus, the potential capacity of kernels to accumulate assimilates did not contribute to the low final weight observed in late planting.

Yield reductions with late planting has been observed by many other authors

(Ford, 1987; Nafziger, 1994; Bollero *et al*., 1996; Imholte and Carter, 1987; Lauer *et al.*, 1999; Nielsen *et al*., 2002). Nafziger (1994) observed accelerating decline in yield as planting date is advanced or delayed from the optimum. Evidence suggests that late planting has negative yield consequences because the reproductive stage occurs when weather conditions are less favorable. However, these negative effects are even worse when the Hybrid planted has a high relative maturity requirement for the region in which is grown. Consequently, the higher the relative maturity of the Hybrid, the higher the yield loss will be when corn is planted after the optimum period (Cirilo and Andrade, 1994a, b; Otegui *et al*., 1995). Nielsen *et al*. (2002) demonstrated that reductions in thermal units to black layer are consistent and predictable. Moreover, they also observed that measured thermal time from planting to black layer for the three Hybrids used in this study were five percent less than company GDD ratings when corn was planted late. Lauer *et al.* (1999) evaluated the Hybrid maturity x planting date interaction on corn grain yield and harvest moisture. Full-season Hybrids yielded more than shorter season Hybrids early in the planting period. However, shorter season Hybrids were more appropriate for late planting. Bauer and Carter (1986) observed that either delayed planting or increased Hybrid relative maturity caused pollination and grain filling to occur later in the season, possibly placing critical periods of development in a more stressful environment.

Evidence clearly demonstrates the importance of timing of planting. Planting full season Hybrids is highly recommended because the entire growing season can be used. However, it is not always possible for producers to plant all their acreage during the optimum planting period.

Optimum Planting Period for Corn

The optimum planting date in the Corn Belt typically occurs between 20 April and 10 May (Nafziger, 1994). Planting before or after this period might be subject to some yield reduction. In west-central Indiana, for instance, corn producers generally accept that April 20-May 5 is the optimum range for planting full season Hybrids, and would be extremely reluctant to plant corn early in the season even if soil conditions were dry in March. The present inability to benefit from early planting "windows" has some disadvantages. On one hand, corn producers need substantial planting equipment to accomplish corn planting within a narrow time frame. On the other hand, excessive precipitation during the optimum planting period will delay planting well past the optimum dates.

The major producer concerns associated with early planting dates are: a) the risk of corn emergence before a late killing frost, b) the risk of a significant reduction in plant population due to pests and other factors, and c) the risk of excessive variability in emergence and development of adjacent plants, as a consequence of low soil temperatures.

White (1978) and Imholte and Carter (1987) documented the importance of timely planting and rapid and complete emergence in areas with short growing seasons. Producers who plant corn early are concerned about potential frost injury, poor emergence, and poor early plant growth. Producers who plant late wonder what relative maturity Hybrids to plant, and how late planting affects grain yield and moisture. With progressively earlier planting the probability of achieving significantly lower corn yields than those planted during the optimum planting period increases. Predicted yield for corn planted 10 days before the optimum period for a plant population of 70,000 plants ha^{-1} is expected to be about 6% lower (Nafziger, 1994).

No-till system: Additional Constraints

No-till corn producers are constrained by the present optimum planting period even more than producers in conventional tillage. Indiana corn acreage in no- till declined from 25 % in 1994 to approximately 20 % in 2000 (CTIC, 2000). Corn producers claim that no-till soils are wetter and colder longer than they are with conventional tillage, especially for early planting. Expansion of conservation tillage acreage is desirable because of many economic and environmental benefits including time savings, reduced machinery wear, fuel savings, reduced soil erosion, improved surface water quality, increased soil organic matter, and improved soil tilth.

Successful stand establishment is achieved by providing a seed environment which encourages early germination and emergence. Environmental factors of critical importance to corn growth between planting time and emergence are the temperature, moisture, and physical condition of the seedbed. Optimum corn emergence can be obtained by creating a seedbed which provides warm soil, ample available soil moisture, and good soil-seed contact.

No-till systems, where all previous crop residue is left on the soil surface at planting, are recommended for soil erosion control on many sloping soils where corn production results in severe erosion under conventional tillage which involves complete residue incorporation. However, unincorporated crop residue depresses early season soil temperatures compared to conventional tillage (Griffith *et al*., 1973; Mock and Erbach, 1977). Cold soil temperatures may lead to slow corn emergence, reduced stands and seedling vigor, and delayed maturity (Willis *et al*., 1957; Burrows and Larson, 1962; Griffith *et al*., 1973). Concern about these problems has slowed adoption of no-till in northern corn-growing regions and has led many farmers who do practice no-till to delay planting until soils become warmer and dryer.

Imholte and Carter (1987) found decreased grain yield with no-till or delayed planting, or both, to be related to reduced cumulative air growing degree days between silk and the first frost. Conversely, in a long-term tillage experiment in West Central Indiana, no significant differences has been found in terms of stand establishment (West *et al*., 1996). Hayhoe *et al.* (1996) observed a lower stand establishment under reduced tillage on a clay loam soil, while the same pattern did not exist for a sandy loam soil in experiments conducted near Ottawa, Canada. Reduced tillage was associated with lower soil temperatures, and time to 50% emergence was significantly extended for no-till. They suggested that lower soil GDDs (which reflect lower maximum temperatures in the seedbed under reduced tillage) probably accounted for much of these differences. In addition, reduced tillage in the clay soil may have led to greater aggregate size and poorer soil-seed contact which could have increased variability in the rate of emergence as well as final stand establishment (Schneider and Gupta, 1985; Hayhoe *et al*., 1993).

Therefore, it is clear that planting early in the season might result in stressful conditions for the crop. However, in some cases corn will encounter more stress in conservation tillage production systems.

Physiological factors affecting germination

“Germination” is considered to be the process that starts with the first metabolic activity during imbibition and ends with the emergence of the radicle from the seed. The continued development until the emergence of the shoot above the soil is usually referred as “early seedling growth” (Miedema , 1982).

The first process that occurs when seeds are set to germinate is the imbibition of water. Metabolic activity starts as soon as the cells are sufficiently hydrated. Toole *et al.* (1956) reported that the elongation of the cells of the coleorhiza starts about 20 hours after the beginning of imbibition. The coleorhiza breaks through the pericarp and extends to about 2 mm beyond the surface, and then the radicle breaks through the coleorhiza.

The effect of temperature on the imbibition of maize seeds was studied by Blacklow (1972a). He observed that the rate of water uptake was very high during the first hours; even at low temperatures the water content of seed increased considerably in a short time. However, he observed minimum water content for germination at different temperatures. For example, at 10 º C, water content for germination was about 75%, whereas the water content when seed were placed at 25ºC was 65% (Blacklow, 1972b). It seems unlikely; therefore, that temperature restricts germination by its effect on imbibition.

Temperatures below and around the minimum temperature for germination and growth may cause various types of physiological damage in maize. These low-temperature effects are often referred to as chilling injury (Miedema, 1982). Chilling injury is physiological damage caused by temperatures between 0 and about 12 º C

(Lyons, 1973). The degree of injury depends on the temperature, the duration of exposure, and the susceptibility of the Hybrid.

Several ideas have been proposed to explain the injury to seed that occurs during germination of warm-season crops at cold temperatures. These include 1) membrane compositional differences, 2) pathogen attack, 3) seed coat characteristics, and 4) membrane disruption.

Lyons (1973) suggested that fatty acid composition in membranes of chilling sensitive crops is more highly saturated than membranes of chilling resistant crop species. This difference in composition results in a change of physical state of the chilling sensitive membranes at low temperatures, which, in turn, adversely affects energy supply and metabolism and results in the build-up of toxins such as acetaldehyde and ethanol. Other studies have also indicated a correlation between the degree of insaturation of phospholipids and failure to germinate at low temperatures (Bartkowski *et al.*, 1977; Dogras *et al.*, 1977; Maluf and Tigchelaar, 1982).

One of the most frequently reported effects of imbibing seeds in low-temperature medium is increased or sustained leakage from the seed (Simon, 1974). Dry seeds placed in a moist environment not only imbibe water rapidly, but there is also a large increase in materials leaked from tissue into the medium (Simon, 1974). The amount of material leaking from the seed rapidly decreases as imbibition proceeds (Simon, 1974). Substances and ions leaking out of seeds during imbibition include amino acids, sugars, organic acids, gibberelic acid, phenolics and phosphates (Simon, 1974). Vedralova and Vedralova and Segeta (1970) incubated maize seeds at low temperature and found that the exudation of amino acids and sugars was much greater at 6 º C than at 10 º C, indicating possible association of exudation with the dysfunction of membranes at the lower temperature.

Associated with this leakage is an increased decay, probably promoted by the loss of sugars and other substances into the germinating medium (Flentje and Saksena, 1964; Schrotch and Cook, 1964). Leach (1947) has suggested that soil organisms have a lower optimum growth temperature (compared to that of seed germination and seedling growth), which allows soil pathogens to grow, multiply, and attack the seed. Seed rot and seedling blight are a greater problem in poorly drained, cold (less than 10 to 15ºC), wet soils, and are therefore more likely to be a problem in lower portions of fields (White, 1999). The sensitivity to seed rot depends primarily on seed quality; pericarp injury, frost damage, and insufficient maturity of the seeds facilitate fungal attacks (Tatum and Zuber, 1943).

Cold conditions after germination can also result in seedling blight. Brown lesions on the roots and the basal part of the mesocotyl are symptoms of such a seedling infection (White, 1999). Those seedlings progressively wilt and eventually die since the vascular connection between the shoot and the seed and root system is disrupted.

However, seed rot and seedling blights have become of lesser importance since seed dressing with fungicides is common for Hybrid corn seed. Fungicides are intended to reduce the risk of seedling diseases when the seed is planted under adverse conditions. Seed treatments with fludioxonil or captan for seed and soil-borne microorganisms have been found to significantly improve emergence counts and grain yields (Munkvold and Shriver, 2000; Sweets and Wiebold, 2000). In addition, the quality of commercial seed has been improved (Bruggink *et al*., 1991).

The integrity of the seed coat is highly important in preventing injury during imbibition at low temperatures (Simon and Mills, 1983; Tully *et al.*, 1981). Simon and Mills (1983) reported that when *Pisum sativum* embryos without seed coats imbibed water very rapidly, more K leaked from the seed coats and more damage occurred than did intact seeds with good seed coat integrity. Tully *et al*. (1981) found that peas in which the seed coat had been nicked imbibed water at a rapid rate and were injured by imbibition at low temperatures. Thus, one of the functions of the intact seed coat may be to slow the rate of imbibition.

Several reports indicate that the absolute rate of water uptake is not the factor that controls the imbibitional injury occurring at low temperature. Low moisture may act specifically by protein denaturation, while chilling may act on the lipid component of membranes. The combination of low moisture content and imbibition at low temperatures can be very damaging (Herner, 1986). Increasing the initial moisture content of seeds by placing them in high relative humidity prior to imbibition also protects corn as well as bean seeds from injury when subsequently imbibed at low temperature (Cal and Obendorf, 1972; Obendorf and Hobbs, 1970; Pollock *et al.,* 1969).

Schneider and Gupta (1985) used aggregate size distribution to characterize the physical condition at seedbed. They found that emergence was delayed for the largest aggregate size treatments likely because of poor-soil-seed contact, as well as the smallest aggregate size treatments because of high soil penetration resistance. However, for a wide range of seedbed matric potentials (-10 Kpa to –500 Kpa) and aggregate size distributions, emergence is determined mainly by seed zone temperature (Schneider and Gupta, 1985). To some extent, the negative effect of low soil temperature on corn emergence time could be compensated by high soil water potential. Emergence was most rapid when soils were warmest (20-30º C), regardless of soil water content or aggregate size. Cooler soil temperature (5-15 º C) not only delayed emergence, but also affected the number of seedlings emerged.

Evidence suggests that temperature affects the rate of emergence by its effect on germination and shoot growth. An investigation of the effect of constant temperatures on imbibed corn seeds planted at a depth of 4 cm showed that the time from planting to emerge0nce was 23 days at 10 º C, 8 days at 15 º C, 4 days at 21 º C, and 2 days at 32 º C (Miedema, 1982). Similar results were observed by Beauchamp and Lathwell (1967). Moreover, Blacklow (1972b) found that corn germination and radicle and shoot elongation were most rapid at 30 º C, that corn seedling growth ceased at below 9º C and above 40 º C, and that rate of shoot elongation prior to emergence was a linear function of temperature between and 10 and 30 º C.

Chilling after Emergence

The early vegetative stage of growth is very vulnerable to low temperatures. There is potential for frosts influencing the aerial parts of the plant, but perhaps more significantly, periods of reduced temperature will reduce the rate of growth and the establishment of photosynthetic area, upon which continued growth is dependent. Plant injury is not usually visible during chilling, but appears after the subsequent increase in temperature. A wilting and discoloration of the leaves are symptoms of chilling injury; with severe chilling, plants or plant parts are killed.

Corn is particularly sensitive to low temperatures early in the season. This crop is characterized by the high optimum temperature needed for germination and growth; it belongs to the so-called thermophilic plant species (Miedema, 1982). After emergence, the aerial parts are easily killed by frosts. Young seedlings, however, may recover if the shoot apical meristem, which is below soil level, is not killed (Miedema, 1982). Based on a prediction model developed by Blacklow (1972b), for a planting depth of 5 cm, and when corn plants are at V-stage 3, the apical meristem, located at the junction of the first internode and the coleoptile, remains 10 mm below the soil surface. However, the degree of killing is mentioned in relation to air temperature and the duration of temperature exposure.

The effects of artificial freezing have been investigated in maize seedlings to discover killing temperatures and genetic variation in frost resistance. The lowest temperature tolerated by corn is also reported to vary widely. Temperatures between 0 º C and –1.5 º C have been reported to reduce the growth of maize, while temperatures between –2 and –3 º C resulted in severe damage (Dhillon *et al.*, 1988). Evaluation of maize seedlings in controlled environments showed that germinating plants could withstand temperatures of about –4.4 º C, while some survived a 5 hour period at –6.1 º C, but with considerable leaf damage (Gardner et al., 1987). Temperatures of – 3 º C and –5º C were used by Hardacre *et al*. (1990) at V-stage 2 to 4, and caused more severe damage than expected from the work of Gardner et al. (1987), with the same genetic material, but were similar to damage reported for some field experiments (Rahn and Brown, 1971). The reason for the differences in the relationship between temperature and damage are not clear, but may reflect differences in the induced freezing stress under controlled environment conditions.

Creencia and Bramlage (1971) investigated the effects of chilling at 0.3 º C and low light intensity in 7-day-old maize seedlings. After chilling, the seedlings were transferred to 21º C to study physiological and biochemical after effects. Leaf injury began to develop after 36 hours of chilling; after 72 hours of exposure the injury was irreversible. Leaf segments of chilled plants showed increased ion leakage and increased oxygen uptake presumably by uncoupling of oxidative phosphorilation.

Miedema (1982) reported necrotic cross bands and other leaf damage in maize seedlings subjected to 4º C in the dark for 3 days. Most of the injury disappeared after transfer to normal temperatures. Irreversible damage occurred after exposure to 4ºC for 6 days. Tissue in the cell extension zone of the leaves was more sensitive to chilling than full-grown tissue. It seems that leaves are more sensitive to chilling than other organs because of the chilling sensitivity of the chloroplasts.

Plant-to-plant Variability

It has long been recognized in plant monocultures of consistent age that a normal frequency distribution of seedling masses may develop (over time) into a positively skewed distribution of plant masses in which there are a few large, dominant individuals (Ford, 1975; Weiner and Thomas, 1986), and that positive skewness increased with time from planting and with plant density (Obeid *et al*., 1967). In contrast, grain yield per plant of field-grown maize was found to be normally distributed, and tended towards negative skewness as density increased (Glenn and Daynard, 1974). Such mass distributions have been called “size hierarchies” or “size inequalities” (Weiner and Solbrig, 1984) and are of tremendous ecological and evolutionary significance. However, the cause of these size inequalities is still not fully understood and has been the subject of considerable controversy.

Within a population, plants will vary in size. Differences in size may be determined by (1) age differences (as a consequence of uneven emergence), (2) genetic differences, (3) environmental heterogeneity, (4) maternal effects, (5) differential effects of parasites or pathogens, and/or (6) competition (Weiner and Thomas, 1986). In most cases, size distribution will be the result of interactions among these factors.

Plant competition is a spatial process in which differences in growth rates are generated by a disproportionate sharing of available resources among plants depending on the number of competing neighbors, their proximity, and their relative sizes (Weiner, 1990). A plant with fewer, smaller, or more distant neighbors will have a greater relative growth rate than a similar plant with larger, closer, or more numerous neighbors, and size differences will enhanced over time.

Uneven emergence often occurs where corn is grown under cold soil temperature. Delayed emergence of some plants is usually attributed to limited moisture, irregular depth of seed placement, soil compaction, or high levels of plant residue with reduced tillage. Variable emergence could result in non-uniform stands, where bigger or taller plants would have a competitive advantage over the smaller or shorter ones.

Trials by Ford (1987) in Minnesota compared the effect of planting alternating corn seeds within the row at different times. For example, treatments included those where every other seed was planted either 7 to 14 days later than a uniform stand planted on the base date. Uniform stands also were planted 7 and 14 days later than the base date. The yield decline due to delayed planting of the uniformly seeded plots was about as expected. The decline in yield when 50 % of the stand was delayed in planting by 7 or 14 days was nearly the same as when the entire planting was delayed for a similar time. Plants from the early planting yielded considerably more in a given stand than those that were planted later, and yield differences between the early and late emerging plants also increased as population was increased. Although such nonuniformity of plant emergence (every other plant) may be an extreme case, this work illustrates that uneven emergence could be a factor in replant considerations. In an other experiment, Ford and Hicks (1992) observed a 5 % yield reduction in maize when half of the stand was delayed in planting by 7 days, and a 12.8 % yield reduction when half of the plant stand was delayed by 14 days of late planting. The yield reduction increased both with an increase in the proportion of the stand that was delayed and with an increase in plant population density.

A study by Glenn and Daynard (1974) on the effects of plant-to-plant variation on maize grain yield demonstrated that plant-to-plant variation per se lowered grain yield. They suggested that cultural procedures designed to encourage uniform plant establishment, like uniform seedbed and constant planting depth, should maximize yield.

Intensive research on delayed emergence effects on corn grain was conducted in Illinois and Wisconsin (Nafziger *et al*., 1991). This research was conducted with two Hybrids, various planting dates within a row, and various planting dates for adjacent rows. Emergence delays due to delayed planting intervals of approximately 10 to 21 days resulted in yield reductions of from 6 to 22 % compared to a full stand of normal emergence (based on common planting dates from April 30 to May 15). The extent of yield reduction varied with the proportion of late emerging plants compared to normal emerging plants. However, even in this detailed study, there was no measurement of the uniformity of emergence amongst plants seeded on the same day. Thus readers can not conclude much about the effects of emergence variability within a common planting date, although they can conclude that extended emergence delays for adjacent plants are more detrimental to overall yield than short emergence delays.

Adjacent plants of unequal height (resulting from genetic differences) can be detrimental to grain yield per unit area. Pendleton and Seif (1962) found that within a mixture with a normal corn Hybrid and its brachytic dwarf, the shorter genotype was seriously depressed in yield compared to its yield in pure stand, whereas the taller component did not experience a sufficient yield increase to counteract the yield reduction in the shorter genotype. Under-compensatory interactions among plants of the same genotype are due to unequal sharing of resources and a curvilinear response of productivity to input resources at the single plant level. Edmeades and Daynard (1979a, b) found that variability in days to silk and in silk delay (that is anthesis to silking interval) increased much more with plant density than did days to anthesis.

Wu (1998) studied the response of plant-to-plant variability to plant density with maize Hybrids from different eras in Ontario. For this study, two Hybrids were planted at a low (3.5 plants m^{-2}) and a high (11 plants m^{-2}) plant density. At each density seeds were planted either all on the same day to produce uniform stand, or on alternative planting dates to produce non-uniform stands. Results indicated that stand uniformity and stress tolerance are highly associated. Moreover, differences in the tolerance between old and new Hybrids were observed. The difference in grain yield between the newer and the older Hybrid was 30% in the uniform stand and 46% in the nonuniform stand. Overall, stand uniformity declined with an increase of interplant competition, and its impact on grain yield was greater in the older than in the newer Hybrid.

Another component of stand establishment variability is spacing variability. Nielsen (1997) found that approximately 0.06 Mg ha^{-1} are lost for every 1 cm increase in the standard deviation of plant-to-plant spacing. Moreover, Doerge *et al*. (2002) observed a 0.08 Mg ha^{-1} increase for each cm improvement in standard deviation. Where increased plant variation arises from variable spacing per plant, yield per unit area may fall (Krall *et al.*, 1977), probably in proportion to the increase in radiation striking the ground between plants.

There is some disagreement over the actual effects of spacing uniformity on corn yields. Muldoon and Daynard (1981) suggested that uniformity of seedling size would be a more important influence on yield. They claimed that variability in spacing would not be expected to affect grain yield through an effect on the absorbance of radiant energy until the irregularity became sufficiently large that more light penetrated through to the soil surface, or that rate of assimilation per plant became so extreme as to cause sink limitations. Furthermore, they concluded that variability in intra-row spacing, to the extent likely to be encountered in most commercial maize fields seeded with properly adjusted planters had no significant effect on grain yield. A greater importance was suggested for variability in seedling size, which is presumably related to non-uniformity in seeding depth, seedbed preparation or seedling vigor.

More recent studies (Liu *et al*., 2001) showed no differences in corn grain yield for different plant spacing variability, indicating that uniformly spaced stands are not required to maximize yields. However, they found uneven seedling emergence to have a negative effect on corn yield.

Corn planter maintenance, planting speed, and operation primarily affect spacing variability (Nielsen, 1997); however, low germination percent, pests, and adverse soil conditions can also compound the actual plant-to-plant variability achieved. Spacing variability may further accentuate the effects of variability in emergence due to environmental heterogeneity factors such as non-uniform seeding depths, or variable soil moisture, and/or soil temperature in the seed zone.

Although uneven emergence of plants within rows is considered in of the biggest risk factors of early planting, comparatively few studies have described the relationship and magnitude of different individual plant growth and development variables.

Potential of Polymer Seed Coatings in Corn Establishment

The successful establishment of maize depends on a broad array of factors including Hybrid selection, the inherent vigor of the seeds, the soil type and its fertility, the climatic conditions during the growing season, planting depth, soil tilth, tillage and planting methods, and finally, the presence of antagonist organisms such as weed, insects, or diseases. However, producers can only control some of these factors; many remain uncontrolled and can, either singly or in combination, cause a delay or reduction in stand establishment.

Producers attempt to overcome some of these adverse conditions by careful planter calibrations and depth adjustments, by applying materials such as insecticides or fertilizers to the row area at planting, and by fungicide application to the seed. In order to increase effectiveness of fungicides, insecticide or certain fertilizer treatments, materials can be applied on the seeds themselves in seed coatings.

Seed coatings act as efficient carriers of chemicals, which can be applied with great accuracy on the seed surface. The chemicals involved are mostly fungicides and insecticides, but coatings can also include nutrients, hormones (Scott, 1990). In some situations, seed coatings can also provide protection against water stress: hydrophilic polymers are used to enhance the water uptake rate (Baxter and Waters, 1986), whereas hydrophobic coatings are used to reduce it (McGowan and Williams, 1971; Hwang and Sung, 1991).

A seed coating process to enable synchronous flowering of male and female inbred parent lines in Hybrid seed production by creating controlled delays in germination has been described by Porter and Scott (1980). Seed treatments to delay barley emergence have also been reported (McGowan and Williams, 1971).

Temperature-activated coatings on corn delay germination until environmental conditions are satisfactory for continued or optimum crop growth. They are comprised of a polymeric material, with a temperature-dependent permeability (Stewart, 1992). These coatings for seeds are based on a crystalline polymer and a seed-coating additive. The polymeric reaction product of a monomer component comprises: I) a hydrophobic monomer component, II) a hydrophilic monomer, and III) a sufficient amount of at least one cross-linking monomer having at least two polymerizable groups that the polymeric reaction product has a gel content of at least 50 %.

Coatings are based on C-12 to C-15 side chained polymers, which vary in number and length of the monomer side chain (Stewart, 1992). Varying the monomer side chains results in polymers with different melting point temperatures (in a range form 0 to 100º C). The polymeric material undergoes a temperature-dependent phase change, which dramatically modifies the water permeability of the material. The phase change permits seeds, which were previously impervious to water to imbibe water and begin germination.

These polymers could allow seeds to achieve optimum germination and growth while allowing early planting within a wide time period. By allowing producers to plant early in the season, a greater flexibility and efficiency with respect to the timing of seed planting could be gained. The potential for utilization of these polymers on Hybrid corn production is obvious if producers can be assured that yields associated with early planting would be at least equal to those obtained when corn is planted during the optimum period. Relative to uncoated seeds, temperature-sensitive polymers applied to corn seed coats could reduce plant-to-plant variability in emergence, when corn is planted early. If more uniform stands can be achieved with polymer-coated corn risks associated with early planting would decrease and corn yields might increase, compared to early planting of uncoated seed. The benefits of temperature-activated polymer coatings may be more evident as early season stress increases. Planting polymer coated seed late in the season might not have a negative impact on yields of corn planted, since warmer temperatures would have a little emergence delay.

Although farmers have typically avoided very early planting of corn due to risk of low populations, variable plant development and low yields, little research information is available on corn plant growth, development, and yield response to seed coat polymers in a field environment. Hicks *et al*. (1996) studied the responses of seed coatings on early plant corn at different locations. Results, however, were inconsistent. Seed coatings improved stand establishment and grain yield for certain locations, Hybrids and planting dates. Moreover, polymer seed coating composition has changed since then. It is evident, therefore, that more research is needed in order to make more definitive conclusions about the actual effects of polymer seed coatings, and the possible interactions with Hybrids and planting dates.

The objectives of this study are a) to determine the average corn emergence delay resulting from temperature-sensitive polymer coatings for corn with multiple planting dates, b) to determine whether temperature-sensitive polymers applied to the seed coats of selected corn Hybrids will improve uniformity of emergence and subsequent plant development, relative to uncoated seed, when corn is planted early, c) to evaluate whether final plant populations and overall grain yields will increase in response to the application of the temperature-activated polymers, relative to uncoated corn seed, d) to understand the possible interacting effects of polymer treatments, Hybrid treatments, and planting date treatments on plant-to-plant variability and final grain yields, and finally, e) to determine whether the temperature-activated polymers have any negative impacts on grain yields or maturity with later planting dates.

