Journal of Plant Nutrition
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lpla20

EFFECT OF DELAYED EMERGENCE ON CORN (ZEA MAYS L.) GRAIN YIELD

Emily Rutto [a], Cody Daft [b], Jonathan Kelly [a], Bee Khim Chim [a], Jeremiah Mullock [a], Guilherme Torres [a] & William Raun [a]

[a] Department of Plant and Soil Sciences, Oklahoma State University, Stillwater, Oklahoma, USA

[b] Pioneer Hi-Bred, Des Moines, Iowa, USA

Published online: 17 Jan 2014.

Journal of Plant Nutrition, 37:198–208, 2014

ISSN: 0190-4167 print / 1532-4087 online
DOI: 10.1080/01904167.2013.859691

EFFECT OF DELAYED EMERGENCE ON CORN (*ZEA MAYS* L.) GRAIN YIELD

Emily Rutto,[1] Cody Daft,[2] Jonathan Kelly,[1] Bee Khim Chim,[1] Jeremiah Mullock,[1] Guilherme Torres,[1] and William Raun[1]
[1]*Department of Plant and Soil Sciences, Oklahoma State University, Stillwater, Oklahoma, USA*
[2]*Pioneer Hi-Bred, Des Moines, Iowa, USA*

□ *Uneven crop stands result in a reduction in corn yield production. This study was conducted to determine the effect of delayed emergence on corn yields and the effect of nitrogen (N) applications to compensate for yield reductions. The design used was a randomized complete block, with 4 sequences of delayed planting (0,4,7,and 10 days after planting) and 3 rates of nitrogen fertilizer (0, 40, 80 kg N ha^{-1}). At maturity, individual plants were tagged in sets of three and hand harvested. Corn ears were shelled, and yield per plant calculated. Grain yield of the delayed plant compared to that of the neighbors was reduced by 27, 8, 20 and 12 kg ha^{-1}day^{-1} for 2007 LCB1, 2007 LCB2, 2010 LCB1 and 2010 LCB2, respectively. Over locations and years, the mean grain yield decrease of the delayed plant versus neighboring plants for each day delay was 122 kg ha^{-1}.*

Keywords: corn, precision agriculture, macronutrients

INTRODUCTION

Homogenous plant stand establishment is important for achieving maximum corn grain yields. Spatial and temporal variability are generally common in crop fields (Solie et al., 1996), which inevitably leads to heterogeneous stands. Several factors have been established to cause uneven emergence of crops in the field. These include soil temperature, which affects germination and speed of coleoptile elongation (Blacklow, 1974), soil compaction (Stibbe and Terpstra, 1982; Schneider and Gupta, 1985), and

Received 25 March 2011; accepted 27 October 2011.
Address correspondence to William Raun, Department of Plant and Soil Sciences, 044 Agricultural Hall, Oklahoma State University, Stillwater, OK 74078–6028, USA. E-mail: bill.raun@okstate.edu
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/lpla.

presence of surface residue as a result of no-tillage practices, which has been demonstrated to reduce soil temperature leading to delayed seed germination (Hayhoe and Dwyer, 1990). Variation in seed moistening, as a result of differences in seed-soil contact in a coarse seed bed, death after germination, excess or scarcity of water, presence of seeds unable to germinate, uneven distribution of the drill generating small skips, and stand establishment in stony fields (Benson, 1990; Finck, 1997; Nielsen, 1998), are other factors that contribute significantly to uneven corn stands.

The current nitrogen (N) recommendations for corn have been developed for large geographic regions and are traditionally employed without considering in-field variability (Schmidt et al., 2002). In an uneven crop stand this will result in treating the whole field as if no variability were present, hence over-fertilizing the field, increasing the cost of production and reducing nitrogen use efficiency (NUE).