CHAPTER ONE

POLYMER SEED COATING EFFECTS ON CORN RESPONSE TO HYBRID AND PLANTING DATE VARIABLES

Abstract

Most producers are reluctant to plant corn two or more weeks earlier than the optimum planting period, even when soil conditions are sufficiently dry to achieve suitable seedbed. Early planting can lead to poor stand establishment due to stresses imparted by cold, wet soils. This research was conducted to investigate the feasibility of temperature-sensitive polymer seed coatings on corn growth and development. Our objectives were to evaluate the effects of different formulations of polymer coatings relative to non-polymer coated seed, on two different Hybrids in three planting dates on corn emergence, growth and yield.

Field experiments were established in 2000 and 2001 on a poorly drained, dark prairie soil (mesic Typic Haplaquolls) on fields previously in soybeans in west central Indiana. Two corn Hybrids (Fielder's Choice 9307 and 8509) were no-till planted on three dates representing early (28 March 2000, 2 April 2001), intermediate (14 April 2000, 19 April 2001) and late (16 May 2000, 11 May 2001) planting times. Each Hybrid had the following seed coating treatments in Year 2000: the control (UTC), coating A (2 % of seed weight), coating B (3 % of seed weight), and in 2001: the control (UTC), coating C (slightly different polymer than in 2000, 2 % of seed weight), coating D (same polymer as in 2000, 2.5 % of seed weight).

Polymer coatings resulted in emergence delays ranging from 1 to 6 days for early, intermediate and late planting dates for both Hybrids and in both years. For early-planted corn, coated seed only improved emergence uniformity relative to uncoated seed in one season and for one Hybrid. In fact, after early planting in 2001, coated treatments decreased emergence uniformity for both Hybrids. Number of seedlings emerged was generally not affected by coating treatments. Mid-April frosts after the early planting date in 2001 reduced the proportionately more emerged stand of the uncoated seed treatment by 38% for Hybrid 9307, and by 15% for 8509. Coated seeds planted on the same date were less affected by frost since only 50% of the seedlings had emerged when freezing temperatures occurred. Main effects of Hybrid and planting date impacted corn growth and yield response more than polymer treatments.

After the early planting date in both years, coated treatments of one Hybrid resulted in shorter and less developed plants than the uncoated treatment, as a consequence of delayed emergence. In general, variability in plant height or vegetative stages was not pronounced with coated versus uncoated treatments. Final plant height increased as planting date was delayed. Grain yields were affected by Hybrid and planting dates, but not by polymer seed coatings except for the early planting date in 2001. Coated seed of Hybrid 9307 resulted in 15-18% yield gains, relative to uncoated seed, due to the larger frost damage experienced by uncoated seed.

Corn growth and yield advantages with polymer coatings may have been more apparent if cooler and wetter soil conditions had prevailed after the first 2 planting dates in both years. Overall polymer effects on emergence were small and inconsistent.

Introduction

Most producers are reluctant to plant corn two or more weeks earlier than the beginning of the optimum planting period, even when soil conditions are sufficiently dry to achieve a suitable seedbed. In west-central Indiana, for instance, corn producers generally accept that April 20 to May 5 is the optimum range of planting full-season Hybrids, and would be reluctant to plant corn before the optimum period even if soil conditions were dry in March. The major risks associated with corn emergence before a late killing frost include the risk of a significant reduction in plant population due to pests and other factors, as well as the risk of excessive variability in emergence and subsequent development of adjacent plants. Uneven emergence of corn may occur because of variable moisture in the seed-zone, uneven depth planting, soil compaction, seed zone temperature differences, or variable plant residue cover in the row zone. Differences in plant size early in the season have been shown to continue into later stages of corn development (Landi and Crosbie, 1982). Variation per se has an important negative impact on yield per unit area (Glenn and Daynard, 1974; Muldoon and Daynard, 1981; Ford and Hicks, 1992; Nafziger *et al.,* 1991).

The current inability of farmers to plant in weeks or months prior to the optimum planting period has some disadvantages. On one hand, corn producers need substantial planting equipment to accomplish corn planting within a narrow time frame since yield reductions result from planting after the optimum date (Cirilo and Andrade, 1996; Nafziger, 1994). On the other hand, excessive precipitation during the optimum planting period may delay planting well past the optimum dates. Suitable field conditions are a major problem influencing corn planting. Based on the last 30 years, the average number of suitable days for the period from April 20 to May 5 is about 7 days for a conventional tillage system. Previous research on different tillage systems demonstrated that in a no-till system there is at least a 25% reduction in number of suitable days, due to slower soil-drying rate (Arends, 2001). Therefore, for a no-till system the average number of suitable days would be reduced to 5. Assuming a 16-30’ row planter with a speed of 5 MHP, a field efficiency of 63, and 10 working hours per day, about 300 ha could be planted during the optimum period, thus, large farmers might not be able to plant all acreage during this period.

No-till corn producers are constrained by the present optimum planting period even more than conventional till producers. Unincorporated crop residue depresses early season soil temperatures compared to conventional till (Griffith et al., 1973; Mock and Erbach, 1977). Cold soil temperatures may lead to slow corn emergence, reduced stands and seedling vigor, and delayed maturity (Burrows and Larson, 1962, Arends, 2001). Concern about these problems has slowed adoption of no-till and has led many no-till corn farmers to delay planting until soils become warmer (Imholte and Carter, 1987).

Recently patented, temperature-activated polymers can be used as seed coatings for Hybrid corn seed to enable earlier planting, but delayed emergence, of corn. The temperature-activated seed coatings are based on C12 to C15 side chained polymers which vary in number and length of the monomer side chain (Stewart, 1992). Varying the monomer side chains results in polymers with different melting point temperatures (in a range from 0 to 100 ºC) the "melting" process permits coated seed previously impervious to water to imbibe water and begin germination. These polymers are biodegradable.

Relative to uncoated seeds, these polymers could improve emergence uniformity, final population and grain yield when corn is planted early. This benefit could be even more evident as stress increases (whether because of cool soil temperatures, stress susceptible Hybrids, or conservation tillage). Hicks *et al.* (1996) observed that polymer coated seed treatments improved stand establishment and grain yield relative to uncoated seeds, but only for certain Hybrids, planting dates and locations. Polymer coating formulations have changed since then; thus, more research is required to assess the potential benefits of polymer seed coatings. These seed coatings may allow corn producers to minimize risks associated with colder and wetter soils and, therefore, take more advantage of conservation tillage options.

The objectives of this study are to determine corn growth and development responses to polymer seed coatings. Different formulations of polymer seed coatings were investigated on two Hybrids with multiple planting dates.

Materials and Methods

Site Description

The study was conducted at the Agronomy Research Center (ARC) in west central Indiana (40º28’ N Lat., 86º59’ W Lon.). Corn treatments were after soybean in rotation in 2000 and 2001. The soil is a Drummer silty clay loam to clay loam characterized as somewhat poorly to poorly drained (mesic Typic Haplaquolls).

The experiment was with a split-plot arrangement of a randomized complete block with 6 treatments in 2000, and 5 treatments in 2001. Each plot consisted of 8 rows 0.76 m apart and 15 m in length. Planting dates were whole units, and Hybrids and seed coatings were subunits. This experiment involved a comparison of two different Hybrids, Fielder’s Choice 9307 (106 days relative maturity) and 8509 (109 days relative maturity), with two coatings and one control in year 2000, but two coatings and one control for FC 9307 and one coating and one control for FC 8509 in 2001. A detailed description of the coating treatments is listed below.

Main Treatments:

Three planting dates of:

1. Early: 28 March 2000, 2 April 2001.
2. Intermediate: 14 April 2000, and 19 April 2001.
3. Late: 16 May 2000, 11 May 2001.

Sub-Treatments:

In 2000, two Hybrids from Fielder's Choice Direct with two coatings treatments and one control:

1. FC 9307 untreated
2. FC 9307 coating A
3. FC 9307 coating B
4. FC 8509 untreated
5. FC 8509 coating A
6. FC 8509 coating B

Coating A and B were the same coating, but applied at either 2 % of seed weight (A) or 3 % of seed weight (B).

In year 2001, the same Hybrids were used with the following treatments:

1. FC 9307 untreated
2. FC 9307 coating C
3. FC 9307 coating D
4. FC 8509 untreated
5. FC 8509 coating D

Coating D consisted of the same polymer than in 2000, but applied at a 2.5 % of the seed weight. Coating C consisted of a different polymer than the one used in 2000, applied at 2% of the seed weight. Coating treatments were changed in 2001 only because Landec, Ag, (Monticello, IN) was unable to provide identical polymer coatings on those in 2000. All seed was treated with the fungicides captan, metalaxyl, and thiram.

Cultural Practices

Corn was no-till planted at 80,000 seeds/ha with a Case-IH 955 planter. All experiments followed soybeans in rotation. A starter fertilizer of 107 kg ha $^{-1}$ (34-0-0) was applied and a sidedress application of 160 kg ha^{-1} as Anhydrous Ammonia was applied at the V4 to V6 corn growth stage (Hoeft et al., 2000). The insecticide deltametryna was applied with the planter at a rate of 6 kg ha $^{-1}$. The following pre-emergence herbicides were applied: acetochlor + atrazine at 5.8 L/ha, glyphosate at 1.7 L/ha, and paraquat at 3.5 L/ha.

Soil Measurements

Soil temperatures were measured with watchdog data loggers at 5 cm depth, and post-plant soil growing degree days (GDD) until complete emergence were calculated during the growing season. Soil thermal time was quantified by calculating the amount of soil growing degree-days (GDD) accumulated on a daily basis. Soil GDD was calculated by averaging the daily minimum and maximum temperature measured in degrees Celsius and then subtracting by 10 (Hoeft *et al*., 2000). For these GDD calculations, minimum temperature less than 10ºC were set at 10; likewise, maximum temperatures exceeding 30ºC were set at 30.

Corn Measurements

The total number of plants (coleoptiles) emerged in two rows of 5 m length per plot (emergence row) were counted on a daily basis. Emergence was considered to be final when the count did not change for 7 consecutive days. The days to 50% emergence and time from 10 to 90% emergence were once emergence was complete. Due to stand loss after an early frost before complete emergence in 2001, initial plant populations were calculated as total seedlings emerged, and also as total living seedlings after complete emergence.

Plant height was evaluated four weeks after planting by measuring the soil surface to the uppermost fully extended leaf for each plant. The standard deviation of corn height was calculated for each plot. The distance between plants in each emergence row was measured and the standard deviation of plant spacing was calculated. This measurements were taken in order to evaluate whether an improvement in emergence uniformity resulting from with polymer coated seed would result in a more uniform stand throughout the season.

Individual plant developmental stage in each of the emergence rows were recorded twice during the growing season, 6 and 8 weeks after emergence for the early planting date, and 4 and 6 weeks after emergence for intermediate and late planting.

Silk emergence date was also recorded for each individual plant belonging to the emergence row. Plants were checked on a daily basis and days from planting to 50 % emergence, and the range from 10 to 90 % silking, were calculated for each treatment.

Plant populations at the time of harvest were calculated by counting the total number of plants in the emergence rows per plot. The percent barren plants was determined by counting the number of ears with fewer than 20 kernels in each emergence row and dividing by the total number of ears. The percent of plants that were lodged was determined by counting the number of plants in the same emergence rows which were bent more than 45 degrees below the ear. In 2000, there was a problem with diplodia ear rots (*Diplodia maydis*); therefore the percent of plants with visible diplodia presence was also determined.

Corn grain yield was determined by hand harvesting two 5 m rows per plot after physiological maturity. In 2000, plots were harvested on September 20 for the first and second planting dates and September 30 for the third planting date. In 2001, corn was harvested on September 18, 27, and November 6, for the first, second and third planting dates respectively. Differences in harvest time were due to weather conditions and time availability. The ear samples were mechanically shelled and then grain weight. Yields were adjusted to 15.5 % moisture content. Grain moisture content of individual plants were determined with a Farmex MT3 moisture meter.

Statistical Analysis

All statistical analyses to determine treatment effects of each corn variable were performed using SAS (SAS Institute). Analysis of variance for the split-plot with two sub-samples was performed for each year separately for days to 50% emergence, days from 10 to 90% emergence, plant population, days to 50% silking, days from 10 to 90% silking, final height, plant spacing, grain yield, % barrenness, and % diplodia. A randomized complete block with 2 sub-samples was performed within each planting date for corn development stages and heights at 4, 6 and 8 weeks after planting, and grain moisture. Sub sample error could not be pooled with Error (b), and Error (b) could not be pooled with Error (a) for the majority of the measurements ($P < 0.25$), so they were not pooled for any measure. Fisher protected LSD ($P < 0.05$) mean separation tests were performed where possible. Contrast statements were performed in order to evaluate whether improvement in emergence uniformity, plant population and grain yields obtained by polymer coated treatments after early planting were comparable to those obtained after the intermediate planting date.

The ANOVA model in 2000 had coatings and Hybrids as two factors. In 2001 because the number of coating treatments was different for the two Hybrids, the ANOVA model was unbalanced, and the factor treatment was used, with Hybrid and coating combinations considered as a single factor group.

Results and Discussion

Corn Emergence

There was adequate rainfall from time of planting through the emergence period in both 2000 (Figure 1) and 2001 (Figure 2). In 2000, no frost occurred after planting, but two consecutive frost days occurred in 2001 early in the growing season (April 17 and 18) affected both corn emergence and final population. In general, soil GDD accumulated at a faster rate (warmer temperatures) in 2001 than in 2000 for the early and intermediate plantings (Figure 3). Soil temperature differences between years were less evident after late planting.

Time to 50% Emergence

Cooler soils in 2000 resulted in a longer emergence time for the early-planted corn (31 days after planting) than for the intermediate planted corn (17 days after planting) (Figure 4). Conversely, he warmer early season of 2001, no differences in days to 50% emergence were found between early and intermediate planting (Figure 4). Late soil temperatures were warmer, and less time was required to reach 50% emergence when corn was planted later than with the two first planting dates in both years.

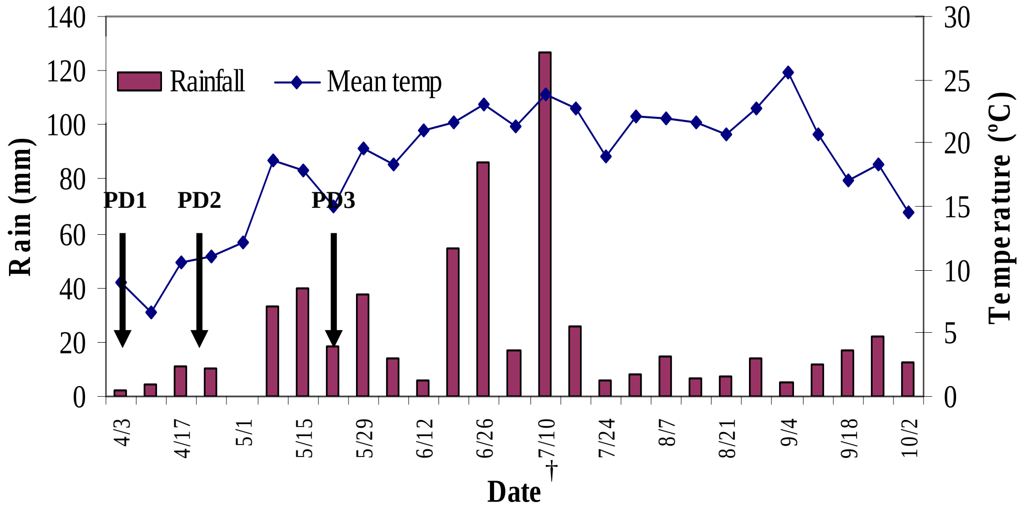


Figure 1. Weekly rainfall and weekly mean air temperatures for Agronomy Research Center in West Central Indiana in 2000.
† Dates represent the end of the week.

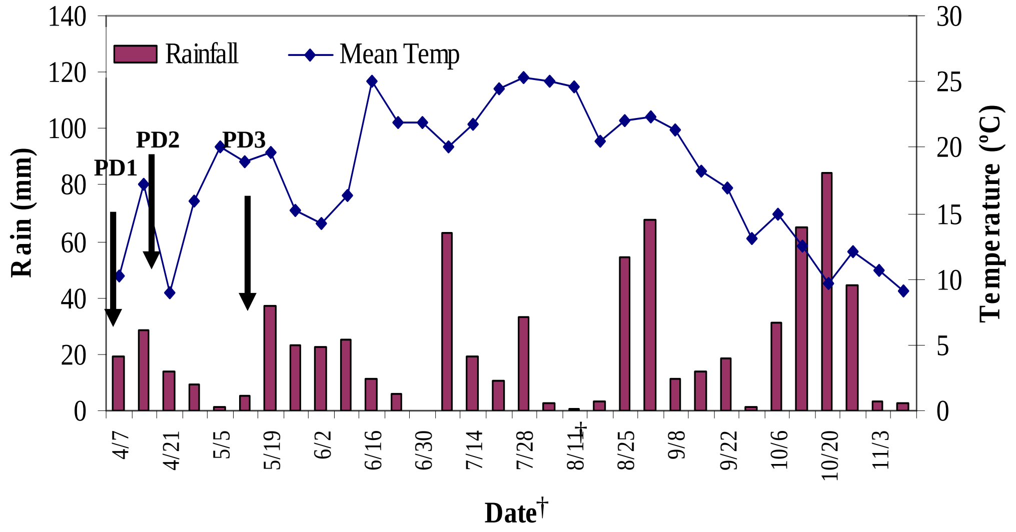
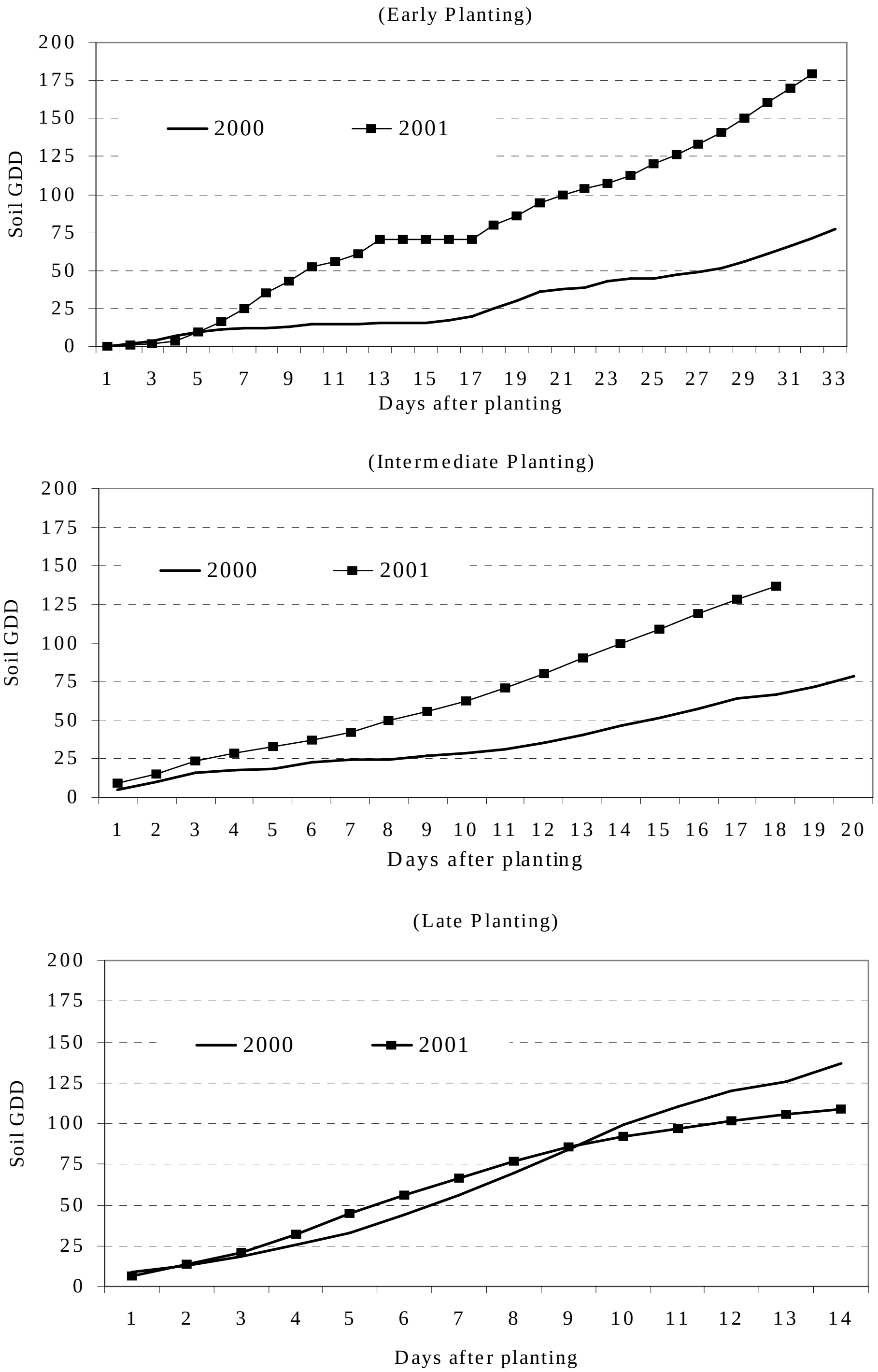


Figure 2. Weekly rainfall and weekly mean air temperatures for Agronomy Research Center in West Central Indiana in 2001.
† Dates represent the end of the week.


(Early Planting)

(Intermediate Planting)

(Late Planting)

Figure 3. Accumulated soil growing degree-days (GDD) at the 5cm depth after planting for the different planting dates in 2000 and 2001 for ARC in West Central Indiana.

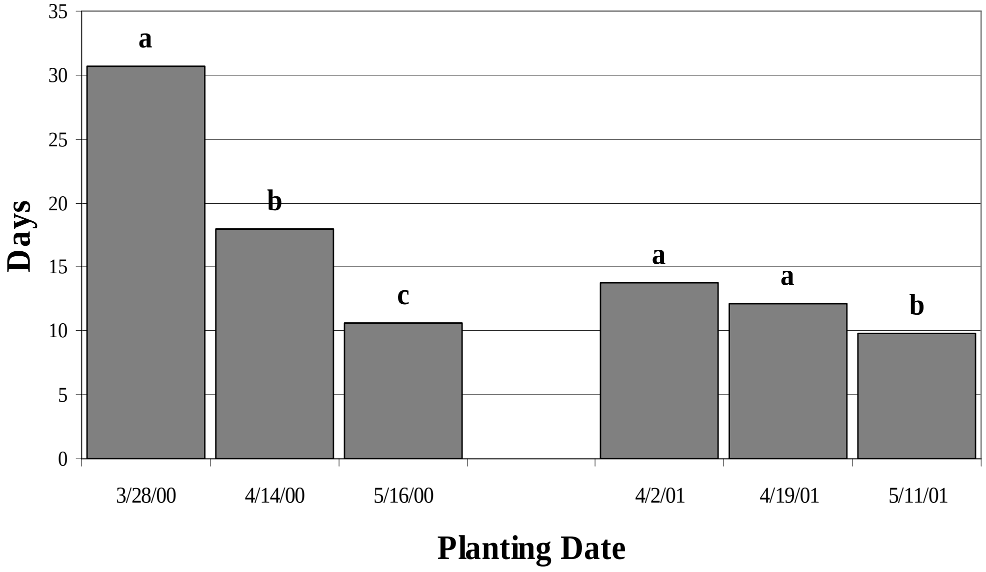


Figure 4. Days to 50% emergence (averaged for both Hybrids and respective coating treatments) for three planting dates in 2000 and 2001 at the ARC in West Central Indiana. Within year, data followed by the same letter are not significantly different according to a protected LSD (0.05) test.

Table 1. Coating treatment effects on days to 50% emergence for different planting dates and Hybrids in years 2000 and 2001 at the ARC in West Central Indiana.

2000	Days to 50 % Emergence			2001	Days to 50 % Emergence		
Treatment †	3/28 ‡	4/14	5/16	Treatment	4/2	4/19	5/11
8509/UTC	29.7 b §	16.3 b	9.8 a	8509/UTC	10.8 b	10.7 b	8.1 b
8509/A	30.3 b	18.4 a	10.8 a	8509/D	15.1 a	13.2 a	10.1 a
8509/B	31.5 a	18.7 a	10.9 a				
9307/UTC	28.2 c	16.4 b	10.2 a	9307/UTC	10.9 b	10.2 b	8.0 c
9307/A	31.1 b	18.5 a	11.2 a	9307/C	15.8 a	13.6 a	12.4 a
9307/B	33.3 a	19.2 a	11.1 a	9307/D	16.3 a	13.1 a	10.3 b

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC = control, A= coating A, B= coating B, C= coating C, D= coating D.

‡ Planting date

§ Data followed by the same letter within year, planting date and Hybrid are not significantly different according to a protected LSD (0.05) test.

Several other studies have also reported delayed emergence with lower soil temperatures (Hayhoe *et al.*, 1993; Miedema *et al.*, 1982; Johnson and Wax, 1981). Imholte and Carter (1987), in a study with different tillage systems, associated slower corn emergence with colder soils. Gupta *et al.* (1988) found that deep planting (75 mm) delayed emergence from 2.8 to 18 days as mean soil temperatures decreased from ranges of 15 to 25 º C range to the 5 to 15 º C. The growing degree days (GDD) in the seed zone needed to achieve 75% emergence increased with an increase in planting depth.

In terms of polymer coating effects on emergence, the three way interaction of date x Hybrid x coating was significant ($P < 0.05$) in 2000 (Appendix B.1), and in 2001, the two-way interaction of date x treatment was significant ($P < 0.01$) (Appendix B.2). Almost all coated treatments resulted in emergence delays for the first two planting dates in 2000 and all planting dates in 2001. Uncoated seed emerged 1.6 to 5.4 days earlier in 2000 and from 3 to 6 days earlier across all planting dates, in 2001 than coated seed (Table 1).

For the early planting date in 2000, uncoated seed of Hybrid 9307 emerged (50% VE) 3 to 5 days sooner than coated seed (Table1). Coating B of Hybrid 9307 resulted in the longest delay. Coating B of Hybrid 8509 emerged 1.8 days later than uncoated and 1.2 days later than coating A. For the intermediate planting date, the uncoated treatments of both Hybrids reached 50% emergence from 2.1 to 2.8 days earlier than their respective coated seed treatments (Table 1).