Past studies have demonstrated that delayed emerging plants surrounded by earlier emerging plants will show delay in leaf stage and plant height. The shading from neighboring plants will reduce light penetration and increase competition for moisture and nutrients from taller plants with more developed root systems (Weiner, 1990). This leads to decreased corn yields even if within-row plant spacing is relatively uniform (Nafziger et al., 1991), especially at high population densities (Ford and Hicks, 1992). Liu et al. (2004) demonstrated that corn yielded 4% and 8% less when one out of six plants had a delay in emergence of two leaf stages and four leaf stages, respectively. Nafziger et al. (1991) found that if the differences in emergence times of plants in an unevenly emerged field is <2 weeks, there will be a yield loss, but not significant enough to warrant replanting. If the emergence delays for some plants approach 3 weeks, then replanting may produce a yield increase of about 10% if the proportion of delayed plants exceeds 25%. Also, a growth stage difference of two leaves or greater between adjacent plants can result in the younger plant being barren at end of the season (Nielsen, 2001).

This information necessitates the need to decide whether or not to destroy the late-emerging plants, in order to increase food production. This could increase NUE in cereals to near 50% and above the current world estimates of NUE in cereals that hover near 33% (Raun and Johnson, 1999). Moreover, while advances in agriculture technologies and intensive management strategies have contributed to improved crop performance, tackling problems related to seed emergence and uneven crop stand remains a difficult hurdle. This study addresses this issue by hypothesizing that there is no advantage of modifying nitrogen fertilization rates on plants that are delayed in emergence by more than four days when compared to neighboring plants.

Theobjective of thisresearch was to determine the effect of delayed emergence on corn grain yields with and without fertilizer N.

TABLE 1 Initial surface (0–15) soil test results prior to experiment initiation at Lake Carl Blackwell (LCB), OK, 2007 and 2010

Year	Location	K (mg kg^{-1})	P (mg kg^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	pH
2007	LCB 1	105	27	17	3.2	6.2
	LCB 2	144	45	28	4.3	5.6
2010	LCB 1	100	29	19	3.0	6.2
	LCB 2	150	40	30	4.1	5.5

pH – 1:1 soil water.
K and P – Mehlich III extraction.
NH4-N and NO3-N, 2M KCl extraction.

MATERIALS AND METHODS

Site Description

Two experiments were established in 2007, 2008, 2009, and 2010 at the Lake Carl Blackwell (LCB) irrigated research station, located in north central Oklahoma, 14 km west of Stillwater. The average annual air temperature is 15ºC and a mean annual rainfall of 932 mm (Stillwater, Oklahoma Mesonnet). Most of the precipitation occurs in the spring and early summer. Many different soil profiles are represented at varying degrees of slope, with Pulaski Fine Sandy Loam (coarse-loamy, mixed, superactive, nonacid, thermic Udic Ustifluvent) and Port Silt Loam (Fine-silty, mixed, superactive, thermic Cumulic Haplustolls) being common (USDA / NRCS soil taxonomy).

Experiment and Management

The experiment employed a randomized complete block design (RCBD) with 14 treatments and 3 replications (Table 1). Soils samples (0–15 cm) from each site were collected and characterized before application of treatments. In 2007, 2008, and 2009 Dekalb (DKC 66–23) Bt corn hybrid was planted at a seedling rate of 73,779 seeds ha^{-1}. The row spacing was 76.2 cm and the distance between individual plants was 17.8 cm. In 2010 Dekalb (DKC 61–35) Bt corn was planted at 81,000 seeds ha^{-1}. Border rows were planted with a 4-row John Deere Maxemerge-2, vacuum planter (Deere & Company, Moline, IL, USA), while the center row was planted by hand.

To achieve equal inter-row spacing and 5.08 cm planting depth, a planting device was made from 3.81 cm^2 square metal tubing. Bolts positioned 0.95 cm deep were placed every 17.8 cm apart along the tube. This was then used to create a fixed depression in the soil and ensuring specific planting points for each of the seeds. Fifteen seeds were planted in each row, which were further divided into five 3-plant subgroups. The subgroups containing three plants had two seeds planted on the same day and a delayed seed

TABLE 2 The influence of delayed planting by 0, 4, 7 and 10 days and application of sidedress nitrogen (N) fertilizer at 0, 45 and 90 kg ha^{-1}, on corn grain yield at Lake Carl Blackwell (LCB), OK, 2007 and 2010 cropping seasons