In 2001, uncoated seed of both Hybrids emerged faster than the coated treatments on all three planting dates. In Hybrid 8509, coating D emerged 4.3 days later than uncoated seed in the early planting date. For the intermediate and third planting date, uncoated seed of both Hybrids emerged at least 2 days earlier then coated seed. On the first planting date, uncoated seed of Hybrid 9307 reached 50% emergence 4.9 and 5.4 days earlier than coating C and D, respectively (Table 1). The emergence delay with coated treatments on the third planting date in 2001 contrasted with 2000 results. One possible explanation of the delay with coating C, relative to uncoated seed, could be a result of the use of a different polymer than those used in 2000. However, coating D was the same coating as in 2001 and its weight percentage was only slightly altered from 2000, thus, reasons for these differences remain unclear.

In 2001 freezing temperatures occurred in April 17 and 18; emergence slowed for several days until temperatures became warmer. The latter event may have contributed to the larger emergence delays noted with polymer coatings for the first planting date in 2001 versus 2000.

In a previous study regarding polymer-coating effects on corn, Hicks *et al.* (1996) conducted a germination test for coated and uncoated seeds at 25º C in wet paper towels. They observed that germination of coated seed was generally delayed by one or two days compared to uncoated seed. These results suggest that even when temperatures were above the phase transition temperature, there was still some delay with coated treatments. The authors suggested that this delay was probably due to a slower initial entry of water. On the other hand, they also performed a cold germination test. After 48 hours coated seed achieved a 7-17% water uptake, whereas water uptake for uncoated seed ranged from 29-34%. These results suggest that even at temperatures below the polymer's transition temperature some water uptake will occur, and that the polymers are not completely impermeable. The fact that in 2000 seeds planted early stayed in the soil for more than 20 days, might have resulted in smaller polymer coating effects if compared with 2001. Polymers are not completely impermeable, and perhaps the effect of the polymer disappeared due to swelling of water after such a long period of time that the seed stayed in the soil ungerminated.

The results of Gesh *(*personal communication) agree with our results. They investigated the polymer-coating (same formulations as coatings A and B used in our study) effects on early-planted corn in Morris, Minnesota. They observed that coated and uncoated seed planted on March 29 (2000) started to emerge at 31 days after planting. When days to 50% emergence were evaluated, practically no differences were observed among treatments, whereas when seeds were planted on May 1 (2000) coatings resulted in emergence delays. During March mean soil temperatures ranged from –3 to 5 º C, and in May mean soil temperatures ranged from 5 to 16 º C, thus, temperatures were too low for the polymers to undergo phase changes. However, germination for coated treatments occurred despite soil temperatures not exceeding 16 º C.

Polymer coating responses for the different experiments are somewhat inconsistent, and reasons for these differences remain unclear. Relative emergence delays with polymer coatings vary with the composition of the polymer, are season and Hybrid dependent, and are influenced by environmental factors other than temperature fluctuation alone.

Time from 10 to 90% Emergence

The time interval from 10 to 90% emergence can be used to describe emergence uniformity. Planting date main effects were significant (*P* < 0.01) in both 2000 and 2001 (Appendix B.3, B.4). In both years emergence uniformity decreased significantly when corn was planted early regardless of the coating treatment (Figure 5). Early planted corn averaged 2.6 (2000) and 3.0 (2001) more days from 10 to 90% emergence than corn planted on the intermediate date. No differences existed between late and intermediate planting dates in terms of emergence uniformity in 2000. However, in 2001, corn planted during the intermediate planting date resulted in a more uniform emergence than late-planted corn (Figure 5).

The interaction of date x Hybrid x coating was significant (*P* < 0.01) in 2000. For the early planting date in 2000, significant differences among coating treatments were not evident in Hybrid 9307 (Table 2). However, the uncoated seed treatments of 8509 took more time to proceed from 10 to 90% emergence than the coated counterparts. On the other two planting dates, no differences among coating treatments within a Hybrid were evident (Table 2).

Some contrasts statements were performed to compare whether coating treatments for early planting resulted in emergence uniformity that was comparable to that one obtained by planting corn in the intermediate planting date. In 2000 contrasts showed significant differences for all comparisons except from uncoated seed corn of Hybrid 9307 of the early planting versus the same treatment of the intermediate planting date (Table 2). These contrasts confirm the fact that coated seed planted in the first planting period was associated with a less uniform emergence in comparison to the intermediate planting date.

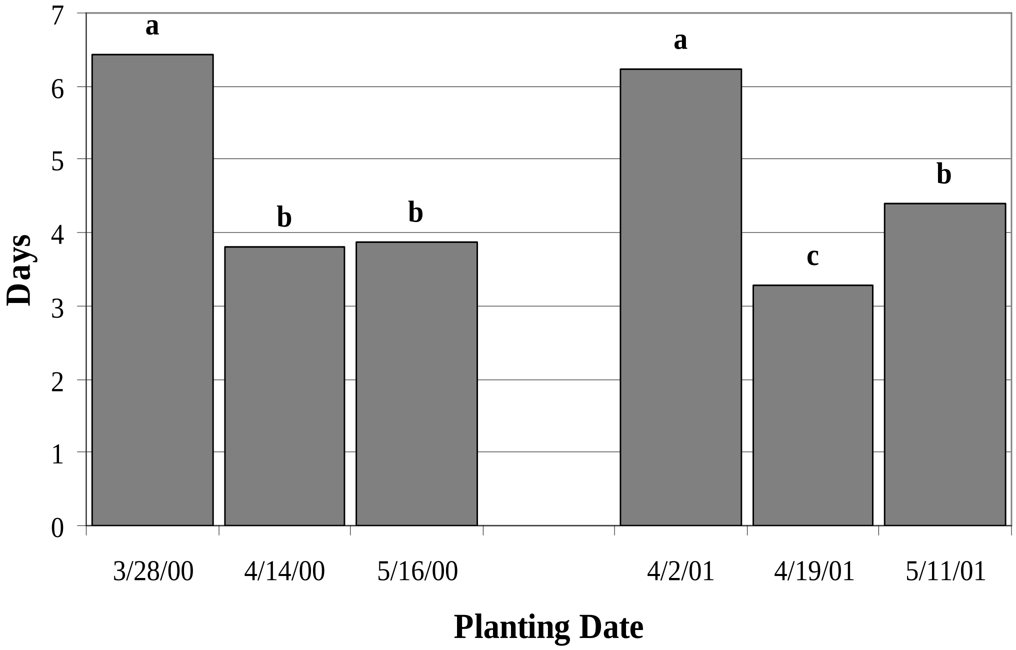


Figure 5. Days from 10 to 90% emergence (averaged for both Hybrids and respective coating treatments) for three planting dates in 2000 and 2001.
Within year, data followed by the same letter are not significantly different according to a protected LSD (0.05) test.

In 2001, the interaction of date x treatment was significant ($P < 0.01$) (Appendix B.4). For early-planted corn, uncoated treatments of both Hybrids resulted in fewer days from 10 to 90% emergence than coated treatments. Coated seed treatments required approximately double the time to proceed from 10 to 90% than for uncoated seed (Table 3). Part of these differences was probably caused by the freezing temperatures on April 17 and 18. Almost 100% of the uncoated seed corn had emerged by the time of frost occurrence, whereas about 50% of the coated seed had not yet emerged. Freezing temperatures apparently delayed emergence until the soil re-warmed to suitable temperatures. These findings agree with Blacklow (1972b), who observed that seedling growth ceased below 9º C and that rate of shoot elongation prior to emergence was a linear function of temperature between 10 and 30 º C. No significant differences among coating treatments were apparent for the intermediate date (Table 3). The number of days from 10 to 90% emergence averaged 3.3 for the intermediate date. On the third date, coating treatments did not influence emergence time in Hybrid 8509. Coating C of Hybrid 9307, however, required significantly more days to progress from 10 to 90% in comparison to alternate coating treatments (Table 3).

Contrast statements in 2001 showed that coated treatments of both Hybrids emerged less uniformly in the early planting than the untreated control in the intermediate planting (Table 3). The uncoated treatments emerged similarly for both the early and intermediate dates.

Many authors have found emergence variability on corn to lower grain yield (Ford, 1987; Ford and Hicks, 1992; Nafziger *et al*., 1991). For example, Ford and Hicks (1992) observed a 5 % yield reduction in corn when half of the stand was delayed in planting by 7 days, and 12.8 % yield reduction when half of the stand was delayed by 14 days of late planting. However, in these studies there was no measurement of the uniformity of emergence among plants seeded on the same day.

Planting date seemed have a large effect on emergence uniformity, and, among planting dates, early planting resulted in the least uniform emergence. This was probably due to lower soil temperatures encountered by the seed early in the season. It was expected that coated seed would improve emergence uniformity after early planting, but results did not support that hypothesis. After early planting, only 8509 in 2000 resulted in a more uniform emergence; thus, in 2001 all coated treatments were associated with a less uniform emergence.

Table 2. Coating treatment effects on days from 10 to 90% emergence, for different planting dates and Hybrids in 2000.

	Days from 10-90 % Emergence		
Teatment [†]	28-Mar [‡]	4-Apr	16-May
8509/UTC	9.3 a[§]	2.8 a	4.0 a
8509/A	5.0 b	4.1 a	3.4 a
8509/B	5.6 b	3.4 a	2.8 a
9307/UTC	5.5 a	4.3 a	4.6 a
9307/A	6.4 a	4.0 a	4.0 a
9307/B	6.9 a	4.4 a	4.4 a

Treatment Comparisons[†]	Significance	
	Within Hybrid 8509	Within Hybrid 9307
PD 1 (A + B) vs PD 2 (A + B)	NS	NS
PD 1 (A + B) vs PD 2 (UTC)	NS	NS
PD 1 (A) vs PD 2 (UTC)	NS	NS
PD 1 (B) vs PD 2 (UTC)	*	NS
PD 1 (UTC) vs PD 2 (UTC)	NS	NS

* significant at 0.05 probability levels.

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC = uncoated, A= coating A, B= coating B, PD1= early planting, PD2= intermediate planting, PD3= late planting.

‡ Planting dates.

§ Data followed by the same letter within year, planting date and Hybrid are not significantly different according to a protected LSD (0.05) test.

Table 3. Coating treatment effects on days to from 10 to 90% emergence, for different planting dates and Hybrids in 2001.

	Days from 10-90 % Emergence		
Teatment †	2-Apr ‡	19-Apr	11-May
8509/UTC	3.5 b§	2.9 a	2.9 a
8509/D	6.8 a	3.4 a	2.6 a
9307/UTC	4.0 b	2.5 a	3.4 b
9307/C	8.1 a	4.4 a	8.9 a
9307/D	8.8 a	3.3 a	4.1 b

Treatment Comparisons †	Significance	
	Within Hybrid 8509	Within Hybrid 9307
PD 1 (C + D) vs PD 2 (C + D)	NA	**
PD 1 (C + D) vs PD 2 (UTC)	NA	**
PD 1 (C) vs PD 2 (UTC)	NA	**
PD 1 (D) vs PD 2 (UTC)	*	**
PD 1 (UTC) vs PD 2 (UTC)	NS	NS

* , ** significant at 0.05 and 0.01 probability levels, respectively.

NA= not applicable.

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC = uncoated, C= coating C, D=coating D. PD1= early planting, PD2= intermediate planting, PD3= late planting.

‡ Planting date

§ Data followed by the same letter within year, planting date and Hybrid are not significantly different according to a protected LSD (0.05) test.

Initial Plant Population

In 2000, total seedlings emerged was only affected by Hybrid ($P < 0.01$) and planting date factors ($P < 0.01$), but not by coating treatments (Appendix B.5). Over all planting dates and coating treatments, Hybrid 8509 had 7,2000 more seedlings ha^{-1} emerged than 9307 (data not shown). It seemed that Hybrid 9307 had poorer seed viability in 2000, since plant population was consistently lower than 8509, despite being seeded at the same rate as 8509. Late planting resulted an average of 3300 fewer plants ha^{-1} than the early and intermediate planting dates, respectively (Figure 6).

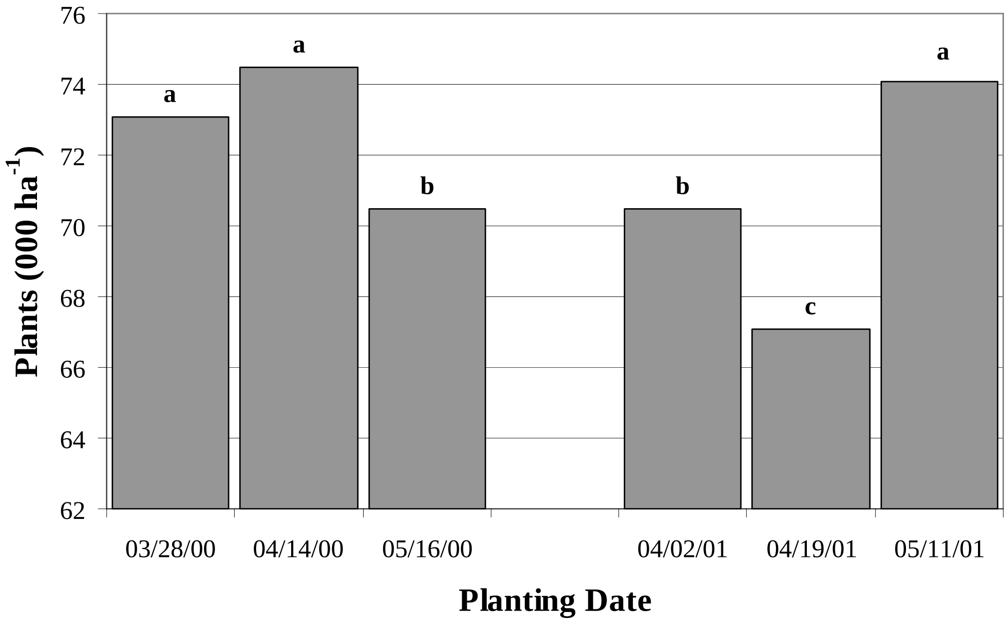


Figure 6. Effect of planting date on initial plant population (averaged for both Hybrids and respective coating treatments) in 2000 and in 2001.
Within year, data followed by the same letter are not significantly different according to a protected LSD (0.05) test.

Selected contrasts in 2000 indicated that planting date, Hybrid and coating treatment influences on initial plant populations were rarely significant in 2000 (Table 4). These results suggest that total emergence was not influenced by early planting date.

In 2001, planting date effect was also significant ($P < 0.01$) (Appendix B.6). Late planting resulted in significantly larger plant populations than for the two other planting dates (Figure 6). Plant population with early planting resulted in a higher number of seedlings emerged.

The fact that early planting did not result in lower plant populations relative to intermediate plantings is in agreement with previous findings. Dwyer *et al.* (1999) in a study with 3 different planting dates, found that average stand establishment was generally not reduced when mean soil temperatures were above 12.5 º C (represented by the means for the first 10 days following planting). Even when temperatures below 12.5 º C were considered, only 5 of 45 planting date-site-year combinations had stands below 80% of the seeding rates. Results indicated that stand establishment is reduced by a combination of low (<12.5º C) soil temperature and high (> field capacity) soil water content.

In 2001, the interaction of date x treatment was also significant ($P < 0.05$) (Appendix B.6). For the first planting date, uncoated seed of Hybrid 8509 resulted in a lower number of seeds emerged than coating B (Table 5). Nevertheless, both treatments resulted in good stand establishment (> 70,000 ha^{-1}). No significant differences among coating treatments occurred with Hybrid 9307 in the first planting date (Table 5).

Coating C of Hybrid resulted in a lower initial plant population for both the intermediate and late planting dates, relative to the uncoated and coating D treatments in 2001 (Table 5). In the late planting date coating C was also associated with a significant delay to mid-emergence (Table 1), as well as lower rate of emergence (Table 3), in comparison to coating D and uncoated seed. For the intermediate planting, however, emergence differences between coatings C and D were not significant. Therefore, it is impossible to conclude that rate of emergence or emergence delay alone accounted for initial population differences. Moreover, when total seedlings emerged were plotted versus rate of emergence for all planting dates in 2001, no particular relationship was apparent (Figure 7).

In contrast to our results, Gesh *et al*. (2001) observed that 10 to 40% more coated than uncoated corn seed emerged when planted in March in a conventional tillage system. However, when corn was planted in a no-till system in the same month, emergence differences of uncoated and coated seed were smaller.

However, when our plant population results were analyzed in terms of surviving seedlings after complete emergence, significant differences were evident in 2001. The frost on April 17 and 18 resulted in a stand reduction of 38% for uncoated seed versus just 10-15% for coated seed of 9307 (Figure 8). Hybrid 8509 was less affected than 9307, since only 12% of the uncoated and 6% of the coated seedlings were killed by frost. Even though the growing point region of corn younger than V6 is below the soil surface and protected from above ground damage (Nielsen and Christmas, 2002), the fact that some plants were killed by the frost suggests that the temperature at the growing point dropped to lethal levels. The difference in damage caused to the different Hybrids might be related to a higher early-season cold tolerance of Hybrid 8509.

Variation for susceptibility to frost damage has been reported among maize genotypes (Hardacre and Eagles, 1986; Dhillon *et al*.; 1988; Gardner *et al*., 1987, Hardacre et al., 1990). The lowest temperature tolerated by maize is also reported to vary widely. Temperatures between 0º C and –1.5º C have been reported to reduce the growth of maize, while temperatures between – 2º C and - 3ºC resulted in severe damage to the plants (Dhillon et al., 1988). However, reasons for genetic differences in the relationship between temperature and damage are not clear.

Polymer coatings never increased total number of seedlings emerged in either year, but improved final established stands in 2001, when mid-April frosts reduced the stand of uncoated seed of 9307 more than 8509 and coated seed treatments of both Hybrids were less damaged.

Table 4. Coating treatment effects on emerged seedlings, for different planting dates and Hybrids in 2000.

	Emerged Seedlings		
Treatment †	28-Mar ‡	14-Apr	16-May
	------------------------ Plants ha^{-1}	----------------------------------	
8509/UTC	77300	78000	75300
8509/A	76300	78900	73000
8509/B	75000	78300	75000
9307/UTC	67100	71100	65800
9307/A	71100	71100	67800
9307/B	71700	69700	66400

Treatment Comparisons †	Significance	
	Within Hybrid 8509	Within Hybrid 9307
PD 1 (A + B) vs PD 2 (A + B)	NS	NS
PD 1 (A + B) vs PD 2 (UTC)	NS	NS
PD 1 (A) vs PD 2 (UTC)	NS	NS
PD 1 (B) vs PD 2 (UTC)	NS	NS
PD 1 (UTC) vs PD 2 (UTC)	NS	*

* significant at the 0.05 probability levels, respectively.

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC=uncoated, A= coating A, B= coating B, PD1= early planting, PD2= intermediate planting, PD3= late planting.

‡ Planting dates

Table 5. Coating treatment effects on emerged seedlings, for different planting dates and Hybrids in years 2001.

	Emerged Seedlings					
Treatment †	2-Apr‡		19-Apr		11-May	
	------------------------ Plants ha^{-1} ----------------------------------					
8509/UTC	71400	b§	63500	a	74000	a
8509/D	77300	a	67800	a	75000	a
9307/UTC	69400	a	70400	a	75300	a
9307/C	67100	a	64100	b	70000	b
9307/D	67400	a	69700	a	76000	a

Treatment Comparisons†	Significance	
	Within Hybrid 8509	Within Hybrid 9307
PD 1 (C + D) vs PD 2 (C + D)	NA	NS
PD 1 (C + D) vs PD 2 (UTC)	NA	NS
PD 1 (C) vs PD 2 (UTC)	NA	NS
PD 1 (D) vs PD 2 (UTC)	**	NS
PD 1 (UTC) vs PD 2 (UTC)	*	NS

* , ** significant at 0.05 and 0.01 probability levels, respectively.

NA= not applicable.

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC =uncoated, C= coating C, D=coating D. PD1= early planting, PD2= intermediate planting, PD3= late planting.

‡ Planting date

§ Data followed by the same letter within year, planting date and Hybrid are not significantly different according to a protected LSD (0.05) test.

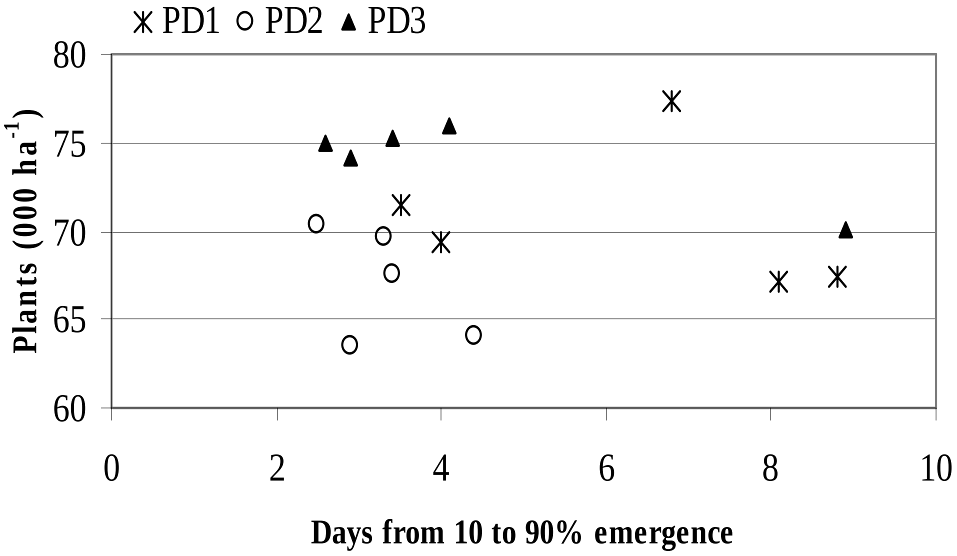


Figure 7. Plants per hectare (total seedlings emerged) as a function of days from 10 to 90% emergence in 2001 for three planting dates (each planting date includes 2 coating treatments means of Hybrid 8509 and 3 of 9307)
PD1= early planting date, PD2= intermediate planting date, PD3= late planting date.

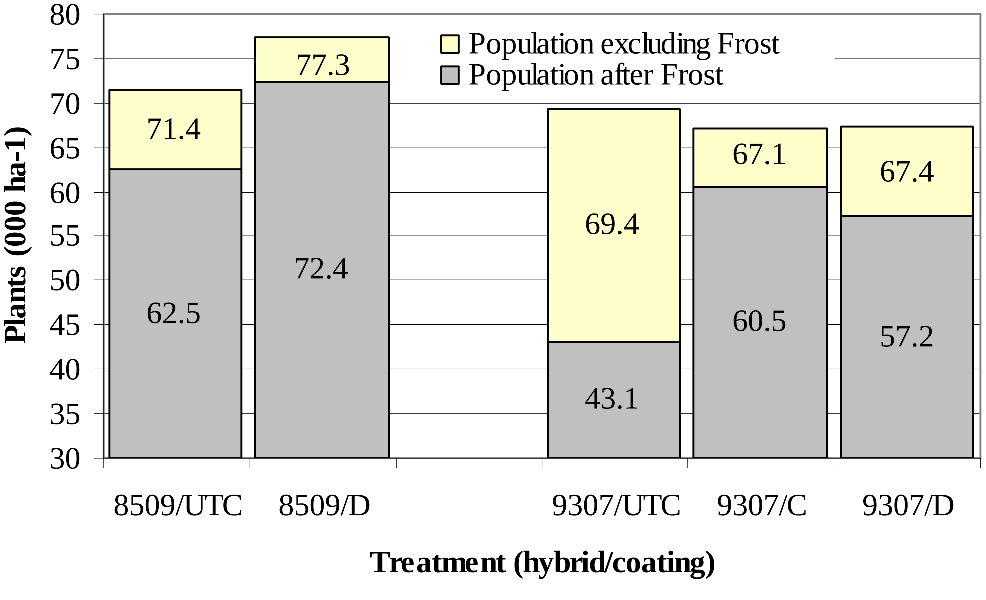


Figure 8. Effect of frost on plant population reduction for early-planted corn in 2001.
8509= Hybrid 8509, 9307= Hybrid 9307, UTC= control, C= coating C, D= coating D.

Early Season Corn Height

I) Early Planting Date

In 2000, the coating x Hybrid interaction for height was the only significant interaction at 6 weeks ($P < 0.05$) as well as at 8 weeks after emergence ($P < 0.01$) (Appendix C.13, C.19). At 6 weeks after emergence, uncoated seed of Hybrid 9307 averaged 8.6 cm taller than coating B of the same Hybrid (Table 6). However, no differences were observed between the control and coating A. This may have resulted from an earlier emergence of the uncoated and coating A treatments in comparison to coating B, since the latter treatment emerged 5.1 days later than the control and 2.2 days later than coating A (Table 1). Height was not influenced by coating treatments for Hybrid 8509 (Table 6). In this case, the difference in days to emergence was not as large as it was for Hybrid 9307; coatings delayed emergence of 8509 by approximately 1 day. These smaller differences in emergence of 8509 make the lack of height differences understandable.

In 2000, at 8 weeks after emergence, uncoated seed of Hybrid 8509 averaged 6.5 and 9.6 cm shorter than coating A and B respectively (Table 6). Even though the control did not attain 50% VE significantly later than coated seed, the interval from 10 to 90% took about 4 more days than coated corn, resulting perhaps in a less uniform plant growth (Table 2). Plant height of coating B of Hybrid 9307 was shorter both at 6 and 8 weeks after emergence, probably due to a later emergence in comparison with the two other treatments.

In 2001, treatment effects were significant at both 6 weeks ($P < 0.05$) and at 8 weeks after emergence for 9307 but not for 8509 (Table 6) (Appendix C.14, C.20). Coating D of Hybrid 9307 was 4.3 cm shorter than the control.

Table 6. Effect of coating treatments within Hybrid on corn height at 6 and 8 weeks after emergence for early planting in 2000 and 2001.

	Plant Height in 2000			Plant Height in 2001	
Treatment †	6 weeks ‡	8 weeks	Treatment	6 weeks	8 weeks
	--------------- (cm) ----			--------------- (cm) ----	
8509/UTC	73.4 a §	123.0 b	8509/UTC	49.5 a	105.2 a
8509/A	77.3 a	129.5 a	8509/D	50.6 a	108.5 a
8509/B	78.4 a	132.6 a			
9307/UTC	81.3 a	131.6 a	9307/UTC	47.3 a	96.5 a
9307/A	78.8 a	128.7 a	9307/C	45.6 ab	91.5 b
9307/B	72.7 b	120.6 b	9307/D	43.6 b	91.6 b

†8509= Hybrid 8509, 9307= Hybrid 9307, UTC= uncoated, A= coating A, B= coating B, C= coating C, D= coating D

‡ Weeks after emergence

§ Data followed by the same letter are not significantly different according to a protected LSD (0.05) test.

II) Intermediate Planting Date

In 2000, neither Hybrid nor coating treatments significantly influenced plant height at 4 or 6 weeks after emergence ($P > 0.50$) (Appendix C.15, C.21). However, in 2001 uncoated corn resulted in the tallest plants for both Hybrids (Table 7). Height differences between the uncoated and coated treatments averaged 6.9 cm in 8509, and 5.5 cm in 9307.

Table 7. Effect of coating treatments within Hybrid on corn height at 4 and 6 weeks after emergence for the intermediate planting date in 2001.

	2001 Plant Height	
Treatment†	4 weeks‡	6 weeks
	------------------	(cm) -----------------
8509/UTC	51.1 a§	109.8 a
8509/D	44.2 b	100.1 b
9307/UTC	50.8 a	104.1 a
9307/C	45.3 b	97.8 a
9307/D	45.3 b	98.8 a

† 8509= Hybrid 8509, 9307=Hybrid 9307, UTC= uncoated, C= coating C, D= coating D.
‡ Weeks after emergence.
§ Data followed by the same letter within a Hybrid and measurement time are not significantly different according to a protected LSD (0.05) test.

III) Late Planting

In 2000, coating effects on corn height were significant at 4 weeks after emergence (Appendix C.17). Uncoated corn averaged 4.4 cm taller than coating A, yet no significant differences were found with coating B (data not shown). In contrast, 6 weeks after emergence corn height was affected only by Hybrid (Appendix C.23). Hybrid 8509 was taller (154 cm) than Hybrid 9307 (148 cm) (data not shown).

In 2001, coatings reduced plant heights at 4 weeks after emergence for 9307, but not for 8509 (Table 8). Uncoated seed of Hybrid 9307 resulted in 11.4 cm taller plants than coating C. This may be associated with the later emergence of coating C, since it emerged 5.2 days later than the control (Table 1, pg. 41). At 6 weeks after emergence, however, treatment differences were not significant (Appendix C.24).

Table 8. Effects of coating treatments on plant height at 4 weeks after emergence for late planting in 2001.

Treatment†	Plant Height	Treatment	Plant Height
	(cm)		(cm)
8509/UTC	75.1 a‡	9307/UTC	74.4 a
8509/D	72.4 a	9307/C	63.0 b
		9307/D	67.4 ab

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC=uncoated, C=coating C, D=coatingD.
‡ Data followed by the same letter within Hybrid are not significantly different according to a protected LSD (0.05) test.

Results for all three planting dates suggest that emergence delays resulted in inconsistent height differences among coating treatments. Height differences were less evident in the second period. Moreover, as emergence delay increased, larger differences in height were observed.

Final Height

In both years of the study, coating treatments did not have any significant effect on final plant height. However, plant height was affected by planting date in 2000 ($P < 0.05$), as well as in 2001 ($P < 0.01$) (Appendix B.7, B.8). Tallest plants resulted from the late planting date in both 2000 and 2001 (Figure 10). This height advantage could be associated with longer internodes for late-planted corn. Al-Darby and Lowery (1987) also observed that plant heights are taller with later planting dates.

Hybrid 8509 averaged 9 cm taller than 9307 in 2000, and 31 cm taller than 9307 in 2001 (Figure 9). These results agree with those from Wu (1998). He found that Hybrid had a significant influence on final plant height, but uniformity in emergence had no effect on this variable.

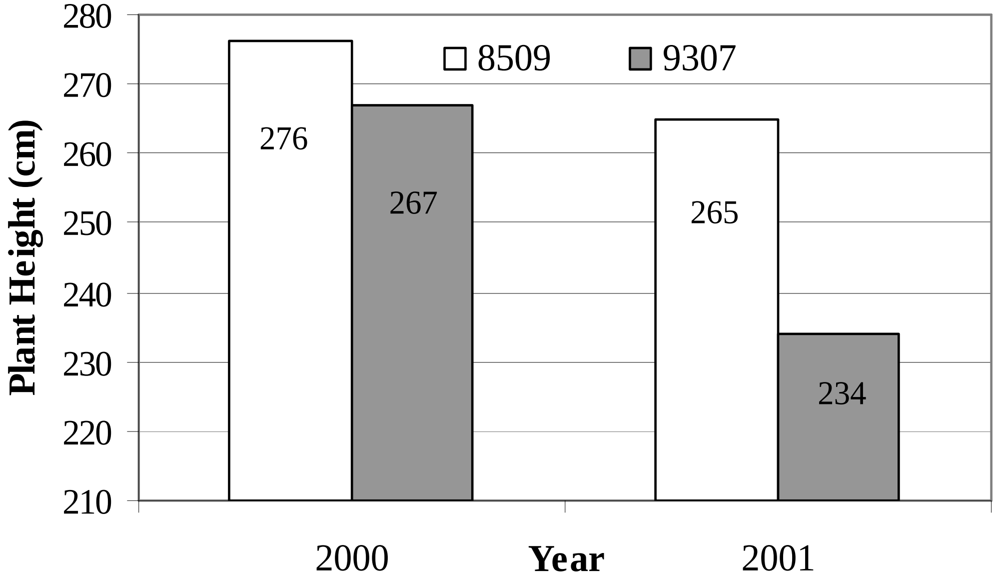


Figure 9. Hybrids effects (averaged for all 3 planting dates and respective coating treatments) on final plant height in years 2000 and 2001.

Hybrid main effect significant at *P* < 0.01 in both years.

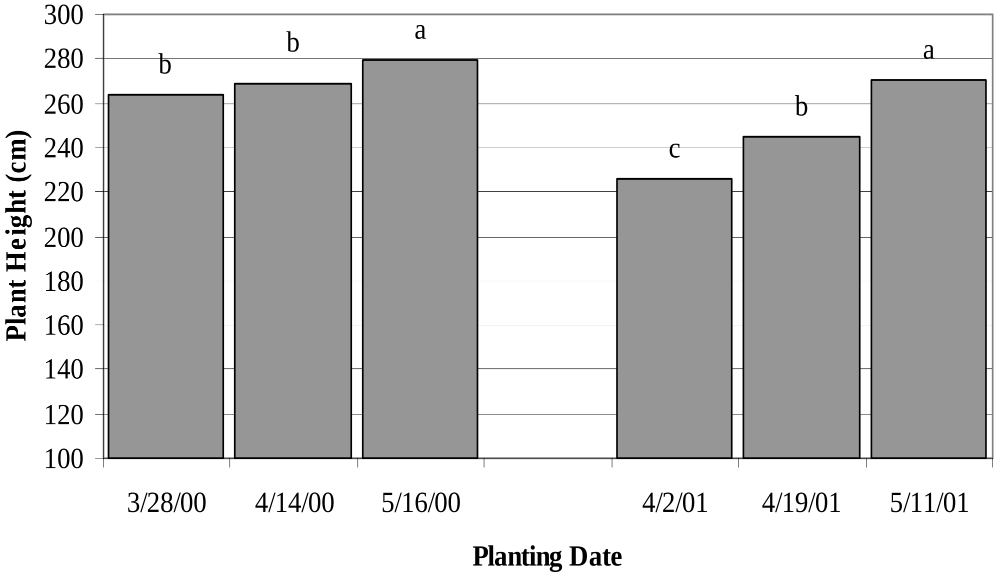


Figure 10. Planting date effect (averaged for both Hybrids and respective coating treatments) on final plant height in years 2000 and 2001.

Data followed by the same letter are not different according to a protected LSD (0.05) test.

Developmental Stages

I) Early Planting

Development during the vegetative period was studied to evaluate whether emergence delays resulting from polymer coatings would be large enough as to delay development throughout the season in comparison to uncoated treatments planted at the same time. In 2000, Hybrid differences for developmental stage were significant ($P < 0.01$) at both 6 and 8 weeks after emergence, and the interaction of Hybrid x coating was significant only at 6 weeks after emergence ($P < 0.01$) (Appendix C.1). At 8 weeks, coating treatments had disappeared and only Hybrid effect was significant (Appendix C.7). Hybrid 9307 resulted in a faster development than 8509 at both 6 and 8 weeks after emergence (Figure 11). The fact that 9307 has a lower relative maturity (106 days) than 8509 (109 days) might have accounted for these differences.

No V-stage differences were apparent among coating treatments for Hybrid 8509 at 6 weeks in 2000 (Table 9). This coincided with the fact that no differences in height were observed at this time (Table 6). Developmental stage differences were evident in 9307 because coating B resulted in the least developed plants (Table 9). In 2001, neither planting dates, Hybrids nor coating treatments had a significant impact on developmental stages at either 6 or 8 weeks after emergence (Appendix C.2, C.8).

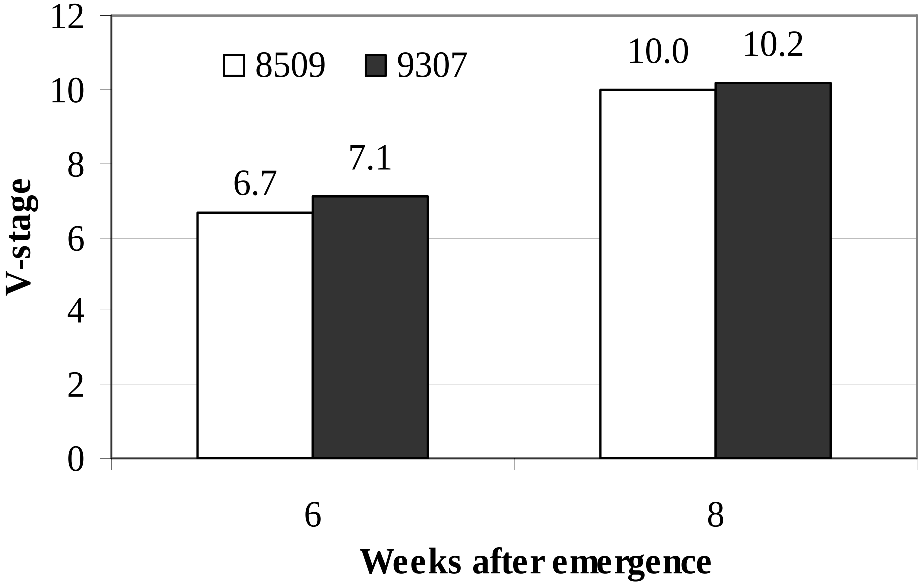


Figure 11. Effect of Hybrids (averaged for respective coating treatments) on developmental stages for early plant corn at 6 and 8 weeks after emergence in 2000. Hybrid main effect significant at $P < 0.01$ at both 6 and 8 weeks after emergence.

Table 9. Effect of coating treatments on developmental stages at 6 weeks after emergence for early-planted corn in 2000.

Treatment †	V-stage	Treatment	V-stage
8509/UTC	6.6 a ‡	9307/UTC	7.4 a
8509/A	6.7 a	9307/A	7.1 ab
8509/B	6.7 a	9307/B	6.9 b

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC = uncoated, A=coating A, B=coating B
‡ Data followed by the same letter within Hybrid are not significantly different according to a protected LSD (0.05) test.

II) Intermediate Planting Date

In 2000, only Hybrids significantly affected developmental stages ($P < 0.01$) (Appendix C.3, C.9). Hybrid 8509 was less developed physiologically than 9307 at both measurement times (Figure 12). In 2001, corn in uncoated seed treatments for both

Hybrids were more developed than coated seed at 4 weeks after emergence (Table 10). At 6 weeks, however, the treatment main effect was not significant (Appendix C.10).

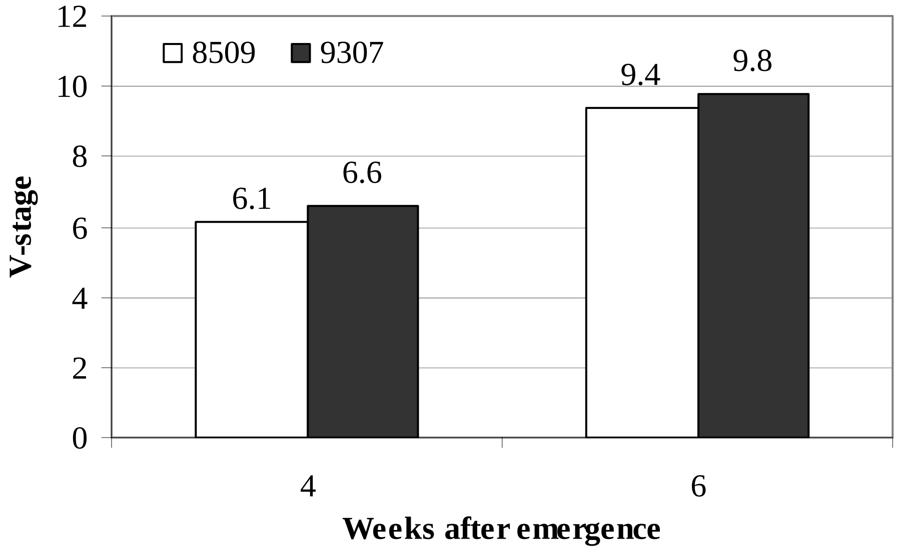


Figure 12. Effects of Hybrids on developmental stages at 4 and 6 weeks after emergence for intermediate planted corn in 2000.
Hybrid significant at $P < 0.01$ at 4 and 6 weeks.

Table 10. Effect of coating treatment within Hybrid on developmental stage for intermediate plant corn at 4 weeks after emergence in 2001.

Treatment	V-Stage		Treatment	V-Stage	
8509/UTC†	5.0	a‡	9307/UTC	5.3	a
8509/D	4.6	b	9307/C	4.9	b
			9307/D	4.9	b

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC=uncoated, C=coating C, D=coatingD.
‡ Data followed by the same letter are not significantly different according to a protected LSD (0.05) test.

III) Late Planting

Seed coating treatments affected V-stages at both 4 and 6 weeks after emergence for Hybrid 9307 in 2001 (Table 11) but no differences were observed in 2000. Uncoated seeds of 9307 were consistently ahead in 2001. Differences among coating treatments were probably associated with the fact that coated seed resulted in emergence delays relative to uncoated seed, whereas in 2000 all late-planted treatments reached 50% emergence at the same time. In 2000, Hybrid 9307 was ahead of 8509 at both 4 and 6 weeks after emergence (Figure 13).

Table 11. Effect of coating treatments on developmental stage at 4 and 6 weeks after emergence for late plant corn in 2001.

Treatment †	V-Stage	
	4 Weeks‡	6 Weeks
8509/UTC	6.53 a§	10 a
8509/D	6.12 b	9.58 a
9307/UTC	6.79 a	10.1 a
9307/C	6.08 c	9.17 b
9307/D	6.38 b	9.63 ab

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC=uncoated, C=coating C, D=coatingD.
‡ Weeks after emergence.
§ Data followed by the same letter within Hybrid and measurement time are not significantly different according to a protected LSD (0.05) test.

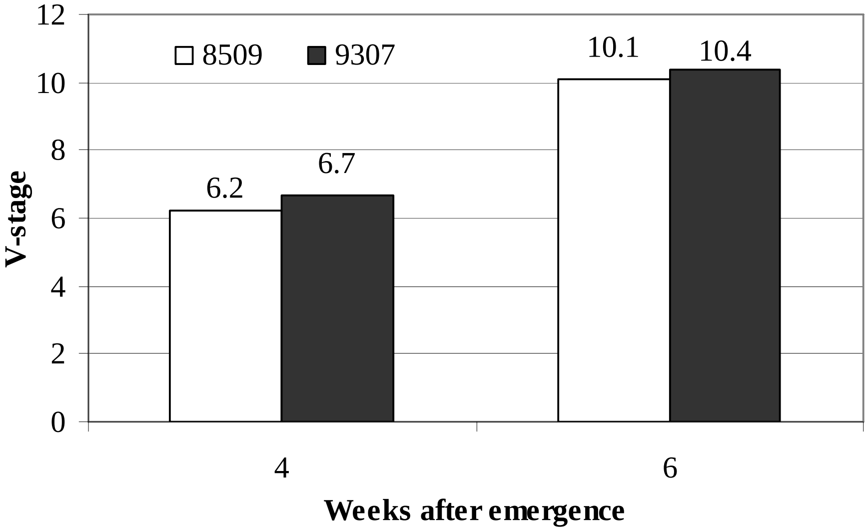


Figure 13. Effects of Hybrids on developmental stage at 4 and 6 weeks after emergence for late plant corn in 2000.
Hybrid main effect significant at P < 0.01 at both 4 and 6 weeks after emergence.

In general, coating treatments that delayed emergence more resulted in less developed plants in comparison to earlier emerged treatments. After early planting some differences among treatments were only evident in 2000 for the first measurement period, whereas for the intermediate and late planting dates, differences were apparent in 2001, but not 2000.

Plant-to-Plant Variation

The effects of planting date, Hybrid, and coating treatments on plant-to-plant height variation were analyzed by calculating standard deviations of 6 and 8 weeks plant heights and V-stages for the two measurement periods following all 3 planting dates. These analyses were performed to evaluate whether polymer coated seed would result in more uniform stands throughout the season in comparison to non-coated seed.

Plant height or V-stage standard deviations were not affected by coating treatments at any measurement time for all planting dates in both 2000 and 2001 (Appendix C.1-C.24). Alternately, the extent of the emergence variability was not great enough to cause subsequent plant development variability.

This is in agreement with Wu (1998). He studied the response of plant-to-plant variability of two Hybrids (an old (released in 1959) and new one (released in 1988)) to plant density. He planted seeds either all on the same day to produce uniform stands, or on alternative sowing dates of three to produce non-uniform stands. Consistent with our findings, plant final height variation was not affected by the uniformity in planting date. He found, however, that variation in height was less evident in the newer Hybrid, suggesting it was a more stress tolerant genotype than the old one.

Plant Spacing Standard Deviation

In 2000, neither main factors nor main factor interactions had significant ($P > 0.05$) effect on plant spacing standard deviation (Appendix B.13). Plant spacing standard deviation ranged from 4.9 to 6.2 cm for the early planting date, from 4.9 to 6.6 cm for the intermediate planting date, and from 5.2 to 7.2 cm for late planting (results not shown).

In contrast, in 2001, the interaction of planting date x treatment was significant ($P < 0.01$) (Appendix B.14). Uncoated seed of Hybrid 9307 averaged 6.7 cm higher standard deviation than coating C, and 7.3 cm higher than coating D (Table 12). The reason for this higher variability in plant spacing was the result of frost damage occurred in April, which randomly killed 38% of the stands of uncoated seed, and 10-15% of the coated stands, increasing plant spacing variability immensely for the first planting date. In contrast, differences within 8509 were not found, since this Hybrid did not lose as many plants as Hybrid 9307. Spacing standard deviation on intermediate and late planting dates ranged from 4.7 to 7.4 cm and from 5.2 to 5.8 cm, respectively, but no differences were found among treatments.

Nielsen (1997) suggested that the ideal spacing standard deviation for minimal corn yield loss should be less than 5.0 cm, a deviation of 7.62 cm has the potential to decrease yield by 0.16 Mg ha^{-1}relative to that at 5 cm. Moreover, Doerge (2001) observed a 0.08 Mg ha^{-1} increase for each cm improvement in standard deviation. However, Liu *et al*. (2001) in a more recent experiment of corn response to spatial variability in emergence found that, for a constant plant population, plant spacing standard deviations from 6 cm to 20 cm had no significant effect on grain yield. Our results suggest that plant spacing standard deviation was not affected by Hybrid or coating treatments unless plant populations were reduced.

Table 12. Effect of coating treatments on the standard deviation of plant spacing in 2001.

Treatment †	Mean Standard Deviation of Plant Spacing								
	2-April ‡			19-April			11-May		
	(log)		(cm)	(log)		(cm)	(log)		(cm)
8509/UTC	0.87	a §	7.9	0.82	a	6.9	0.72	a	5.4
8509/D	0.76	a	5.9	0.80	a	6.6	0.72	a	5.5
9307/UTC	1.19	a	17.4	0.66	b	4.7	0.71	a	5.2
9307/C	0.88	b	10.7	0.83	a	7.4	0.76	a	5.8
9307/D	0.96	b	10.1	0.69	b	5.1	0.73	a	5.6

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC=uncoated, C= coating C, D= coating D.
‡ Planting dates
§ Data followed by the same letter within planting date are not significantly different according to a protected LSD (0.05) test.

Time to Silking

The number of days after planting until 50% silk was affected by planting date in both years ($P < 0.01$) (Appendix B.9, B.10). As expected, early planting delayed corn development in terms of calendar days to silk. On average, in 2000 the early planting date resulted in a significantly higher number of days until silking (101 days) than intermediate (85 days) and late planting dates (68 days) (Figure 14). In 2001, early planting averaged 95 days until 50% silk, whereas late planting resulted in the fewest days (74 days) (Figure 14). Intermediate planting averaged 84 days.

The silk emergence responses to planting date suggest that higher temperatures encountered by later-planted corn during the initial stages accelerated plant development and, therefore, reduced the number of days until silk emergence. An increase in day time temperatures resulted in the acceleration of developmental rate as evidenced by the substantial reduction in days to tassel emergence between 18/10 and 26/10 º C (Boanparte, 1975).

Hybrid main effects on silking were also significant (*P* < 0.01) in 2000 as well as in 2001. In both years, Hybrid 8509 averaged 3 more days to reach 50% silk emergence than 9307 (Figure 15). This is probably associated with the higher relative maturity of Hybrid 8509 (109 days) in comparison to 9307 (106 days).

In 2000, polymer coating did not affect silking significantly, but in 2001, the interaction of date x treatment was significant (*P* < 0.01). After early planting, coating treatments had no impact on silk development in 8509 (Table 13). However, the uncoated seed of Hybrid 9307 took 2.4 to 3.1 fewer days to silk than coated treatment of the same Hybrid. After the intermediate planting date, uncoated treatments of both Hybrids required fewer days to silk than coated treatments (Table 13). Coating D of Hybrid 9307 resulted in the longest period of days to silk. After late planting, however coating treatments did not influence time to time to silking in either Hybrid (Table 13). Higher temperatures encountered by late planted-corn probably minimized polymer-coating effects on emergence delays (Table 1).

The fact that 2000 showed no significant polymer coating effect on days to 50% silking, whereas 2001 did, could be ascribed to relatively shorter emergence delays for 2000 relative to 2001.

Results suggest that longer emergence delays early in the season arising from polymer coatings are more likely to result in silking delays relative to uncoated treatments, and that coated seed planted later in the season, even if producing significant emergence delays, are less likely to result in silking delay, due to higher temperatures encountered by the crop in the pre-flowering period.

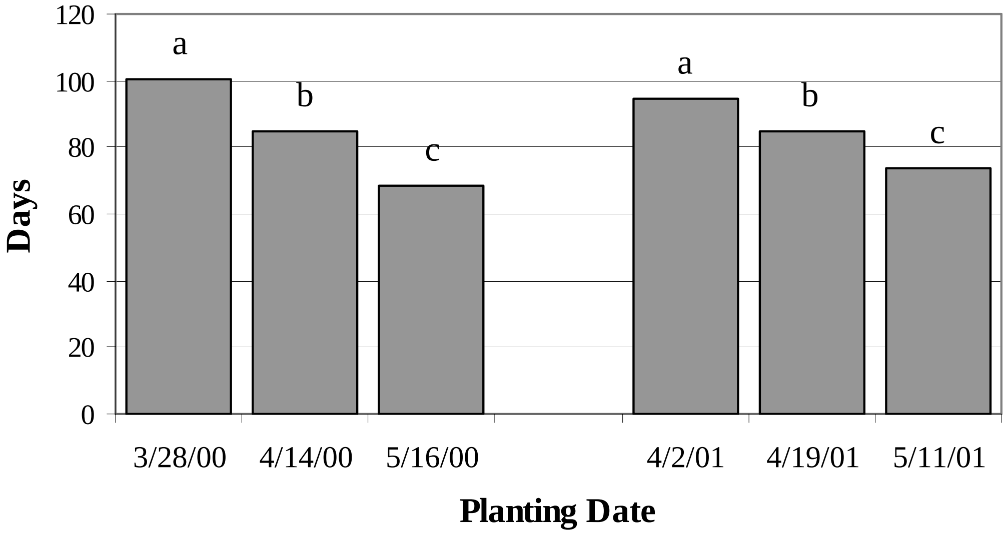


Figure 14. Effect of planting dates on days from planting to 50% silk (averaged for both Hybrids and respective coating treatments) in 2000 and 2001.
Data followed by the same letter within year are not significantly different according to a protected LSD (0.05) test.

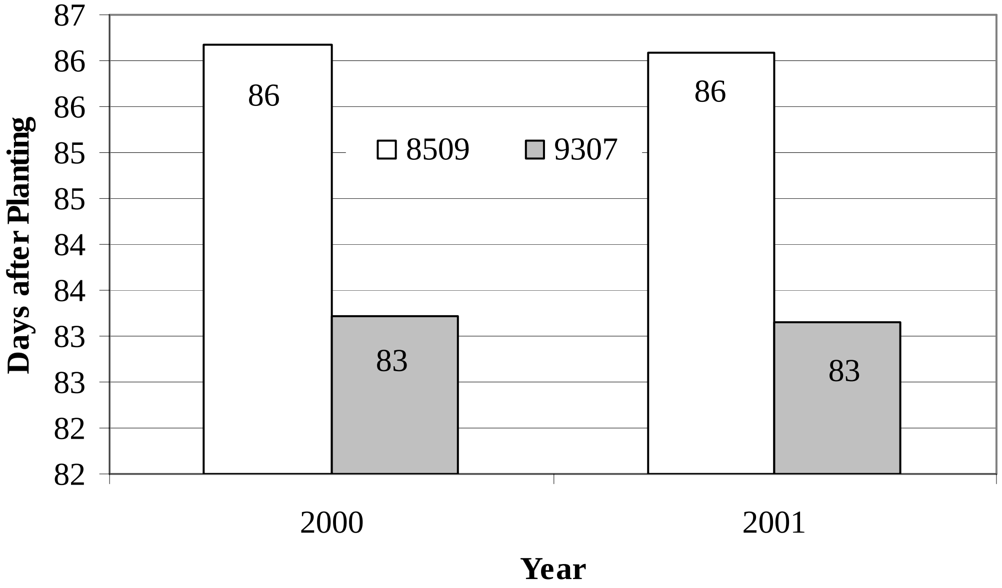


Figure15. Hybrid effects (averaged for respective planting dates and coating treatments) on days to 50% emergence in 2000 and 2001.
Hybrid effect significant at *P* < 0.01 in 2000 and 2001.

Table 13. Effect of coating treatments within Hybrid and planting date on time from planting to 50% silk emergence in 2001.

Treatment†	Mean Days to 50% Silk					
	1-April‡		19-April		11-May	
	---------------------		days		-----------------------------------	
8509/UTC	96.9	a §	85.6	b	77.0	a
8509/D	96.9	a	88.3	a	77.1	a
9307/UTC	91.5	b	81.6	c	75.3	a
9307/C	94.6	a	83.6	b	75.6	a
9307/D	93.9	a	86.3	a	75.4	a

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC= uncoated, C=coatingC, D=coatingD.

‡ Planting date

§ Data followed by the same letter within Hybrid and planting date are not significantly different according to a protected LSD (0.05) test.

Time from 10 to 90% Silking

Time from 10 to 90 % silk emergence was calculated to evaluate whether a more uniform emergence would also be reflected later in the season by a more uniform silking period. In 2000, the number of days from 10 to 90% silk emergence was not significantly affected by polymer coatings ($P > 0.05$) (Appendix B.11). However, in 2001 planting date effects on time from 10 to 90% silking were significant ($P < 0.01$) (Appendix B.12). Late planting showed the most uniform silk emergence, whereas early planting resulted in the least uniform (Figure 16). This corresponds to what happened with emergence uniformity, where early planting resulted in the least uniform emergence. This suggests that earlier variation in development (whether emergence or v-stages) was also evident later in the season. Wu (1998) also observed that more time elapsed between silking of first plants and silking of 50% of the plants in the non-uniform stand than in the uniform treatment. Coating treatments did not affect silking uniformity in either year of this current study, regardless of the emergence delay and later developed plants resulting from coated treatments. Planting date seemed to be the variable that had the highest impact on silking uniformity.

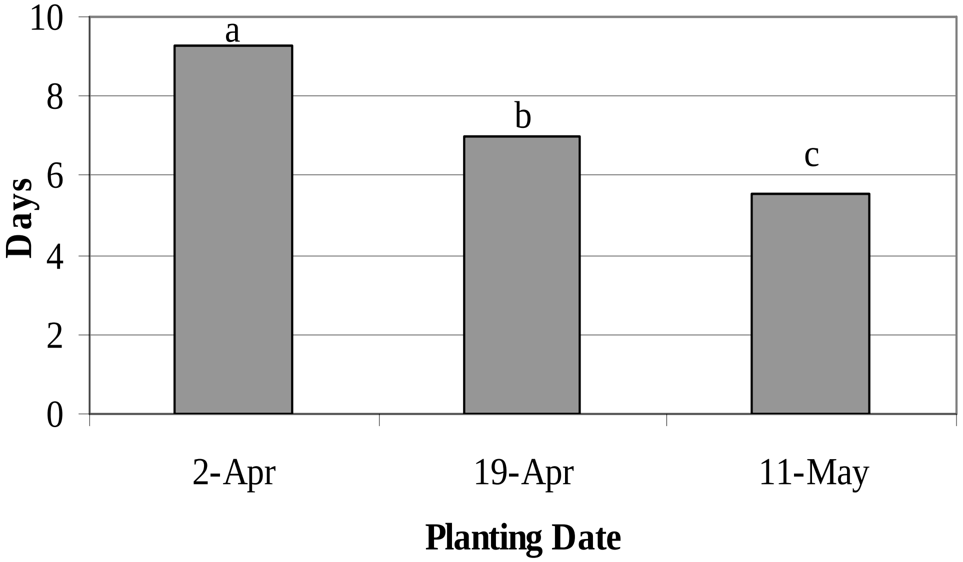


Figure 16. Effects of planting dates (averaged for both Hybrids and coating treatments) on days from 10 to 90% silking in 2001.
Data followed by the same letter are not significantly different according to a protected LSD (0.05) test.

Final Plant Populations at the Time of Harvest

In 2000, final plant populations at the time of harvest were only affected by planting date (*P* < 0.01) and Hybrid (*P* < 0.01) (Appendix B.15). Early-planted corn was not significantly different than intermediate planting date, or late-planted corn (Table 14). However, late planted-corn resulted in 3700 fewer plants ha^{-1} than intermediate-planted corn. Overall, Hybrid 8509 averaged 74700 plants ha^{-1} and 9307 67800 plants ha^{-1} in 2000 (data not shown). In 2001, planting date was also significant (*P* < 0.01) (Appendix B.16). Early planting dates achieved a significantly lower plant population than the two other planting dates, whereas late planting dates were associated with a significantly higher stand (Table 14). In 2001, the planting date x treatment interaction was also significant (*P* < 0.01) (Appendix B.16). For early planted-corn, uncoated seed of both

Hybrids achieved significantly lower populations in comparison with coated treatments of the same Hybrid, due to the frost damage that occurred early in the season (Table 15). The two other planting dates showed no significant differences in plant population (Table 15). Plant populations from early season until the time of harvest were relatively unchanged, except from early-planted seed, where population reductions occurred after frost (Figure 8).

Table 14. Effect of planting dates (averaged for both Hybrids and respective coating treatments) on plant population at harvest in 2000 and 2001.

Date	2000 Final Plant Population		Date	2001 Final Plant Population	
	(plants ha^{-1})			(plants ha^{-1})	
28-Mar	71100	ab†	2-Apr	57632	c
14-Apr	73200	a	19-Apr	67237	b
16-May	69500	b	11-May	73684	a

† Data followed by the same letter within year are not significantly different according to a protected LSD (0.05) test.

Table 15. Effect of treatments on plant population for intermediate and late planting dates at harvest in 2001.

	Final Plant Population					
Treatment †	2-Apr ‡		19-Apr		11-May	
	---------------		Plants ha^{-1}		--------------------	
8509/UTC	61513	b §	63200	b	73700	a
8509/D	68750	a	68400	b	75300	a
9307/UTC	41447	b	70700	a	74300	a
9307/C	59211	a	64500	a	70100	a
9307/D	57237	a	69400	a	75000	a

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC=uncoated, C=coating C, D=coating D.
‡ Planting dates
§ Data followed by the same letter within a planting date and Hybrid are not significantly different according to a protected LSD (0.05) test.

Grain Yields

Grain yields for the different coating treatments and planting dates were analyzed to determine whether polymer coated seed after early planting would result in higher grain yields relative to untreated seed. Barren plants were not a major factor affecting corn yield. The percent barren plants were low (< 2.5%) in both 2000 and 2001 and was not affected by the different coating treatments, Hybrids or planting dates (Appendix B.17, B.18). Diplodia ear rot infection was apparent in 2000 and the infection percentage was affected by planting date ($P < 0.01$) and Hybrid ($P < 0.01$) (Appendix B.19). Early and intermediate planting dates resulted in higher infections (Table 17). However, infection only ranged from 2 to 5%. Overall, Hybrids 8509 and 9307 averaged 5.8 % and 1.8 % infection respectively. Mean weight reduction by diplodia was calculated, and relative to healthy ears, a mean weight loss of 60% was observed. This means, that for a 5% infection, a yield reduction of only 3% can be expected.

Table 16. Planting date effect on diplodia ear rot infection in 2000.

Date	Diplodia Infection		
	(sqrt)		(%)
28-Mar	1.82	a †	4.85
14-Apr	1.62	a	4.79
16-May	0.74	b	1.73

† Data followed by the same letter within planting date are not significantly different according to a protected LSD (0.05) test.

In 2000, leaf rust and stalk rot, as well as strong winds prior to harvest, affected the amount of lodging present. The interaction of date x Hybrid for the percentage of lodged plants was significant ($P < 0.01$) (Appendix B.20). The percent lodged plants ranged from 1.3 to 2.5 for Hybrid 9307, and from 3 to 8.2 for Hybrid 8509. For the early and the intermediate planting date, Hybrid 8509 had more lodged plants than 9307.

Hybrid differences were not evident on the late planting date. In 2001, the incidence of lodging was minimal for all planting dates.

Overall grain yields in 2000 averaged 10.7, 10.5 and 9.5 Mg ha^{-1} for early, intermediate, and late planting, respectively. The only significant ($P < 0.05$) interaction affecting grain yield was planting date x Hybrid (Appendix B.23). No significant differences between Hybrids occurred when planted early, but Hybrid 9307 yielded 1.5 to 1.6 Mg ha^{-1} higher than 8509 for the intermediate and late planting dates (Table 18). The yield advantage for 9307 was not due to population, since 8509 achieved significantly higher populations in all planting dates.

Table 17. Effect of Hybrid on grain yield in 2000.

Hybrid	Grain Yield		
	28-Mar†	14-Apr	16-May
	------------------	(Mg ha^{-1})	------------------
8509	10.5 a‡	9.8 b	8.7 b
9307	10.9 a	11.3 a	10.3 a

† Planting dates.

‡ Data followed by the same letter within planting date are not significantly different according to a protected LSD (0.05) test.

The general lack of significance for yield contrasts in 2000 suggests that yields achieved in the first planting date (for coated and uncoated seed) were never lower than for the second planting date (Table 19). Moreover, no yield benefits were gained by planting coated seed when planting early.

Table 18. Effect of coating treatments on grain yield (based on 15.5% moisture) for different planting dates in 2000.

Treatment †	Grain Yield		
	28-Mar ‡	14-Apr	16-May
	----------- Mg ha^{-1} -----------		
8509/UTC	10.6	9.4	8.8
8509/A	10.2	9.6	8.6
8509/B	10.7	10.2	8.7
9307/UTC	10.8	11.7	10.7
9307/A	10.7	11.4	10.2
9307/B	10.8	11.3	10.1

Treatment Comparisons †	Significance	
	Within Hybrid 9307	Within Hybrid 8509
PD 1 (A + B) vs PD 2 (A + B)	NS	NS
PD 1 (A + B) vs PD 2 (UTC)	NS	NS
PD 1 (A) vs PD 2 (UTC)	NS	NS
PD 1 (B) vs PD 2 (UTC)	NS	*
PD 1 (UTC) vs PD 2 (UTC)	NS	NS

* Significant at the 0.05 probability levels.

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC=uncoated, A=coating A, B=coating B, PD1= planting date 1, PD2=planting date 2, PD3= planting date 3.

‡ Planting dates.

In 2001, overall grain yields averaged 10.6, 12.1 and 11.4 Mg ha^{-1} for early, intermediate and late planting dates respectively (data not shown). The planting date x treatment interaction was significant ($P < 0.01$) (Appendix B.24). This was probably due to the stand reduction of early plant corn after frost. With early planting, uncoated seed yielded 1.8 Mg ha^{-1} less than coated seed for 9307 (attributed to low populations) but no significant yield loss in Hybrid 8509 was observed (Table 20).

Table 19. Effect of coating treatments on grain yield (based on 15.5% moisture) for different planting dates in 2001.

Treatment †	Grain Yield		
	2-Apr‡	19-Apr	11-May
	----------------------	Mg ha^{-1}	----------------------
8509/UTC	12.6 a§	12.7 a	11.1 a
8509/D	13.3 a	12.1 a	12.0 a
9307/UTC	7.9 b	11.9 a	11.0 a
9307/C	9.4 ab	12.2 a	11.5 a
9307/D	9.7 a	11.9 a	11.3 a

Treatment Comparisons †	Significance	
	Within Hybrid 8509	Within Hybrid 9307
PD 1 (C + D) vs PD 2 (C + D)	NA	**
PD 1 (C + D) vs PD 2 (UTC)	NA	**
PD 1 (C) vs PD 2 (UTC)	NA	**
PD 1 (D) vs PD 2 (UTC)	NS	*
PD 1 (UTC) vs PD 2 (UTC)	NS	**

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

NA= not applicable.

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC=uncoated, C=coatingC, D=coating D, PD1= planting date 1, PD2=planting date 2, PD3= planting date 3.

‡ Planting dates

§ Data followed by the same letter within planting date and Hybrid are not significantly different according to a protected LSD (0.05) test.

In 2001, coated and uncoated seed treatments of 8509 on the first planting date were not different in yield from that after the second planting date (Table 20). Although coated treatments of 9307 increased yields with early planting, the latter yields were still significantly lower than for seed planted during the intermediate date (Table 20) (regardless of the coating treatment). These results suggest that Hybrid response to early stress conditions was a more important factor in final yield determination than polymer seed coatings themselves. Polymer coatings may result in some yield benefits when post-emergence frosts occur, but that alone does not guarantee that yields will be at least to corn planted in the optimum period.

Results suggest sub-optimal plant densities reduced the use of incident radiation by the canopy, and increased kernel number per ear could not overcome yield loss from low plant densities. When sub-optimal plant densities are experienced, corn presents a relatively low capacity to differentiate additional reproductive sinks in response to higher plant CGR (Edmeades and Daynard, 1979a). Edmeades and Daynard (1979b) observed that partitioning of total assimilates produced per plant at silking only produced a slight increase in the number of kernels per ear when plant density was lowered from 10 to 5 plants m^{-2}. Moreover, Andrade *et al.* (1993) found that reducing plant density from 6 to 22 plants m^{-2} only increased number of kernels per plant by 21%. Although reductions in plant density are usually associated with small increases in kernel weight (Andrade, 1996). This suggests that at sub-optimal plant densities, changes in kernels per ear or kernel weight are not likely to compensate for stand reduction.

In previous research with polymer-coated corn, Hicks *et al*. (1996) found that grain yields were increased with seed coating at Lafayette, IN, when corn was planted in early in April, due to higher stand establishment achieved with coated seed. However in the current study only in 2001 uncoated seed experienced significantly lower populations for early-planted corn, thus, only yield differences among coating treatments were expected for 9307 for that year, since 8509 did not experienced a population loss as extreme as 9307.

In a conventional tillage system, Gesh *et al*. (2001) observed corn yield gains of up to 22% with coated seed for March (2000) planting date in Morris (MN) associated with improved corn plant populations, but in another experiment (Gesh et al. 2001) with a no-till system, yield benefits from using coated seed was smaller (about 0.5 Mg ha-^{1}) in comparison to uncoated seed. These lower differences might be attributed to the fact that early stress was much higher in the no-till system than in the conventional tillage system and, even with the coating, seedlings were under stress.

An interesting result in our experiment is that planting date had no significant effect on yield in either year. In contrast, many authors have observed yield reductions as planting date was advanced or delayed from the optimum stages (Cirilo and Andrade 1994a; Nafziger, 1994; Bollero *et al.*, 1996; Swanson and Wilhelm, 1996). Late planting is associated with high crop growth rates during the vegetative period but also high respiration rates, due to the large amount of accumulated biomass and high temperatures during that period (Penning de Vries, 1975). However, in our study late plantings were only 10 days later than the end of the optimum planting period; thus, negative effects were not expected to be very large. Swanson and Wilhelm. (1996) and Lauer *et al*. (1999) found that yield declined with earlier or later planting in comparison to the optimum date: yield declined more rapidly when planting was delayed than when planting was advanced.

In general, polymer coatings did not result in higher grain yield relative to uncoated seed, except for the early planting date in 2001, when corn with coated seed of Hybrid 9307 resulted in yield gains of from 15-18 % due to larger frost damage experienced by the uncoated seed treatment. On the other hand polymer coated treatments after late planting were not associated with a yield loss in comparison with uncoated treatments in either year.

Summary

The hypothesis of this study were that: 1) soil temperature sensitive polymers applied to corn seed coats delay emergence and reduce plant-to-plant variability in emergence, relative to uncoated corn seed, when corn is planted early; 2) more uniform stands achieved with polymer-coated corn will reduce risks associated with early planting, plus improve overall corn yields, compared to early planting of uncoated seed; 3) the benefits of temperature-activated polymer coatings will be more evident as stress increases; and 4) the temperature- activated polymer will not have a negative impact on yields of corn planted past the optimum date.

In both years temperature-sensitive polymer coatings delayed corn emergence, relative to uncoated seed by 2 to 5 days. After early planting, polymer coatings never increased total number of seedlings emerged in either year, but improved final established stands in 2001, mid-April frosts reduced the stand of uncoated seed treatment by 38% for Hybrid 9307, and by 13% for 8509. Coated seed treatments were less affected by frost since only 50% of the seedlings had emerged when freezing temperatures occurred.

Polymer coating effects on emergence uniformity were inconsistent. With early planting in 2000, coated seed of Hybrid 8509 actually increased emergence uniformity relative to uncoated seed. However, emergence rate was less uniform with coated seed of both Hybrids in 2001 relative to uncoated seed. Polymer seed coatings had no impact on plant spacing variability, except in 2001, when treatments affected by frost resulted in high plant-to-plant variability due to stand reductions.

Emergence delays resulting from polymer-coating treatments resulted in height and v-stage differences relative to the control. Uncoated seed of early planted corn usually resulted in taller plants at 6 and 8 weeks after emergence due to earlier emergence. In general, there was no difference in plant uniformity among coating treatments (height and v-stages).

Time to silk emergence was affected by both planting date and Hybrid, but not by coatings. Hybrid 8509 averaged 3 more days to reach 50% silk emergence in both years. Polymer coatings did not improve silk emergence uniformity.

At harvest uncoated seed resulted in somewhat lower grain moisture contents at the time of harvest relative to coated seed, but reductions were not always significant. Polymer seed coatings did not affect corn yield performance in 2000. In 2001, significant differences among coating treatments were observed only in early planting. Stand reduction associated with uncoated seed resulted in reduced yields compared to those ones of the coating treatments. In contrast, Hybrid 8509, which behaved as a more cold tolerant genotype, resulted in no yield differences between coating treatments.

In conclusion, the use of polymer coatings delayed emergence. Polymers did not increase number of seedlings emerged, but resulted in higher plant populations when post-emergence frosts reduced corn stand establishment of uncoated seed in early planting treatments. Hybrid differences in susceptibility to early season stress conditions were evident. Polymer coatings helped ensure adequate stands in early planting (> 90% of that seeded) in 2001, but could not ensure that final yields would be at least equal to those of uncoated seed planting during optimum planting period.

CHAPTER TWO- INDIVIDUAL PLANT RESPONSE TO EMERGENCE VARIABILITY IN CORN RESULTING FROM HYBRID, PLANTING DATE AND POLYMER COATING VARIABLES

Abstract

Early planting can lead to poor stand establishment in corn due to stresses imparted by cold, wet soils. Polymer seed coatings have recently been advocated for early planting situations. The polymeric material undergoes a temperature-dependent phase change, which increases the water permeability of the material when favorable soil temperatures occur in the seed zone. Polymer seed coatings may improve corn stand establishment by postponing emergence, but within-row variability in emergence may still have negative effects on corn yields. Our objectives were to investigate the effects of within-row variability in emergence resulting from polymer seed coatings, Hybrids and planting dates on subsequent developmental and yield variability of individual corn plants.

Field experiments were established following soybean in rotation, on a poorly drained, dark prairie soil (mesic Typic Haplaquolls) in west central Indiana. Two corn Hybrids (Fielder’s Choice 9307 and 8509) were no-till planted on three dates representing early (28 March 2000, 2 April 2001), intermediate (14 April 2000, 19 April 2001) and late (16 May 2000, 11 May 2001) planting dates. Each Hybrid had the following coating treatments in year 2000: the control (UTC), coating A (2 % of seed weight), coating B (3 % of seed weight), and in 2001: the control (UTC), coating C

(slightly different polymer than in 2000, 2 % of seed weight), coating D (same polymer as in 2000, 2.5 % of seed weight).

Relative emergence of plants within a row affected subsequent early plant height and v-stages of individual plants. Later emerging plants tended to be shorter and develop later than their earlier emerged counterparts within the row. However, final heights of individual plants showed almost no relationship with emergence delays. Silking delays were somewhat associated with emergence delays, but relative heights during the vegetative growth stage affected silk emergence more than emergence delays. Moreover, taller mature plants were not associated with earlier silking. Individual corn plant yield was affected more by plant-to-plant variability in development later in the season than by variability in emergence, and emergence differences appear to exert only a minor influence on variability in later season growth. Plants within a row that silked earlier had higher grain yield, but individual plant grain yields were more related to height (during vegetative growth as well as final height). Variation in plant spacing per individual plant showed no strong relationship with yield. Early and final height had a much stronger relationship with individual yield than any other variable. Hybrids or polymer coatings had much less influence on these relationships. Planting date was the factor that most influenced the magnitude of the relationship between individual grain yield and emergence, early growth or development.

More studies of individual plants are required to identify factors besides emergence that influence relative plant size and grain yield of adjacent plants in a corn community.

Introduction

The optimum planting period in west-central Indiana is from April 20 to May 5, and corn producers are very reluctant to plant corn earlier, even when soil conditions are sufficiently dry to achieve a suitable seedbed. The major concerns associated with early planting are the risks associated with corn emergence before a late killing frost, the risk of a significant reduction in plant population due to pests and other factors, as well as the risk of excessive variability in emergence and subsequent development of adjacent plants.

Uneven emergence of corn may occur because of variable moisture in the seed zone, uneven planting depth, soil compaction, seed zone temperature differences, or variable plant residue cover in the row zone. Differences in plant size early in the season have been shown to continue into later stages of corn development (Landi and Crosbie, 1982). Adjacent plants of unequal height can be detrimental to grain yield. Variability in plant size for adjacent plants of a consistent Hybrid has been associated with yield loss (Glenn and Daynard, 1974).

Intensive research on delayed emergence effects on corn grain has been conducted in Illinois and Wisconsin (Nafziger *et al.*, 1991). Emergence delays due to delayed planting intervals (within the row) of approximately 10 to 21 days resulted in yield reductions of from 6 to 22 % compared to a full stand of normal emergence (based on common planting dates from April 30 to May 15). The extent of yield reduction varied with the proportion of late emerging plants compared to normal emerging plants. However, even in this detailed study, there was no measurement of the uniformity of emergence amongst plants seeded on the same day. Thus readers can not conclude much about the effects of emergence variability within a common planting date. Neither was there any assessment of individual plant yields resulting from delayed planting.

Another component of stand establishment variability is spacing variability. Dr. R. Nielsen of Purdue University has conducted numerous studies from 1987 to 1993 and concluded that approximately 62 kg/ha are lost for every 1 cm increase in the standard deviation of plant-to-plant spacing (Nielsen, 1997). Conversely, Muldoon and Daynard (1981) suggested that variability in intra-row spacing, to the extent likely to be encountered in most commercial maize fields seeded with properly adjusted planters, had no significant effect on grain yield when overall plant populations were constant. A greater importance was suggested for variability in seedling size, which is presumably related to non-uniformity in seed depth, seedbed preparation or seedling vigor.

Recently patented, temperature-activated polymer seed coatings can be used for Hybrid corn seed to enable earlier planting, but delayed germination of corn seed until soil temperatures are more favorable. Relative to uncoated seeds, temperature-sensitive polymers applied to corn seed coats could reduce plant-to-plant variability in emergence when corn is planted early, by delaying emergence until soil conditions become warmer. If more uniform stands can be achieved with polymer-coated corn, risks associated with early planting could decrease and corn yields might increase, compared to early planting of uncoated seed.

Uneven emergence of plants within rows is considered one of the biggest risk factors of early planting. However, comparatively few studies have described the relationship and magnitude of different individual plant growth and development variables, or their dependence on variability in emergence date itself. The purpose of this study was to investigate the effects of within-row variability in emergence resulting from polymer seed coatings, Hybrids and planting dates on subsequent developmental and yield variability of individual corn plants.

Materials and Methods

The study was conducted at the Agronomy Research Center (ARC) in west central Indiana (40º28’ N Lat., 86º59’ W Lon.). Corn treatments were after soybean in rotation in 2000 and 2001. The soil is a Drummer silty clay loam to clay loam characterized as somewhat poorly to poorly drained (mesic Typic Haplaquolls).

The experiment was with a split-plot arrangement of a randomized complete block with 6 treatments in 2000, and 5 treatments in 2001. Each plot consisted of 8 rows 0.76 m apart and 15 m in length. Planting dates were whole units, and Hybrids and seed coatings were subunits. This experiment involved a comparison of two different Hybrids, Fielder’s Choice 9307 (106 days relative maturity) and 8509 (109 days relative maturity), with two coatings and one control in year 2000, but two coatings and one control for FC 9307 and one coating and one control for FC 8509 in 2001. A detailed description of the coating treatments is listed below.

Main Treatments:

Three planting dates of:

4. Early: 28 March 2000, 2 April 2001.
5. Intermediate: 14 April 2000, and 19 April 2001.
6. Late: 16 May 2000, 11 May 2001.

Sub-Treatments:

In 2000, two Hybrids from Fielder's Choice Direct with two coatings treatments and one control:

7. FC 9307 untreated
8. FC 9307 coating A
9. FC 9307 coating B
10. FC 8509 untreated
11. FC 8509 coating A
12. FC 8509 coating B

Coating A and B were the same coating, but applied at either 2 % of seed weight (A) or 3 % of seed weight (B).

In year 2001, the same Hybrids were used with the following treatments:

6. FC 9307 untreated
7. FC 9307 coating C
8. FC 9307 coating D
9. FC 8509 untreated
10. FC 8509 coating D

Coating D consisted of the same polymer than in 2000, but applied at a 2.5 % of the seed weight. Coating C consisted of a different polymer than the one used in 2000, applied at 2% of the seed weight. Coating treatments were changed in 2001 only because Landec, Ag, (Monticello, IN) was unable to provide identical polymer coatings on those in 2000. All seed was treated with the fungicides captan, metalaxyl, thiram.

Cultural Practices

Corn was no-till planted at 80,000 seeds/ha with a Case-IH 955 planter. All experiments followed soybeans in rotation. A starter fertilizer of 107 kg ha $^{-1}$ (34-0-0) was applied and a sidedress application of 160 kg ha^{-1} as Anhydrous Ammonia was applied at the V4 to V6 corn growth stage (Hoeft et al., 2000). The insecticide deltametryna was applied with the planter at a rate of 6 kg ha $^{-1}$. The following pre-emergence herbicides were applied: acetochlor + atrazine at 5.8 L/ha, glyphosate at 1.7 L/ha, and paraquat at 3.5 L/ha.

Corn Measurements

Individual plant measurements were taken for each plant in two rows of 5 m length. The number of days until 50% emergence was reached was determined by counting the total number of plants (coleoptiles) emerged on a daily basis in two rows 5-m long per plot (emergence rows). Emergence was considered to be final when the count did not change for 7 consecutive days. The days to 50% emergence and from 10 to 90% emergence were calculated after determining the total number of plants in the emergence rows once emergence was completed. The total number of plants in the total 10 m row length ranged from 45 to 60, except for early planting in 2001, where number of plants was reduced by frosts.

Plant height was measured four weeks after emergence for each plant within a plot's sampling area from ground level to the uppermost fully extended leaf. The standard deviation of corn height was calculated for each treatment. The distance between plants in each emergence row was measured in order to evaluate the plant spacing and its relationship with individual plant yield. The space available for each plant was calculated as the average of the distance to the plant preceding and following it within the row. In 2000 due to late measurement time only 60% of the data were used for the analysis.

Individual plant developmental stages in each of the emergence rows were recorded twice during the growing season, measurement occurred 6 and 8 weeks after emergence for the early planting date, and 4 and 6 weeks after emergence for intermediate and late planting.

Silk emergence counts were also recorded for each individual plant belonging to the emergence row. Plants were checked on a daily basis for silk emergence. Days from planting to 50 % emergence, and the range from 10 to 90 % silking were calculated for each treatment.

Corn grain yield was determined by hand harvesting the two 5m emergence rows per plot. In 2000, plots were harvested on September 20 for the first and second planting dates and September 30 for the third planting date. In 2001, corn was harvested on September 18, 27, and November 6, for the first, second and third planting dates respectively. The samples were mechanically shelled and then weighted. Yields were adjusted to 15.5 % moisture content. Individual plant grain moisture content was determined with a Farmex MT3 moisture meter.

Individual data of each measurement were utilized to calculate simple linear regressions. Days from planting to emergence and silking were transformed to “relative emergence time” and “relative silking time”, by taking the first plant to emerge in the plot as day one and the last plant to emerge as the last day. Hereinafter days from the first emerged/silked plant to the last one will be referred as “relative emergence time” and “relative silking time”.

Statistical Analysis

Within each plot, simple linear regression relationships were determined among the total number of plants measured in the emergence rows. The purpose of performing those specific regressions was to evaluate whether early development (emergence, early height or V-stages) would have a lower influence on individual plant grain yield than later development variables, such silking time or final height, as well as to understand the possible relationships existing among all variables measured.

Four groups of relationships were explored:

Independent variable	**Dependent variable**
Relative emergence time	Relative silking time Height at 4-6 weeks Height at 6-8 weeks Final height V-stage at 4-6 weeks V-stage at 6-8 weeks
Height at 4-6 weeks	Final height
Height at 6-8 weeks	Final height
Height at 4-6 weeks	Height at 6-8 weeks
Relative emergence time Height at 4-6 weeks Height at 6-8 weeks Final height V-stage at 4-6 weeks V-stage at 6-8 weeks	Relative silking time
Relative emergence time Relative silking time Height at 4-6 weeks Height at 6-8 weeks Final height V-stage at 4-6 weeks V-stage at 6-8 weeks Plant spacing	Individual plant grain yield

The percent of total plots with significant regression slopes was calculated for each regression, as well as the mean slope and mean R^2 of the significant regression. Statistical analysis to determine treatment effects on the regressions slopes was performed using SAS (SAS Institute). Within each planting date ANOVA were performed on the slopes of the relationships involving height or V-stages at 4-6 or 6-8 weeks after emergence (except for regressions among heights at different measurement times, where no analysis was performed). All other relationship's slopes were analyzed for the entire split-plot experiment. Fisher's protected LSD ($P < 0.05$) mean separation tests were performed where appropriate.

Results and Discussion

Variation of height and developmental stages as a function of relative emergence time

In both years, days from 0 to 100 % emergence ranged from 10 to 15 depending on the treatment. However, the number of days from 10 to 90 % ranged from 3 to 9 days. In 2000, 74 % and 67 % of the regressions of plant height at 4-6 weeks and 6-8 after emergence on relative emergence time were significantly different than zero ($P < 0.1$) respectively (Table 21). In 2001, 50 and 32% of the regressions of plant height at 4-6 and 6-8 weeks on relative emergence time were significant ($P < 0.1$) respectively. Overall, when slopes were significant, height was negatively correlated to relative emergence time in both years (Table 21).

For final height, only 19 % and 15% of the regressions presented significant slopes ($P < 0.1$) in 2000 and 2001, respectively (Table 21). This suggests that final height was not as highly related with relative time to emergence, and that later-developing plants were not necessarily shorter than their early-emerging neighbors. Only 11-12% the variability in plant height was explained by variation in the corresponding plant's emergen00000ce.

0In terms of developmental stages, 69 % and 76 % of the regressions of v-stages at 4-6 weeks after emergence and 6-8 weeks after emergence on relative time to emergence showed slopes different than zero ($P < 0.1$) in 2000. In 2001 fewer significant slopes were observed for the same type of regressions (Table 21). Overall, the relationship of significant regressions showed developmental stages to be negatively associated with relative emergence time.

Table 20. Percent of significant slopes (*P* < 0.1) of regressions of height and developmental stages as a function of relative emergence time and mean slopes and R^2 of significant regressions in 2000 and 2001.

Dependent Variable	Significant Regressions (%) P value			Mean Slope	Rsquare
2000	0.01	0.05	0.1		
Height (4-6 weeks)				(cm/day)	
	54	71	74	-1.92	0.22
Height (6-8 weeks)				(cm/day)	
	46	60	67	-2.72	0.21
Final Height				(cm/day)	
	6	13	19	-1.35	0.11
V-stage (4-6 weeks)				(v-stage/day)	
	44	61	69	-0.11	0.17
V-stage (6-8 weeks)				(v-stage/day)	
	57	71	76	-0.17	0.21
2001					
Height (4-6 weeks)				(cm/day)	
	23	35	50	-1.85	0.16
Height (6-8 weeks)				(cm/day)	
	18	28	32	-2.55	0.17
Final Height				(cm/day)	
	3	12	15	0.65	0.12
V-stage (4-6 weeks)				(v-stage/day)	
	23	38	43	-0.10	0.17
V-stage (6-8 weeks)				(v-stage/day)	
	15	28	42	-0.14	0.15

Analysis of variance on the slopes was performed in order to see whether planting dates, Hybrid or coatings affected the slopes differently. Most treatment main effects on the slopes of the regressions of early height or development stages as a function of relative emergence time were not significant (*P* < 0.05) in either year (Appendix D.1-D.4).

In 2000, slopes of regressions of final height as a function of relative time to emergence was significantly affected by the interaction of planting date x Hybrid (*P* < 0.01) (Table 22) (Appendix D.5). Individual plant height of Hybrid 8509 seemed to be more negatively affected by emergence date after late planting. In 2001, neither treatment main effects nor planting date x treatment interaction were significant ($P > 0.05$) (Appendix D.6).

Table 21. Hybrid effect on the slopes of final plant height as a function of relative emergence time in 2000.

Hybrid	28-Mar†	14-Apr	16-May
	-------------------	(cm/day)	------------------
8509	0.12 a‡	-0.24 a	-1.93 b
9307	0.88 a	-0.55 a	0.84 a

† Planting dates.
‡ Data followed by the same letter are not significantly different according to a protected LSD (0.05) test.

Results suggest that relative emergence time had a larger effect on early height and development than individual final plant. It seems, therefore, that final height was influenced by other factors other than emergence alone. In addition, early planting dates and uncoated seed treatments did not influence the dependency of a corn plant's subsequent height or vegetative development on relative emergence time than late planting dates or polymer-coated seed.

Relationships of height at different measurement times

In order to determine whether final height was related to height at earlier developmental stages, regressions of final height on height at 4-6 or 6-8 weeks after emergence were calculated. Height at 6-8 weeks after emergence was also regressed against height at 4-6 weeks after emergence.

Final heights of individual plants appeared to be relatively unrelated to corresponding heights during vegetative growth since the percent of significant regression slopes ranged from just 20-60% (Table 23). Final heights were less dependent on earlier heights in 2001 than in 2000. However, when heights at 6-8 weeks were regressed against height at 4-6 weeks a very relationship was observed in both years (Table 24). Results therefore suggest that those plants that were shorter at 4-6 weeks, tended to remain shorter throughout the season (6-8 weeks) until onset of flowering, when final height was not much related with earlier height. Daynard and Muldoon (1983) observed similar results in a study on plant-to-plant variability of maize. They observed that taller plants at four sampling times during vegetative growth remained taller but only until flowering had commenced. The reduced differential in final height occurred because initially short plants also flowered late; the additional days of vegetative growth enabled these plants to recoup much of their initial disadvantage in height. The contribution of tassel length to these final height measurements was not determined in our study.

Table 22. Percent of significant ($P < 0.1$) slopes of regressions of final height as a function of height at 4-6 or 6-8 weeks after emergence and mean slopes and R2 of significant regressions in 2000 and 2001.

Independent Variable	Significant Regressions (%) P value			Mean Slope	Rsquare
2000	0.01	0.05	0.1		
Height (4-6 weeks)				(cm/cm)	
	25	44	51	0.29	0.14
Height (6-8 weeks)				(cm/cm)	
	43	53	60	0.23	0.21
2001					
Height (4-6 weeks)				(cm/cm)	
	5	18	20	0.013	0.12
Height (6-8 weeks)				(cm/cm)	
	17	25	27	0.019	0.17

Table 23. Percent of significant ($P < 0.1$) slopes of regressions of plant height at 6-8 weeks as a function of height at 4-6 weeks after emergence in 2000 and 2001.

Year	Significant Regressions (%)			Mean Slope	Rsquare
	P value				
	0.01	0.05	0.1		
2000				(cm/cm)	
	94	96	97	0.99	0.49
2001				(cm/cm)	
	82	85	88	0.97	0.44

Regressions of relative silking time

Relative silking time was significantly dependent on relative emergence time in 65% (2000) and 52% (2001) of the plots (Table 25). Relative time to silking was even more frequently dependent on plant height at 4-6 weeks and 6-8 weeks after emergence and on v-stages at 6-8 weeks (Table 25). The negative slopes indicate that shorter plants and later-developing plants also silked later. Relative time to silking was negatively related to both v-stage measurements (Table 25). Plant final height appeared to be the variable that was the least related to relative silking time in both years (Table 25). The latter results coincide with the ones found for the regressions of final height as function of relative emergence time (Table 21), where very few regressions were significant. This suggests that taller plants early in vegetative development tended to silk earlier than shorter plants, and that final height was not necessarily associated with early development rates. This in agreement with results of Daynard and Muldoon (1983). They observed that taller plants which during vegetative growth flowered earlier than their shorter counterparts, but that final height was not strongly related to dates of flowering.

Table 24. Percent of significant slopes ($P < 0.1$) of regressions of days to silking as a function of relative time to emergence, height and developmental stages, and mean slopes and R^2 of significant regressions in 2000 and 2001

Independent Variable	Significant Regressions (%) P value			Mean Slope	Rsquare
2000	0.01	0.05	0.1		
Relative emergence time				(days/day)	
	42	61	65	0.62	0.18
Height (4-6 weeks)				(days/cm)	
	86	93	93	-0.22	0.32
Height (6-8 weeks)				(days/cm)	
	71	86	86	-0.15	0.31
Final Height				(days/cm)	
	15	31	31	0.04	0.13
V-stage (4-6 weeks)				(days/v-stage)	
	34	51	58	-2.26	0.19
V-stage (6-8 weeks)				(days/v-stage)	
	82	92	94	-2.05	0.27
2001					
Relative emergence time				(days/day)	
	23	42	52	0.61	0.17
Height (4-6 weeks)				(days/cm)	
	80	81	90	-0.22	0.35
Height (6-8 weeks)				(days/cm)	
	73	81	88	-0.20	0.34
Final Height				(days/cm)	
	12	30	35	0.07	0.15
V-stage (4-6 weeks)				(days/v-stage)	
	48	62	70	-2.58	0.22
V-stage (6-8 weeks)				(days/v-stage)	
	58	70	75	-2.24	0.29

In 2000 and 2001, regression slopes of days to silking as a function of days to emergence were significantly affected by planting date ($P < 0.01$) (Appendix E.5, E.6). Consistently in both years, slopes were smallest for the early planting and largest for the latest planting dates (Figure 17). These results suggest that silking was less dependent on a plant’s relative emergence time with very early planting. The smaller dependency of silking time with emergence may be due to the fact that early planted corn had a longer growing season to “catch up” in development and that air GDD per day of emergence delay would have been higher progressively later planting dates. In 2001, frost affected early-emerged plants; thus, the emergence date effect on later development might have been diminished.

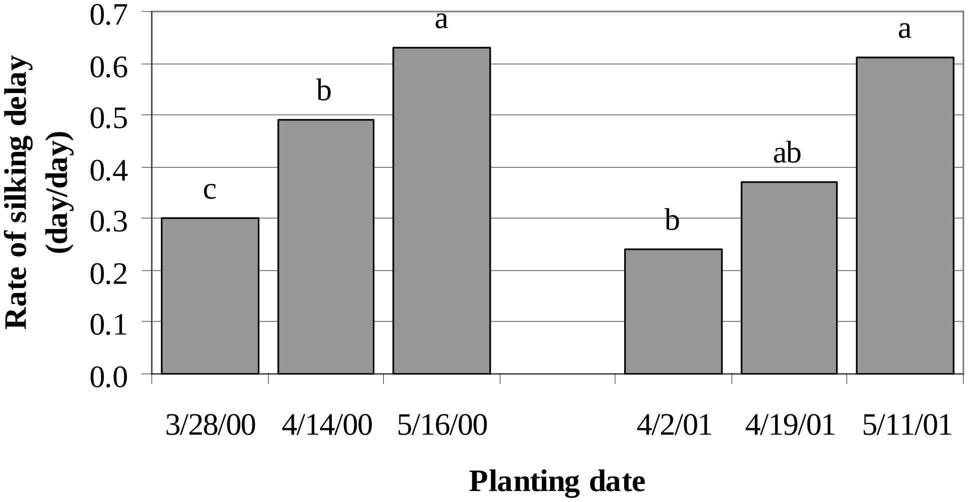


Figure 17. Mean rate of relative silking time as a function of increasing time to emergence, relative to their neighbors within row, for corn plants in 2000 and 2001. Data followed by the same letter within year are not significantly different according to a protected LSD (0.05) test.

In 2001 relative silking time as a function of relative emergence time was also affected by treatment (Figure 18). Overall, uncoated seed of Hybrid 8509 had more silking delay per emergence day delay than coated seed. No differences among coating treatments existed for 9307, however, in both Hybrids the same tendency was apparent, and reasons for these results are unclear. In 2000, Hybrids and polymer coatings treatments did not affect the dependency of silking on emergence (data not shown).

Statistical analysis on the slopes of relative time to silking as a function of height and v-stages at 4-6 and 6-8 weeks after emergence in 2000 and 2001, resulted in no significant main effects for majority of the cases (*P* > 0.05) (Appendix E.1-E.4). This suggests that polymer coatings or Hybrids did not have much influence on the slopes of the relationship between days to silking and height or v-stages.

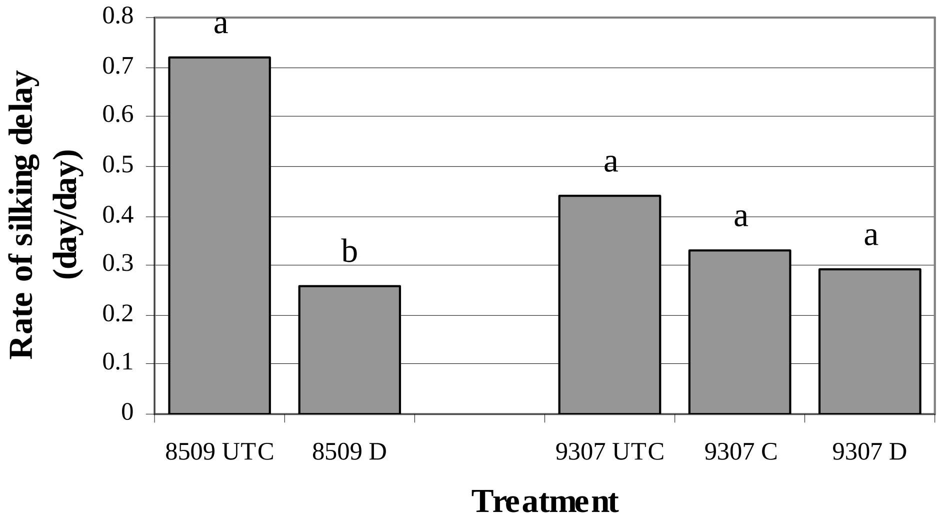


Figure 18. Mean rate of relative silking time as a function of increasing time to emergence, relative to their neighbors within row, for corn plants in 2001.
Data followed by the same letter within Hybrid are not significantly different according to a protected LSD (0.05) test.

In 2000, slopes of relative time to silking as a function of final height were not significantly affected by planting date, Hybrid or coating treatments ($P > 0.05$) (Appendix E.5). In 2001, treatment main effect was significant ($P < 0.05$) (Appendix E.6). Uncoated treatment of Hybrid 8509 seemed to be more dependent on relative silking time (Figure 19) and final height (Figure 19) than 9307.

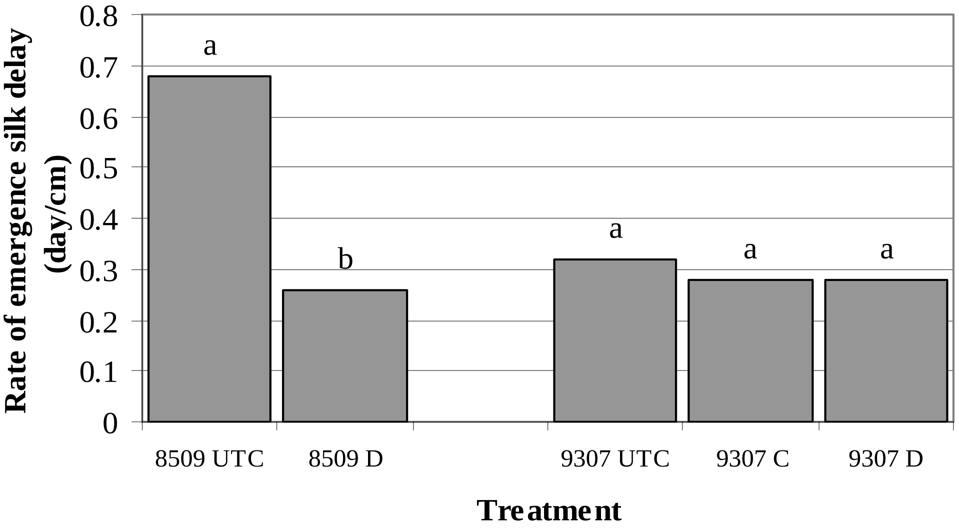


Figure 19. Mean rate of relative silking time as a function of plant final height, relative to their neighbors within row, for corn plants in 2001.
Data followed by the same letter within Hybrid are not significantly different according to a protected LSD (0.05) test.

Results suggest that relative time to silking was more dependent on early height than emergence time and final height. Silking was less dependent on emergence time with early than late planting. Moreover, this relationship was occasionally dependent on final height. Silking of individual plants was more affected by many post-emergent factors, and it is too simplistic to conclude that delayed silk emergence resulted of initial emergence delay alone.

Regressions of yields

Individual plant grain yield variation and relative time to emergence was significantly associated in 28 (2000) and 18% (2001) of the total regressions, respectively ($P < 0.1$) (Table 26). This suggests that, for the most part, plants that emerged later were not necessarily lower in yields than earlier emerged plants. In fact, in the majority of the cases, individual plant yields were dependent on factors other than relative emergence time. It has long been recognized that variable emergence could result in non-uniform stands, where bigger or taller plants would have a competitive advantage over smaller or shorter plants (Glenn and Daynard, 1974; Daynard and Muldoon 1983). However, differences in size are usually the result of interactions among several factors in addition to variable emergence, such as genetic differences, environmental heterogeneity, maternal effects, and differential effects of parasites or pathogens (Weiner and Thomas, 1986).

Several authors have studied the effect of emergence uniformity on corn grain yield (Ford, 1987; Glenn and Daynard, 1974; Ford and Hicks, 1992; Nafziger, 1991; Wu., 1998). Emergence delays in these studies, however, were artificially induced by delaying planting of certain plants within a row, or rows within a plot. Most of these authors found a decline in yield per unit area due to delayed emergence in comparison to stands with a uniform planting date. However, conclusions from these previous investigations were based on extreme cases of non-uniform stands, and individual plant yields were not determined. Since only 20 % of the total regressions of yield as a function of time to emergence were significantly related in this research we conclude that variability in emergence resulting from a common planting date (non-uniformity in seeding depth, seedbed soil properties, or seedling vigor, etc.) might not be large enough as to exert a major effect on individual plant grain yield.

Table 25. Percent of significant slopes ($P < 0.1$) of regressions of individual plant yield as a function of relative time to emergence, relative time to silking, spacing, height and developmental stages, and mean slopes and R^2 of significant regressions in 2000 and 2001.

Independent Variable	Significant Regressions (%) P value			Mean Slope	Rsquare
2000	0.01	0.05	0.1		
Relative emergence time				(g per plant/day)	
	13	24	28	-8.04	0.13
Relative silking time				(g per plant/day)	
	46	63	72	-6.36	0.21
Height (4-6 weeks)				(g per plant/cm)	
	64	68	75	2.68	0.23
Height (6-8 weeks)				(g per plant/cm)	
	63	71	76	1.99	0.25
Final Height				(g per plant/cm)	
	60	71	74	1.3	0.24
V-stage (4-6 weeks)				(g per plant/v-stage)	
	18	31	33	32.01	0.14
V-stage (6-8 weeks)				(g per plant/v-stage)	
	41	57	64	17.59	0.17
Plant Spacing				(g per plant/cm)	
	9	18	22	1.9	0.21
2001					
Relative emergence time				(g per plant/day)	
	10	13	18	-10.95	0.15
Relative silking time				(g per plant/day)	
	38	54	70	-7.72	0.22
Height (4-6 weeks)				(g per plant/cm)	
	48	58	65	2.70	0.19
Height (6-8 weeks)				(g per plant/cm)	
	57	73	78	2.10	0.23
Final Height				(g per plant/cm)	
	32	47	52	1.32	0.21
V-stage (4-6 weeks)				(g per plant/v-stage)	
	15	32	40	34.48	0.13
V-stage (6-8 weeks)				(g per plant/v-stage)	
	32	52	65	26.92	0.14
Plant Spacing				(g per plant/cm)	
	13	37	55	2.61	0.13

In 2000 and 2001, variation of yield as function of time to emergence was significantly affected by planting date ($P < 0.05$) (Appendix F.1, F.2). The latest planting date showed the largest negative slope (Table 27). On the other hand, after early planting the majority of regressions were not significant, regardless of the coating treatment. The fact that early planting is associated with lower temperatures during emergence and a longer growing season might have accounted for some of these differences. A plant that emerges later than the neighbor will therefore, be at a greater disadvantage for late planting than for early planting relative to its neighbor, since each additional day is usually associated with higher GDD due to higher soil temperature. Indeed, the major factors affecting individual plant yields were plant height and relative silking time. For example, 70% or more of the regressions of yield as a function of relative time to silking were significant ($P < 0.1$) in 2000 and 2001 (Table 26). For the significant regressions, plants that silked later tended to achieve lower yields (overall negative slope). Based on the percent of significant slopes, individual plant yield was more strongly related to relative silking time than with relative emergence time.

Table 26. Mean rate of change in individual plant yield as a function of increasing time to relative emergence for the three planting dates in 2000 and 2001.

Date	Slope		Date	Slope	
2000	(g/plant/day)		2001	(g/plant/day)	
28-Mar	-0.77	b †	2-Apr	0.95	b
14-Apr	-2.88	b	19-Apr	-3.74	a
16-May	-6.51	a	11-May	-5.93	a

† Data followed by the same letter within year, planting date and Hybrid are not significantly different according to a protected LSD (0.05) test.

Effect of relative time to silking on yield was significantly affected by the interaction Hybrid x coating in 2000 ($P < 0.05$) (Appendix F.1). In 2001, treatment main effects were also significant ($P < 0.01$) (Appendix F.2). However, no consistent differences were observed in either of the years (Table 28), since the range of silking period due to polymer treatment was not different in either year (data not shown).

Table 27. Mean rate of individual plant yield reductions a function of increased relative time to silking for Hybrid and polymer treatments in 2000 and 2001.

Treatment [†] 2000	Ind. yield loss (g/plant/day)	Treatment 2001	Ind. yield loss (g/plant/day)
8509 UTC	3.31 a [‡]	8509 UTC	8.61 a
8509 A	4.07 a	8509 D	6.81 a
8509 B	3.15 a		
9307 UTC	7.58 a	9307 UTC	1.67 c
9307 A	4.7 b	9307 C	6.43 a
9307 B	7.58 a	9307 D	4.16 b

† 8509= Hybrid 8509, 9307= Hybrid 9307, UTC = uncoated, A= coating A, B= coating B, C= coating C, D=coating D.

‡ Data followed by the same letter are not significantly different according to a protected LSD (0.05) test.

When early height as well as final height were used as the independent variable of individual grain yield, over 50% of the regressions were significant ($P < 0.1$) in 2000 and 2001 (Table 26). Overall, for the significant regressions, shorter plants tended to yield less than taller plants (positive slope). These results are in agreement with those of Daynard and Muldoon (1983), who observed that plants that were taller throughout the season yielded more than their shorter counterparts. They also found that final height was not strongly correlated with silking dates, it was related to yield. They did not, however, explain the rationale for these differences in height, and whether height differences were associated with variable emergence or other factors.

Various development stages had differential effects on individual plant yields. When slopes were significant, plants that developed later tended to yield less. Regressions of yield with v-stage were significant less frequently than those with individual heights (Table 26). Moreover, earlier developmental stages (4-6 weeks after emergence) resulted in fewer significant regressions with yield in comparison to later development stages (e.g. 6-8 weeks after emergence).

Individual grain yields were also regressed against plant spacing; these regressions were significant on 22% of the plots in 2000, and 55% in 2001 (Table 26). These results suggest that there was some relationship between individual plant spacing and grain yield, and that plants that had more area available resulted in higher yields. Muldoon and Daynard (1981) found that uniformity of spacing within the range commonly encountered with properly adjusted commercial maize planters, is unlikely to affect grain yield per unit area. Moreover, they found that gaps up to 1 m did not significantly affect mean yield. This is in agreement with Johnson and Mulvaney (1980). In contrast, Doerge *et al.* (2001) observed a 0.08 Mg ha^{-1} increase for each cm improvement in standard deviation. Similar research at Purdue University showed a 0.06 Mg ha^{-1} yield increase per cm of standard deviation improvement (Nielsen, 1997). However, in all these studies mean yield response to variability in spacing is not based on individual plant data correlations; therefore it is impossible to conclude that individual plant yield either was or was not related to plant spacing. Plants with larger spacing could have yielded more and compensated for plants with smaller spaces and lower yields, therefore maintaining the same mean yield per unit area. Our results clearly demonstrate that some yields compensation occurs with larger spacing, but that individual plant yields are affected proportionally more by within-row variation in plant development (e.g. v-stage and silk emergence).

The fact that space availability for each plant was calculated as the average of the two neighbor plants might not be the best analysis approach, since for example, a plant that has a double on one side and a plant very far away on the other side, might average the same spacing that a plant that has both neighbors at the same distance. In this case even when the total mean spacing is the same for both plants, influence of both neighbors may be very different. Perhaps a different analysis approach should be performed to better assess neighbors' influence and available spacing.

Height and v-stages effects at 4-6 and 6-8 weeks after emergence on yield, were not significantly affected by any treatment main effect for almost all planting dates in both years ($P > 0.05$) (Appendix F.3-F.6).

Final height effects on yield were significantly affected by planting date ($P < 0.01$) in both 2000 and 2001(Appendix F.1, F.2). Consistently in both years, slopes were highest for early planting and decreased as planting dates were delayed (Figure 20). The fact that mean final heights were lower for early planting relative to late planting (Chapter I) could explain some of these differences. Plant height reductions of 1 cm, would probably have a larger negative yield influence on shorter plants than taller plants; therefore, slopes of relationships would be expected to be larger for plants that have shorter mean heights (early planting).

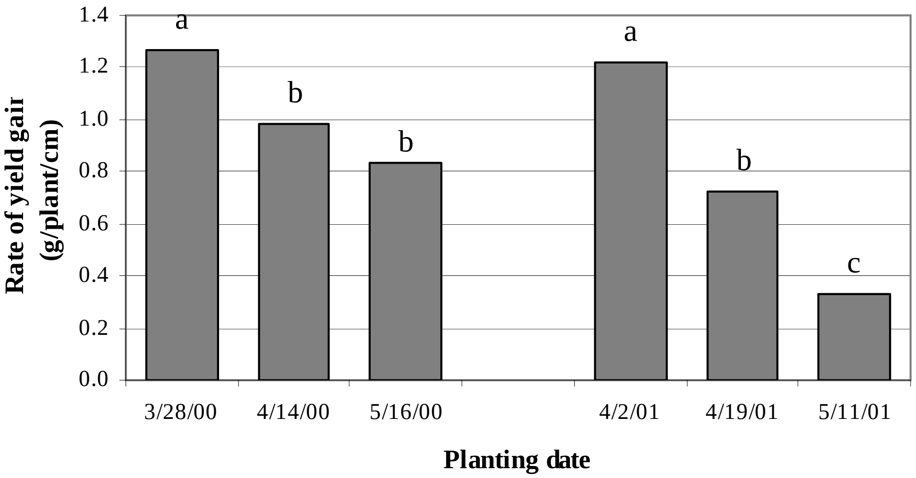


Figure 20. Mean rate of individual plant yield gain as a function of increasing final height of corn plants relative to within-row neighbors in 2000 and 2001.

Data followed by the same letter within year are not significantly different according to a protected LSD (0.05) test.

Summary

The purpose of this study was to investigate the dependency of individual plant yield on different growth and development variables (emergence, height, V-stages, silking, and plant spacing), to also evaluate the relationship among them as well as the effect of planting dates, hybrids and polymer coatings on the different relationships. Relative emergence time affected subsequent plant height and development in the vegetative period. Later emerged plants tended to be shorter and develop later than their early-emerged neighbors. However, final height was less dependent on relative time to emergence than were heights at 4-6 weeks after emergence. Silk emergence of individual plants was positively associated with the relative emergence time, but the time of silking was more strongly related with height differences during vegetative growth. Later planting was associated with a higher rate of silking delay per day of emergence day delay than earlier planting.

Plants that were taller during the vegetative period tended to silk earlier than their shorter counterparts. Later plantings were associated with a longer delay in silking per day of delay in coleoptile emergence.

Shorter plants at maturity tended to yield less than their taller neighbors. In both years earlier planting was associated with higher rates of yield gain as a function of increasing height. Plants that silked earlier were in general associated with higher grain yields. Individual grain yields within the row were less dependent on plant spacing. Individual grain yields within the plant row were not very dependent on variation in emergence, although more yield loss per day of emergence delay was evident for the last planting date than for the first and second. Planting date was the factor that mainly affected the magnitude of the relationship between individual grain yield and emergence, early growth or development. In contrast, Hybrids or polymer coatings had much less influence on these relationships.

These results demonstrate that relative plant height was more closely related with individual plant yield than with any other variable. Early plant heights were generally dependent on relative emergence, but final height depended on other unknown factors. This suggests that emergence explained only a very small part of plant height variability in the post-silking period. Therefore the effect of emergence delays per se resulting from a common planting date are not likely to strongly affect individual plant grain yield. Growing season factors other than emergence uniformity are likely to have a higher impact on relative plant size and individual grain yield. More studies at the individual plant level are required to identify which factor or combination of factors are likely to influence plant size and grain yield of distinct individual plants in a corn community.

GENERAL DISCUSSION

Notable Conclusions:

Polymer coatings resulted in emergence delays ranging from 1 to 6 days for early, intermediate and late planting dates for both Hybrids and in both years. However, corn responses to polymer coatings were inconsistent and reasons for these differences remain unclear. Relative emergence delays with polymer coatings are season and Hybrid dependent, and appear to have been influenced by environmental factors other than temperature fluctuation alone. In general, polymer coated seed planted early did not improve emergence uniformity relative to uncoated seed, and planting date had the greatest effect on emergence uniformity. Early planting resulted in the least uniform emergence, probably as a result of lower soil temperatures encountered by the seed early in the season.

Polymer coatings never increased total number of seedlings emerged in either year, but improved final established stands in 2001, when mid-April frosts reduced the stand of uncoated seed of 9307 more than 8509, and coated seed treatments of both Hybrids were less affected.

In some cases, polymer coating treatments resulted in shorter plants with delayed vegetative development compared to the uncoated treatment. Corn plant v-stages and heights were lowest in treatments that had longer emergence delays. Silk emergence of early planted corn was delayed most when polymer coatings delayed initial emergence the longest. Fewer differences in corn development among coating treatments were evident as plants aged.

Even though some treatments resulted in a more variable emergence than others, treatments with higher emergence variability did not result in larger standard deviation of either height or v-stages. Moreover, coated treatments did not result in lower silking uniformity relative to uncoated seed.

Grain yields were affected by Hybrid and planting dates, but not by polymer seed coatings except for the early planting date in 2001. In that situation, coated seed of Hybrid 9307 yielded 15% to 18% more than uncoated seed due to the larger frost damage experienced by uncoated seed. Corn growth and yield advantages with polymer coatings may have been more apparent if cooler and wetter soil conditions had prevailed after the first 2 planting dates in both years.

Regardless of the coating treatment, individual corn yields were affected more by plant-to-plant variability in development later in the season than by variability in emergence, and emergence differences appeared to exert only a minor influence on variability in later season growth. Plants within a row that silked earlier were generally associated with higher grain yields, but individual plant grain yields were more related to height (during vegetative growth as well as final height) than any other variable. Plant spacing per individual plant influenced yield less than variation in heights and developmental stages. Plant height had a much stronger relationship with individual plant grain yield than any other variable. Our research suggest that within-row variability in microenvironment and (or) soil factors must have continued to differentially affect individual corn plant growth and development in the post-emergence period.

Implications:

The preliminary results suggest that polymer coatings do delay emergence and result in higher plant populations when post-emergent frosts compromise corn stand establishment of uncoated seed in early planting situations. However, corn population gains for polymer-coated seed versus uncoated seed were Hybrid dependent. Simply utilizing polymer coatings in very early planting dates does not guarantee that overall grain yields are at least equal to those of uncoated seed planted in the optimum period. Corn Hybrids with good seedling vigor and cold tolerance would seem to be the best candidates for application for polymer coatings. Since polymer seed coatings did not negatively affect corn yields after intermediate or late planting, producers should be able to utilize polymer-coated seed even if wet soil conditions prevent them from planting before the optimum planting period. Corn producers most likely to benefit from the early planting opportunity with polymer-coated seed are those with variable-drained systems, no-till planting fields, and those who encounter difficulty in consistently completing corn planting during the optimum planting period.

Limitations:

The response of corn growth and development to polymer seed coatings varies with year and location, mainly due to temperature and moisture fluctuations in soil. This study was conducted at one site in Indiana in 2000 and 2001. In 2001, similar experiments were conducted at the Agronomy Research Center and Pinney Purdue Agricultural Center; the latter location involved different Hybrids and polymer coating formulations. The fact that polymer formulations varied for the two years made comparisons impossible across years and made drawing definitive conclusions difficult. Moreover, warmer than normal conditions in both years might have suppressed some of the beneficial effects of polymer coatings.

Future Research:

Future research should focus on: 1) seed germination tests under controlled conditions (growth chamber) to further assess the actual behavior of the different polymers, and their possible interactions with the different genotypes, 2) field experiments with even earlier planting treatments to see whether longer periods of cool soil conditions result in larger differences among coating treatments, 3) different analysis approaches on the individual plant data, 4) even if proof were found that polymer coatings can decrease the stress associated with early planting, an economic analysis should be performed to assess whether the benefits obtained can compensate for the cost of this technology.

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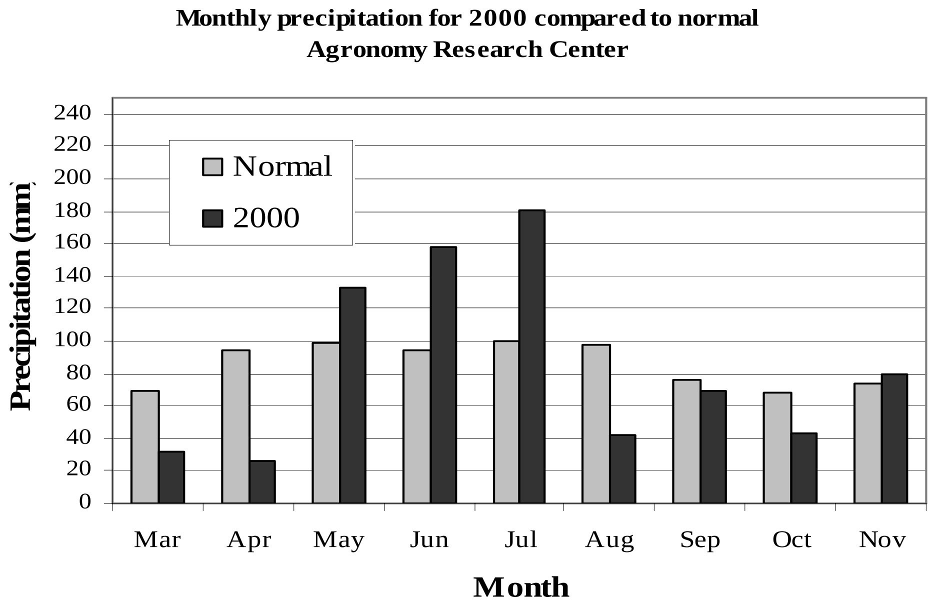
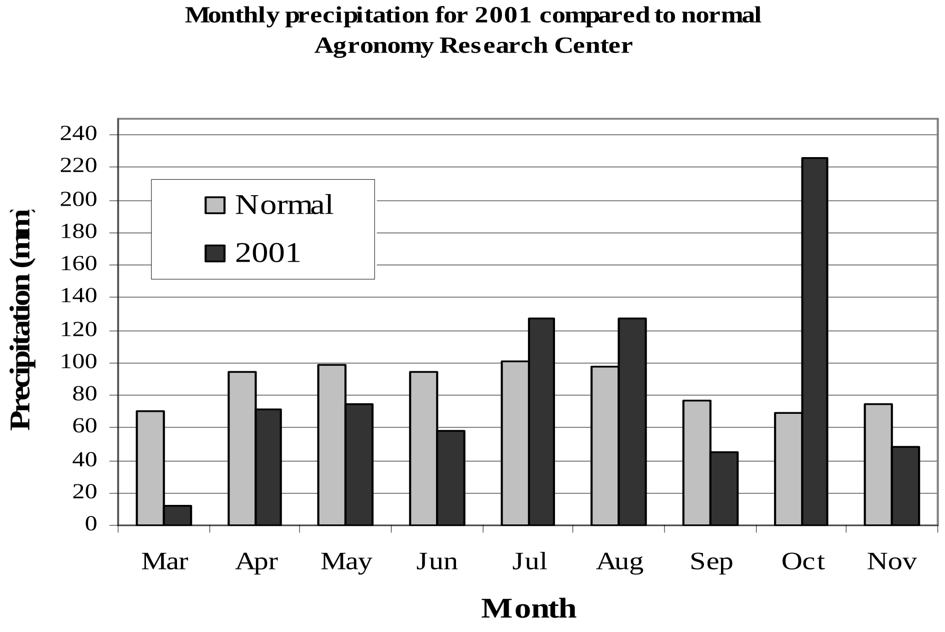
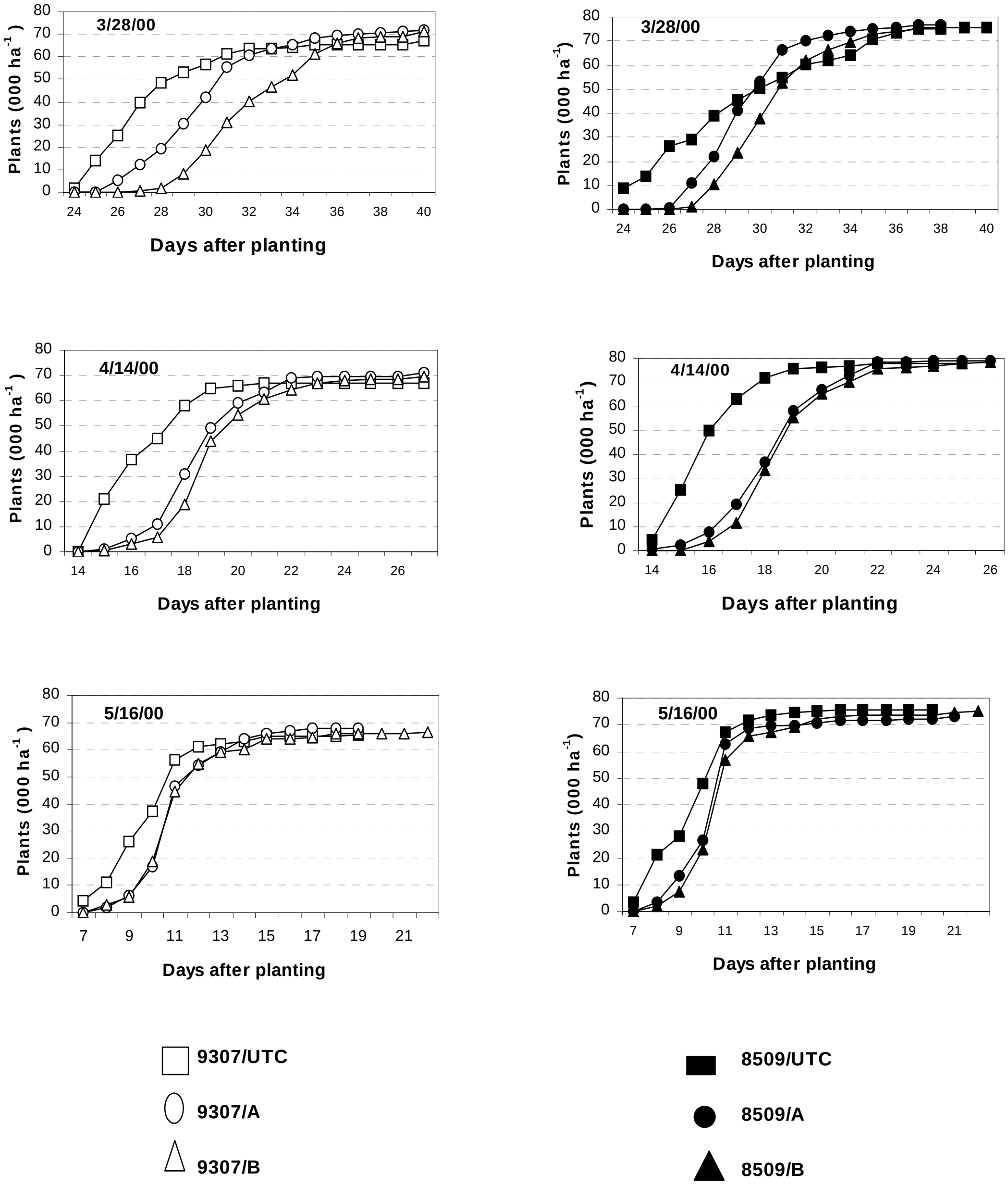
APPENDICES

Appendix A.1. Monthly precipitation in 2000 and 2001 in comparison to normal at the Agronomy Research Center.

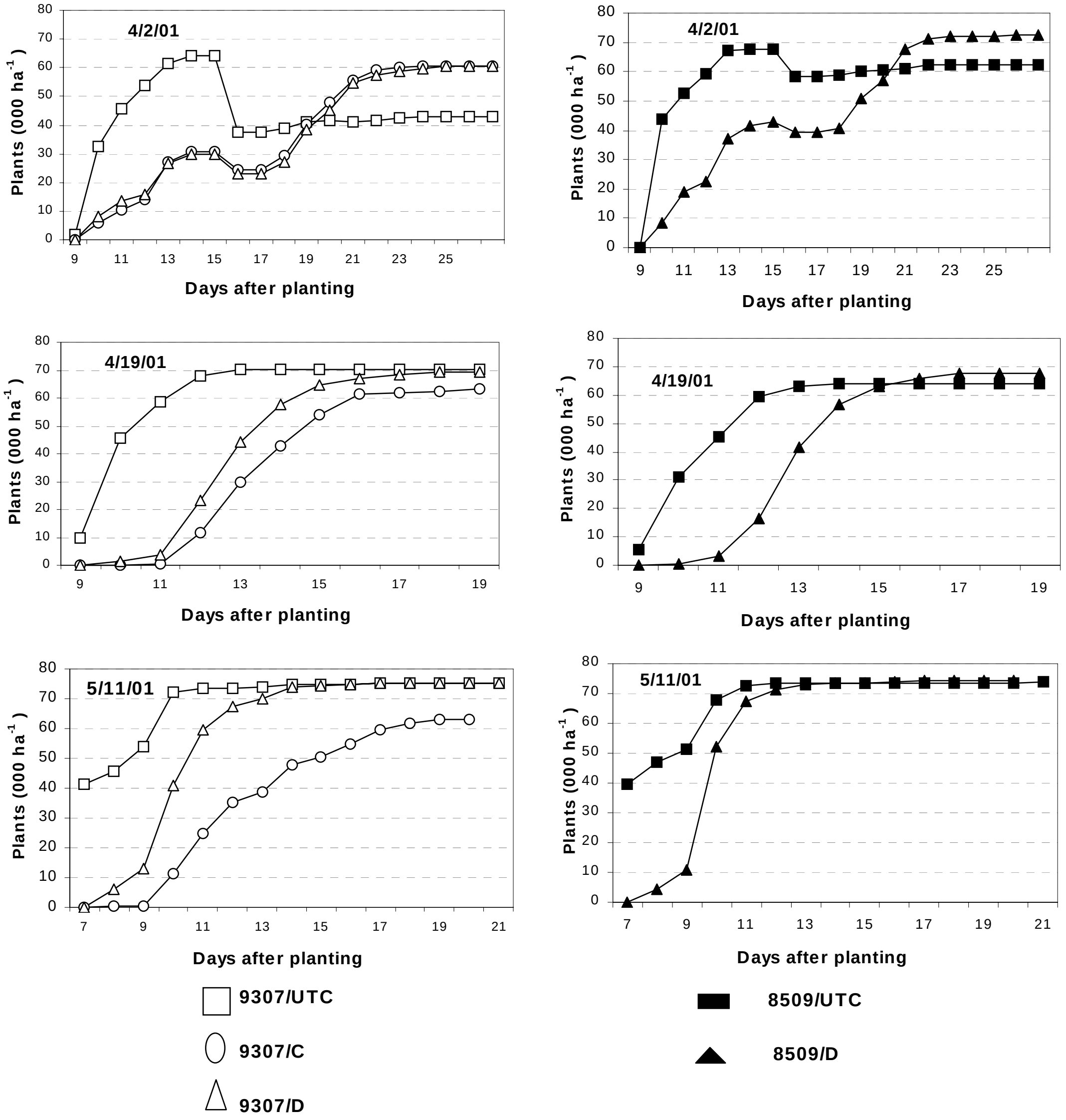




Appendix A.2. Cumulative emergence (living seedling) for three different planting dates, two Hybrids (9307, 8509) and different coating treatments (UTC: control, coating A, and coating B) in 2000.



Appendix A.3. Cumulative emergence (living seedling) for three different planting dates, two Hybrids (9307, 8509) and different coating treatments (UTC: control, coating C, and coating D) in 2001.



Appendix B. Analysis of variance for 2000 and 2001.

B.1. 2000 Days to 50% Emergence

Source of Variation	df	MS	Sig
Block	3	0.71	-
Date	2	4914.63	**
Error (a)	6	2.32	**
Hybrid	1	3.06	-
date x Hybrid	2	0.07	-
Coat	2	72.40	**
Date x Coat	4	7.13	**
Hybrid x Coat	2	4.52	*
Date x Hybrid x Coat	4	4.25	*
Error (b)	45	1.21	**
Error (b')	72	0.53	

B.2. 2001 Days to 50 % Emergence

Source of Variation	df	MS	Sig
Block	3	15.24	-
Date	2	162.69	**
Error (a)	6	10.33	**
Treat	4	94.61	**
Date x Treat	8	5.72	**
Error (b)	36	1.53	-
Error b'	60	1.52	
Selected Contrasts			
Within Planting Date 1			
8509 v 9307	1	19.27	**
Within Planting Date 2			
8509 v 9307	1	1.07	-
Within Planting Date 3			
8509 v 9307	1	12.38	**

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.3. 2000 Days from 10 to 90% Emergence

Source of Variation	df	MS	Sig
Block	3	2.47	-
Date	2	113.82	**
Error (a)	6	1.02	*
Hybrid	1	6.46	-
date x Hybrid	2	6.72	-
Coat	2	4.70	-
Date x Coat	4	4.75	-
Hybrid x Coat	2	9.91	*
Date x Hybrid x Coat	4	12.15	**
Error (b)	45	2.28	-
Error (b')	72	2.37	-

B.4. 2001 Days from 10 to 90 % Emergence

Source of Variation	df	MS	Sig
Block	3	1.74	-
Date	2	88.90	**
Error (a)	6	3.62	-
Treat	4	65.84	**
Date x Treat	8	18.33	**
Error (b)	36	5.07	-
Error b'	60	3.30	-
Selected Contrasts			
Within Planting Date 1			
8509 v 9307	1	31.18	*
Within Planting Date 2			
8509 v 9307	1	0.46	-
Within Planting Date 3			
8509 v 9307	1	71.50	**

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.5. 2000 Seedlings emerged

Source of Variation	df	MS	Sig
Block	3	11349828	-
Date	2	190879093	**
Error (a)	6	16399539	-
Hybrid	1	2040852906	**
date x Hybrid	2	2356532	-
Coat	2	11686475	-
Date x Coat	4	10820810	-
Hybrid x Coat	2	29192141	-
Date x Hybrid x Coat	4	31500581	-
Error (b)	45	21064511	-

B.6. 2001 Seedlings Emerged

Source of Variation	df	MS	Sig
Block	3	51939889	-
Date	2	486388207	**
Error (a)	6	113111354	-
Treat	4	133110394	**
Date x Treat	8	64809440	*
Error (b)	36	23748072	-
Error b'	60	34626593	-
Selected Contrasts			
Within Planting Date 1			
8509 v 9307	1	388279527	**
Within Planting Date 2			
8509 v 9307	1	58432375	-
Within Planting Date 3			
8509 v 9307	1	4876578	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.7. 2000		Plant Final Height		Standard Deviation	
Source of Variation	df	MS	Sig	MS	Sig
Block	3	630.4	-	53.2	-
Date	2	3336.8	*	25.1	-
Error (a)	6	455.8	**	49.2	-
Hybrid	1	14624.8	**	12.7	-
date x Hybrid	2	154.2	-	11.9	-
Coat	2	113.4	-	48.6	-
Date x Coat	4	29.4	-	15.1	-
Hybrid x Coat	2	81.5	-	66.5	-
Date x Hybrid x Coat	4	94.7	-	84.1	-
Error (b)	45	56.6	*	56.3	-
Error (b')	72	30.5	-	66.6	-

B.8. 2001		Plant Final Height		Standard Deviation	
Source of Variation	df	MS	Sig	MS	Sig
Block	3	928.80	*	11.39	-
Date	2	19352.73	**	2.83	-
Error (a)	6	178.47	-	9.88	-
Treat	4	7973.27	**	11.48	-
Date x Treat	8	60.81	-	12.59	-
Error (b)	36	75.79	**	15.22	-
Error b'	60	15.03	-	23.88	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.9. 2000 Days to 50 %Silking

Source of Variation	df	MS	Sig
Block	3	29.4	
Date	2	12515.4	**
Error (a)	6	26.2	**
Hybrid	1	313.5	**
date x Hybrid	2	5.0	-
Coat	2	1.2	-
Date x Coat	4	3.6	-
Hybrid x Coat	2	0.3	-
Date x Hybrid x Coat	4	4.9	-
Error (b)	45	3.4	**
Error (b')	72	1.2	

B.10. 2001 Days to 50 % Silking

Source of Variation	df	MS	Sig
Block	3	57.9	-
Date	2	4431.7	**
Error (a)	6	9.1	**
Treat	4	83.5	**
Date x Treat	8	8.7	**
Error (b)	36	2.3	*
Error (b')	60	1.4	
Selected Contrasts			
Within Planting Date 1			
8509 v 9307	1		-
Within Planting Date 2			
8509 v 9307	1		-
Within Planting Date 3			
8509 v 9307	1		-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.11. 2000 Days from 10 to 90% Silking

Source of Variation	df	MS	Sig
Block	3	9.07	-
Date	2	42.60	-
Error (a)	6	16.70	*
Hybrid	1	2.92	-
date x Hybrid	2	16.54	-
Coat	2	2.64	-
Date x Coat	4	3.79	-
Hybrid x Coat	2	12.06	-
Date x Hybrid x Coat	4	13.76	-
Error (b)	45	5.43	-
Error (b')	72	3.34	

B.12. 2001 Days from 10 to 90 % Silking

Source of Variation	df	MS	Sig
Block	3	3.0	-
Date	2	141.2	**
Error (a)	6	6.4	-
Treat	4	4.8	-
Date x Treat	8	5.8	-
Error (b)	36	2.9	-
Error (b')	60	4.4	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.13. 2000 Plant Spacing Standard Deviation (log)

Source of Variation	df	MS	Sig	MS	Sig
Block	3	1.02	-	0.006	-
Date	2	13.67	*	0.050	-
Error (a)	6	2.01	-	0.017	-
Hybrid	1	86.84	**	0.008	-
date x Hybrid	2	0.44	-	0.178	-
Coat	2	3.85	-	0.144	-
Date x Coat	4	0.98	-	0.263	-
Hybrid x Coat	2	4.74	-	0.001	-
Date x Hybrid x Coat	4	3.14	-	0.013	-
Error (b)	45	2.08	-	0.200	-
Error (b')	72	2.29		0.013	

B.14. 2001 Plant Spacing Standard Deviation (log)

Source of Variation	df	MS	Sig	MS	Sig
Block	3	46.20	-	0.079	**
Date	2	491.42	**	0.472	**
Error (a)	6	20.59	-	0.008	-
Treat	4	103.04	**	0.026	-
Date x Treat	8	128.72	**	0.117	**
Error (b)	36	11.08	-	0.023	-
Error b'	60	24.16		0.167	
Selected Contrasts					
Within Planting Date 1					
8509 v 9307	1	482.30	**	0.348	**
Within Planting Date 2					
8509 v 9307	1	2.24	-	0.065	-
Within Planting Date 3					
8509 v 9307	1	2.04	-	0.001	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.15. 2000 Plant Population at Harvest

Source of Variation	df	MS	Sig
Block	3	557216	-
Date	2	167771852	**
Error (a)	6	22681206	-
Hybrid	1	1672741834	**
date x Hybrid	2	1598739	-
Coat	2	13743893	-
Date x Coat	4	5771469	-
Hybrid x Coat	2	3817528	-
Date x Hybrid x Coat	4	45856355	-
Error (b)	45	20345339	-
Error (b')	72	28771106	-

B.16. 2001 Plant Population at Harvest

Source of Variation	df	MS	Sig
Block	3	165822906	*
Date	2	2610152565	**
Error (a)	6	19698684	-
Treat	4	248099537	**
Date x Treat	8	339730159	**
Error (b)	36	40753576	-
Error (b')	60	52055311	
Selected Contrast			
Within Planting Date 1			
8509 v 9307	1	1500024	-
Within Planting Date 2			
8509 v 9307	1	55864236	-
Within Planting Date 3			
8509 v 9307	1	18034684	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.17. 2000 % Barren Plants

Source of Variation	df	MS	Sig
Block	3	2.995	-
Date	2	10.419	-
Error (a)	6	3.962	**
Hybrid	1	3.902	-
date x Hybrid	2	0.666	-
Coat	2	0.281	-
Date x Coat	4	1.502	-
Hybrid x Coat	2	1.119	-
Date x Hybrid x Coat	4	0.207	-
Error (b)	45	1.005	-
Error (b')	72	1.537	-

B.18. 2001 % Barren Plants

Source of Variation	df	MS	Sig
Block	3	1.76045048	-
Date	2	6.3058167	-
Error (a)	6	2.81908498	-
Treat	4	0.33119859	-
Date x Treat	8	0.89857795	-
Error (b)	36	1.39467552	-
Error (b')	60	1.2529817	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.19. 2000 % Diplodia infected plants

Source of Variation	df	MS	Sig
Block	3	2.3939	-
Date	2	15.7702	**
Error (a)	6	1.3440	-
Hybrid	1	43.8406	**
date x Hybrid	2	3.5616	-
Coat	2	0.4202	-
Date x Coat	4	1.2351	-
Hybrid x Coat	2	1.1637	-
Date x Hybrid x Coat	4	1.4100	-
Error (b)	45	1.4777	-
Error (b')	72	1.2263	-

B.20. 2000 % Logded Plants

Source of Variation	df	MS	Sig
Block	3	6.645	-
Date	2	4.470	-
Error (a)	6	3.499	-
Hybrid	1	24.668	**
date x Hybrid	2	5.985	*
Coat	2	1.126	-
Date x Coat	4	0.459	-
Hybrid x Coat	2	0.241	-
Date x Hybrid x Coat	4	0.707	-
Error (b)	45	1.839	-
Error (b')	72	1.765	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.21. 2000 Poorly Polinated Plants for Planting Date 3

Source of Variation	df	MS	Sig
Block	3	0.117	-
Hybrid	1	0.003	-
Coat	2	0.026	-
Hybrid x Coat	2	0.003	-
Error (b)	15	0.016	-
Error (b')	24	0.009	-

B.22. 2001 Poorly Polinated Plants for Planting Date 3

Source of Variation	df	MS	Sig
Rep	3	0.020	-
Treat	4	0.037	-
Rep x Date x Treat	12	0.019	-
Error b'	20	0.019	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

B.23. 2000 Grain Yield

Source of Variation	df	MS	Sig
Block	3	0.51	-
Date	2	19.57	-
Error (a)	6	10.45	**
Hybrid	1	50.73	**
date x Hybrid	2	6.07	*
Coat	2	0.04	-
Date x Coat	4	0.68	-
Hybrid x Coat	2	1.43	-
Date x Hybrid x Coat	4	0.38	-
Error (b)	45	1.44	-
Error (b')	72	0.95	

B.24. 2001 Grain Yield

Source of Variation	df	MS	Sig
Block	3	7.62	-
Date	2	23.96	-
Error (a)	6	4.80	-
Treat	4	18.90	**
Date x Treat	8	12.02	**
Error (b)	36	2.34	-
Error (b')	60	1.84	
Selected Contrast Statements			
Within Planting Date 1			
8509 v 9307	1	146.80	**
Within Planting Date 2			
8509 v 9307	1	1.85	-
Within Planting Date 3			
8509 v 9307	1	0.70	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

Appendix C. Analysis of variance within planting date in 2000 and 2001.

C.1. 2000 Corn V-stage and standard deviation at 6 weeks (Planting Date 1)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	0.297	*	0.015	-
Hybrid	1	2.464	**	0.542	-
Coat	2	0.192	-	0.113	-
Hybrid x Coat	2	0.521	**	0.012	-
Experimental Error	15	0.080	-	0.147	-
Subsample Error	24	0.074		0.153	

C.2. 2001 Corn V-stage and standard deviation at 6 weeks (Planting Date 1)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	0.059	-	0.004	-
Treat	4	0.031	-	0.010	-
Experimental Error	12	0.076	-	0.009	-
Subsample Error	20	0.018		0.016	
Selected Contrast					
8509 vs 9307	1	0.084	-	0.022	-

C.3. 2000 Plant V-stage and standard deviation at 4 weeks (Planting Date 2)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	0.474	*	0.001	-
Hybrid	1	2.591	**	0.079	-
Coat	2	0.309	-	0.028	-
Hybrid x Coat	2	0.043	-	0.014	-
Experimental Error	15	0.100	*	0.028	**
Subsample Error	24	0.030		0.003	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

C. 4. 2001 Corn V-stage and standard deviation at 4 weeks (Planting date 2)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	0.231	*	0.011	-
Treat	4	0.496	**	0.100	*
Experimental Error	12	0.057	-	0.021	-
Subsample Error	20	0.029	-	0.013	
Selected Contrast					
9307 vs 8509	1	0.469	**	0.224	**

C.5. 2000 Plant V-stage and standard deviation at 4 weeks (Planting date 3)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	0.239	*	0.020	-
Hybrid	1	2.221	**	0.089	*
Coat	2	0.451	**	0.007	-
Hybrid x Coat	2	0.063	-	0.026	-
Experimental Error	15	0.055	-	0.019	-
Subsample Error	24	0.028		0.015	

C.6. 2001 Corn V-stage and standard deviation at 4 weeks (Planting date 3)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	0.067	-	0.026	-
Treat	4	0.700	**	0.047	-
Experimental Error	12	0.054	-	0.023	-
Subsample Error	20	0.026		0.007	
Selected Contrast					
8509 vs 9307	1	0.079	-	0.095	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

C.7. 2000 Plant V-stage and standard deviation at 8 weeks (Planting Date 1)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	0.743	*	0.148	-
Hybrid	1	4.019	**	0.035	-
Coat	2	0.170	-	0.609	-
Hybrid x Coat	2	0.502	-	0.058	-
Experimental Error	15	0.192	-	0.550	-
Subsample Error	24	0.168		0.530	

C.8. 2001 V-stage and standard deviation at 8 weeks (Planting Date 1)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	0.231	-	0.090	-
Treat	4	0.634	*	0.177	-
Experimental Error	12	0.129	-	0.247	-
Subsample Error	20	0.113		0.183	
Selected Contrast					
8509 vs 9307	1	2.149	**	0.038	-

C.9. 2000 Plant V-stage and standard deviation at 6 weeks (Planting date 2)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	2.209	**	0.403	-
Hybrid	1	3.506	**	0.027	-
Coat	2	0.186	-	0.183	-
Hybrid x Coat	2	0.126	-	0.044	-
Experimental Error	15	0.304	*	0.420	-
Subsample Error	24	0.083		0.445	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

C.10. 2001 Corn V-stage and standard deviation at 6 weeks (Planting date 2)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	0.584	**	0.143	-
Treat	4	0.157	-	0.060	-
Experimental Error	12	0.065	-	0.078	-
Subsample Error	20	0.028		0.034	
Selected Contrast					
8509 vs 9307	1	0.002	-	0.134	-

C.11. 2000 Plant V-stage and standard deviation at 6 weeks (Planting Date 3)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	1.972	**	0.018	-
Hybrid	1	1.558	**	0.055	-
Coat	2	0.786	**	0.030	-
Hybrid x Coat	2	0.457	*	0.094	**
Experimental Error	15	0.098		0.018	-
Subsample Error	24	0.071		0.023	

C.12. 2001 Corn V-stage and standard deviation at 6 weeks (Planting Date 3)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	0.446	-	0.027	-
Treat	4	1.070	*	0.095	-
Experimental Error	12	0.268	*	0.125	-
Subsample Error	20	0.050		0.095	
Selected Contrast					
8509 vs 9307	1	0.281	-	0.267	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

C.13. 2000 Corn Height and standard deviation at 6 weeks (Planting Date 1)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	110.42	*	6.76	-
Hybrid	1	17.16	-	3.31	-
Coat	2	27.22	-	13.98	-
Hybrid x Coat	2	183.60	*	31.89	-
Experimental Error	15	24.47	-	10.17	-
Subsample Error	24	12.05		8.48	

C.14. 2001 Corn Height and standard deviation at 6 weeks (Planting Date 1)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	11.23	-	16.47	-
Treat	4	64.98	*	3.72	-
Experimental Error	12	9.68	-	10.50	-
Subsample Error	20	9.55		7.98	
Selected Contrast					
8509 vs 9307	1	199.53	**	2.88	-

C.15. 2000 Corn Height and standard deviation at 4 weeks (Planting date 2)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	308.08	**	8.72	-
Hybrid	1	62.61	-	42.51	*
Coat	2	12.76	-	1.95	-
Hybrid x Coat	2	5.45	-	0.32	-
Experimental Error	15	46.25	**	6.41	-
Subsample Error	24	11.50		2.67	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

C.16. 2001 Corn Height and standard deviation at 4 weeks (Planting date 2)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	51.08	*	1.93	-
Treat	4	89.70	**	4.79	-
Experimental Error	12	10.00	-	2.57	-
Subsample Error	20	7.22		1.28	
Selected Contrast					
8509 vs 9307	1	3.12	-	17.80	*

C.17. 2000 Corn Height and standard deviation at 4 weeks (Planting date 3)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	226.48	**	1.57	-
Hybrid	1	61.28	-	11.43	-
Coat	2	86.54	*	7.43	-
Hybrid x Coat	2	40.93	-	0.30	-
Experimental Error	15	21.99	-	3.39	-
Subsample Error	24	18.71		5.25	

C.18. 2001 Plant Height and standard deviation at 4 weeks (Planting date 3)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	69.57	-	3.19	-
Treat	4	212.87	*	6.17	-
Experimental Error	12	48.88	*	4.37	-
Subsample Error	20	11.50		2.54	
Selected Contrast					
8509 vs 9307	1	291.61	*	7.18	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

C.19. 2000 Plant Height and standard deviation at 8 weeks (Planting Date 1)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	389.76	**	74.49	-
Hybrid	1	22.45	-	0.88	-
Coat	2	25.91	-	7.49	-
Hybrid x Coat	2	422.70	**	132.13	*
Experimental Error	15	55.02	-	32.28	-
Subsample Error	24	26.02		26.65	

C.20. 2001 Plant Height and standard deviation at 8 weeks (Planting Date 1)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	361.91	**	26.36	-
Treat	4	489.00	**	5.02	-
Experimental Error	12	19.76	-	25.85	-
Subsample Error	20	32.65		28.20	
Selected Contrast					
8509 vs 9307	1	1780.35	**	1.24	**

C.21. 2000 Plant Height and standard deviation at 6 weeks (Planting date 2)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	1428.46	**	29.08	-
Hybrid	1	226.29	-	47.03	-
Coat	2	6.61	-	5.90	-
Hybrid x Coat	2	2.93	-	9.77	-
Experimental Error	15	178.97	**	19.71	-
Subsample Error	24	21.68		10.20	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

C.22. 2001 Plant Height and standard deviation at 8 weeks (Planting date 2)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	299.34	**	1.59	-
Treat	4	194.99	*	7.43	-
Experimental Error	12	49.81	-	18.59	-
Subsample Error	20	19.57		6.08	
Selected Contrast					
8509 vs 9307	1	220.87	-	2.72	-

C.23. 2000 Plant Height and standard deviation at 6 weeks (Planting date 3)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	1070.91	**	4.59	-
Hybrid	1	486.04	*	3.58	-
Coat	2	250.80	-	20.35	-
Hybrid x Coat	2	193.89	-	3.23	-
Experimental Error	15	92.82	-	6.75	-
Subsample Error	24	35.63		14.01	

C.24. 2001 Plant Height and standard deviation at 6 weeks (Planting date 3)

		V-stage		Standard deviation	
Source of Variation	df	MS	Sig	MS	Sig
Rep	3	465.02	-	40.71	-
Treat	4	333.51	-	17.73	-
Experimental Error	12	142.84	**	16.38	-
Subsample Error	20	16.06		11.57	
Selected Contrast					
8509 vs 9307	1	540.34	-	28.82	-

*,** signifcant at 0.01 and 0.05 probability levels respectively.

Appendix D. Analysis of variance on the slopes of variation in x as a function of relative time to emergence in 2000 and 2001.

D.1. 2000 Variation in plant height at 4-6 or 6-8 weeks as a function of relative emergence time for 3 planting dates

Planting date 1		Height at 6 weeks		Height at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.1509	-	1.1455	-
Hybrid	1	0.1569	-	2.1850	-
Coating	2	0.8790	-	0.6330	-
Hybrid x Coating	2	0.9370	-	3.7892	-
Experimental Error	15	0.3784		1.3029	

Planting date 2		Height at 4 weeks		Height at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.4260	-	0.9460	-
Hybrid	1	1.0332	-	0.0347	-
Coating	2	0.3106	-	3.4210	-
Hybrid x Coating	2	0.7740	-	0.0007	-
Experimental Error	15	0.5191		2.5284	

Planting date 3		Height at 4 weeks		Height at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	1.6917	-	1.5840	-
Hybrid	1	2.5121	-	2.9100	-
Coating	2	0.8737	-	0.7668	-
Hybrid x Coating	2	4.6571	-	1.8264	-
Experimental Error	15	0.7368		1.7132	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

D.3. 2000 Variation in v-stages at 4-6 or 6-8 weeks as a function of relative emergence time for 3 planting dates

Planting date 1		V-Stage at 6 weeks		V-Stage at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0002	-	0.0049	-
Hybrid	1	0.0005	-	0.0000	-
Coating	2	0.0007	-	0.0025	-
Hybrid x Coating	2	0.0025	-	0.0066	-
Experimental Error	15	0.0012		0.5200	

Planting date 2		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0008	-	0.0031	-
Hybrid	1	0.0022	-	0.0018	-
Coating	2	0.0024	-	0.0064	-
Hybrid x Coating	2	0.0189	-	0.0054	-
Experimental Error	15	0.0034		0.0038	

Planting date 3		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0018	-	0.0067	-
Hybrid	1	0.0002	-	0.0001	-
Coating	2	0.0019	-	0.0088	-
Hybrid x Coating	2	0.0040	-	0.0208	*
Experimental Error	15	0.0034		0.0051	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

D.4. 2001 Variation in v-stages at 4-6 or 6-8 weeks as a function of relative emergence time for 3 planting dates

Planting date 1		V-Stage at 6 weeks		V-Stage at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0060	-	0.0015	-
Treat	4	0.0019	-	0.0021	-
Experimental Error	12	0.0061		0.0156	

Planting date 2		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0047	-	0.0055	-
Treat	4	0.0047	-	0.0012	-
Experimental Error	12	0.0037		0.0028	

Planting date 3		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0021	-	0.0207	-
Treat	4	0.0017	-	0.0089	-
Experimental Error	12	0.0050		0.0071	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

D.5. 2000 Variation in final height as a function of relative emergence time for 3 planting dates

		Final height	
Source of variation	df	MS	Sig
Block	3	3.8641	-
Date	2	7.6248	-
Error (a)	6	6.1124	-
Hybrid	1	20.6933	**
Date x Hybrid	2	14.7300	**
Coating	2	0.8360	-
Date x Coating	4	5.8900	-
Hybrid x Coating	2	2.6050	-
Date x Hybrid x Coating	4	3.1195	-
Error (b)	45	2.5886	

D.6. 2001 Variation in final height as a function of relative emergence time for 3 planting dates

		Final Height	
Source of variation	df	MS	Sig
Block	3	0.831	-
Date	2	1.1049	-
Error (a)	6	2.011	-
Treat	4	2.403	-
Date x Treat	8	2.15	-
Error (b)	36	3.42	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

Appendix E. Analysis od variance on the slopes of relative silking time as a function of x in 2000 and 2001.

E.1. 2000 Variation in relative silking time as a function of height at 4-6 or 6-8 weeks for 3 planting dates

Planting date 1		Height at 6 weeks		Height at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0057	-	0.0068	-
Hybrid	1	0.0109	-	0.0102	-
Coating	2	0.0006	-	0.0029	-
Hybrid x Coating	2	0.0074	-	0.0087	-
Experimental Error	15	0.0049		0.0034	

Planting date 2		Height at 4 weeks		Height at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0131	-	0.0043	-
Hybrid	1	0.0116	-	0.0016	-
Coating	2	0.0030	-	0.0012	-
Hybrid x Coating	2	0.0051	-	0.0083	-
Experimental Error	15	0.0111		0.0035	

Planting date 3		Height at 4 weeks		Height at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0150	-	0.0041	-
Hybrid	1	0.0015	-	0.0024	-
Coating	2	0.0168	-	0.0002	-
Hybrid x Coating	2	0.0058	-	0.0045	-
Experimental Error	15	0.0060		0.0043	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

E.2. 2001 Variation in relative silking time as a function of height at 4-6 or 6-8 weeks for 3 planting dates

Planting date 1		Height at 6 weeks		Height at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0046	-	0.0023	-
Treat	4	0.0224	-	0.0112	*
Experimental Error	12	0.0110		0.0023	

Planting date 2		Height at 4 weeks		Height at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0033	-	0.0040	-
Treat	4	0.0033	-	0.0037	-
Experimental Error	12	0.0046		0.0055	

Planting date 3		Height at 4 weeks		Height at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0153	-	0.0150	**
Treat	4	0.0153	-	0.0039	-
Experimental Error	12	0.0049		0.0001	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

E.3. 2000 Variation in relative silking time as a function of v-stages at 4-6 or 6-8 weeks for 3 planting dates

Planting date 1		V-Stage at 6 weeks		V-Stage at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.2100	-	0.9737	-
Hybrid	1	2.5918	-	0.4004	-
Coating	2	0.0521	-	0.7117	-
Hybrid x Coating	2	2.3101	-	0.5878	-
Experimental Error	15	0.9944		0.5200	

Planting date 2		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.1083	-	0.6422	-
Hybrid	1	1.5696	-	0.0690	-
Coating	2	0.4739	-	0.2711	-
Hybrid x Coating	2	2.1824	-	0.1791	-
Experimental Error	15	1.4092		0.9939	

Planting date 3		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	1.8681	-	0.2887	-
Hybrid	1	2.7924	-	0.1986	-
Coating	2	0.8263	-	0.1776	-
Hybrid x Coating	2	0.8409	-	0.2863	-
Experimental Error	15	3.1945		0.7716	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

E.4. 2001 Variation in relative silking time as a function of v-stages at 4-6 or 6-8 weeks for 3 planting dates

Planting date 1		V-Stage at 6 weeks		V-Stage at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	1.7450	-	1.6124	-
Treat	4	2.5523	-	1.2121	-
Experimental Error	12	1.8540		0.7769	

Planting date 2		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.8545	-	2.1848	-
Treat	4	1.3490	-	0.5312	-
Experimental Error	12	1.4619		0.9332	

Planting date 3		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	1.9386	-	2.7098	-
Treat	4	1.1652	-	0.4905	-
Experimental Error	12	1.2081		0.8757	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

E.5. 2000 Variation in days to silking as a function of relative time to emergence and final height

		Rel. emergence time		Final height	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0107	-	0.0032	-
Date	2	0.6629	**	0.0101	-
Error (a)	6	0.0440	-	0.0040	-
Hybrid	1	0.0475	-	0.0070	-
Date x Hybrid	2	0.0590	-	0.0017	-
Coating	2	0.0230	-	0.0022	-
Date x Coating	4	0.1320	-	0.0019	-
Hybrid x Coating	2	0.0043	-	0.0007	-
Date x Hybrid x Coating	4	1.7900	**	0.0004	-
Error (b)	45	0.0950		0.3580	

E.6. 2001 Variation in relative silking time as a function of relative time to emergence and final height

		Rel. emergence time		Final Height	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.0246	-	0.003	-
Date	2	0.7100	**	0.0023	-
Error (a)	6	0.1140	-	0.0015	-
Treat	4	0.4241	**	0.0067	*
Date x Treat	8	0.0503	-	0.0036	-
Error (b)	36	0.1040		0.0024	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

Appendix F. Analysis of variance on the slopes of variation in individual grain yield as a function of x in 2000 and 2001.

F.1. 2000 Variation in yield as a function of relative emergence time, relative time to silking and final height.

		Rel. emergence time		Rel. Silking time		Final height	
Source of variation	df	MS	Sig	MS	Sig	MS	Sig
Block	3	36.86	-	15.42	-	0.20	-
Date	2	202.41	*	29.84	-	1.21	**
Error (a)	6	24.20	-	8.82	-	0.08	-
Hybrid	1	35.76	-	171.03	**	1.60	*
Date x Hybrid	2	8.63	-	8.80	-	0.50	-
Coating	2	2.88	-	8.10	-	0.29	-
Date x Coating	4	1.30	-	5.38	-	0.28	-
Hybrid x Coating	2	16.90	-	27.23	*	0.02	-
Date x Hybrid x Coating	4	6.67	-	14.08	-	0.33	-
Error (b)	45	13.35		7.68		0.36	

F.2. 2001 Variation in yield as a function of relative emregnce time, relative time to silking, final height and plant spacing.

		Rel. emergence time		Rel. Silking time	
Source of variation	df	MS	Sig	MS	Sig
Block	3	30.68	-	24.26	-
Date	2	247.60	**	66.45	-
Error (a)	6	35.36	-	19.40	-
Treat	4	59.54	*	86.25	**
Date x Treat	8	19.33	-	12.53	-
Error (b)	36	22.43		9.34	

		Final Height		Plant Spacing	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.68	-	3.96	-
Date	2	4.04	**	1.02	-
Error (a)	6	0.31	-	1.26	-
Treat	4	0.27	-	2.35	-
Date x Treat	8	1.23	-	1.11	-
Error (b)	36	0.82		1.78	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

F.3. 2000 Variation in yield as a function of plant height at 4-6 or 6-8 weeks for 3 planting dates

Planting date 1		Height at 6 weeks		Height at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.73	-	0.85	-
Hybrid	1	1.74	-	1.15	-
Coating	2	1.32	-	0.75	-
Hybrid x Coating	2	0.17	-	0.01	-
Experimental Error	15	0.50		0.51	

Planting date 2		Height at 4 weeks		Height at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	1.19	-	0.38	-
Hybrid	1	8.42	*	5.70	**
Coating	2	0.33	-	1.14	-
Hybrid x Coating	2	0.92	-	0.78	-
Experimental Error	15	1.26		0.65	

Planting date 3		Height at 4 weeks		Height at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	3.59	-	2.06	-
Hybrid	1	0.73	-	1.63	-
Coating	2	0.28	-	0.06	-
Hybrid x Coating	2	1.81	-	0.48	-
Experimental Error	15	2.77		1.18	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

F.4. 2001 Variation in yield as a function of plant height at 4-6 or 6-8 weeks for 3 planting dates

Planting date 1		Height at 6 weeks		Height at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	1.00	-	1.30	-
Treat	4	5.68	-	3.55	-
Experimental Error	12	1.91		1.15	

Planting date 2		Height at 4 weeks		Height at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	0.48	-	0.50	-
Treat	4	4.72	-	0.90	-
Experimental Error	12	0.80		0.58	

Planting date 3		Height at 4 weeks		Height at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	3.63	-	2.22	**
Treat	4	3.36	-	0.49	-
Experimental Error	12	1.10		0.28	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

F.5. 2000 Variation in yield as a function of v-stages at 4-6 or 6-8 weeks for 3 planting dates

Planting date 1		V-Stage at 6 weeks		V-Stage at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	67.02	-	92.27	-
Hybrid	1	32.19	-	21.54	-
Coating	2	19.15	-	80.53	-
Hybrid x Coating	2	252.01	-	2.12	-
Experimental Error	15	215.14		80.58	

Planting date 2		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	507.22	-	377.79	*
Hybrid	1	77.56	-	706.30	**
Coating	2	142.68	-	35.85	-
Hybrid x Coating	2	50.65	-	123.07	-
Experimental Error	15	153.92		79.89	

Planting date 3		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	368.60	-	87.63	-
Hybrid	1	1.15	-	15.07	-
Coating	2	330.51	-	71.12	-
Hybrid x Coating	2	173.68	-	181.66	-
Experimental Error	15	559.41		148.85	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

F.6. 2001 Variation in yield as a function of v-stages at 4-6 or 6-8 weeks for 3 planting dates

Planting date 1		V-Stage at 6 weeks		V-Stage at 8 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	139.89	-	119.10	-
Treat	4	717.70	-	329.14	-
Experimental Error	12	297.68		160.24	

Planting date 2		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	181.47	-	84.08	-
Treat	4	447.06	-	71.90	-
Experimental Error	12	339.95		167.09	

Planting date 3		V-Stage at 4 weeks		V-Stage at 6 weeks	
Source of variation	df	MS	Sig	MS	Sig
Block	3	753.98	-	353.35	-
Treat	4	779.14	-	140.90	-
Experimental Error	12	351.91		238.90	

*,** signifcant at 0.01 and 0.05 probability levels respectively.

Appendix G. Simple linear regressions of individual plant grain yield as a function of relative emergence time, relative silking and plant final height for uncoated treatments of 9307 and 8509 after early planitng in 2000.