	Mean Square			
	2007		2010	
Source	LCB 1	LCB 2	LCB 1	LCB 2
Replication	3203961	19934334	29554464	8221937
Days delayed in planting	4776508	4458226	2877563¶	2885505
Sidedress N rate	5639966	11521857¶	18970314**	522405
Error	2446345	3649283	1222939	3277459
		Grain yield (kg ha^{-1})		
Days delayed in planting (days)				
0	4885	13268	7920	10172
4	5424	14525	6841	10774
7	7630	13283	7736	11258
10	4464	12559	6874	9938
Sidedress N rate (kg ha^{-1})				
0	4975	12415	5903	10819
40	5818	14327	8226	10330
80	4790	13633	7899	10471
SED	1277	1560	903	1810
N rate linear	ns	ns	***	ns
N rate quadratic	ns	*	***	ns
DDP§ linear	ns	ns	ns	ns
DDP quadratic	ns	ns	ns	ns

§ Days delayed after planting.
$^{\delta}$ Not determine due to absence of data.
*, **, ¶ significant at the 0.05, 0.01, and 0.10 probability levels, respectively.
SED = standard error of the difference between two equally replicated treatment means.

planted in the middle of the other two. The delayed seed was planted 4, 7, and 10 days after the neighboring 2 seeds (to simulate various delayed emergence scenarios) according to the treatment structure.

A preplant fertilizer application of 67 kg N ha^{-1} was made for all treatments excluding the 0-N control, using a streamer nozzle and urea ammonia nitrate (UAN, 28–0–0). At V8 corn growth stage a side dress UAN application was made at 0, 45, 67, and 90 kg ha^{-1} N (Table 2).

At maturity, subgroups within each row were tagged in sets of three, hand harvested, and each plant bagged separately. After hand harvesting, each bag was individually weighed to obtain the wet weight, oven dried at 66ºC then weighed again to obtain dry weight (15% moisture) and grain yields determined.

Data Management and Analysis

Data was statistically analyzed using generalized linear models (GLM) in SAS version 9.1 (SAS Institute, Cary, NC, USA) to determine treatment

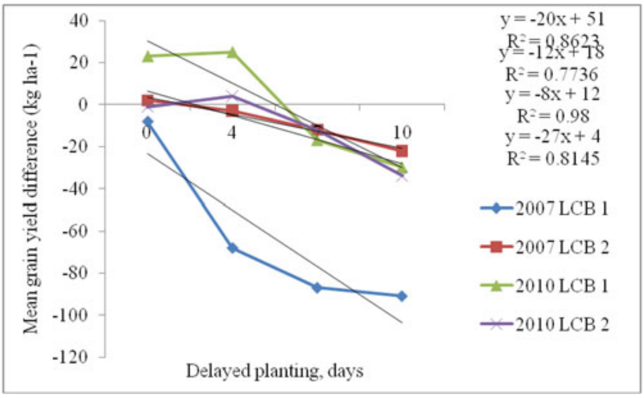

FIGURE 1 Influence of delayed planting by 0, 4, 7 and 10 days on the grain yield of the delayed plant compared to the earlier planted neighboring plants, at Lake Carl Blackwell (LCB), 2007 and 2010 cropping seasons.

effects. Means were separated using Fisher's protected least significant difference (LSD) and non-orthogonal, single-degree-of-freedom contrasts were performed.

RESULTS AND DISCUSSION

In 2007, although yield data was obtained, extreme rainfall amounts above the annual averages were recorded. Large portions of this rainfall were received at planting, which lead to less than optimum plant emergence and homogeneity among treatments. In 2008 and 2009 both experiments encountered significant damage due to feral hogs and excess rainfall, respectively and no reasonable data were collected. The experiment was repeated in 2010 and no damage due feral hogs was encountered. Thus, only results obtained from experiments in 2007 and 2010 are discussed.

Yield Decrease

The grain yield of the delayed plant was calculated by determining the difference in yield between the delayed plant (#2) and the average of the earlier planted neighboring plants (#1 and #3). The yield of the center plant compared to the average of the neighbors, significantly ($P<0.05$) decreased with each delay in planting for 2007 LCB 2 and 2010 LCB 2 cropping seasons (Table 2). In 2007 LCB 1 and 2010 LCB 1, the decrease was not significant, but still with each day delay yield losses were recorded (Figure 1). Apart from LCB 1 in 2007, which had a yield decrease of 27 kg ha^{-1} for each day delay in planting, the rest of the locations and seasons showed that the yield depression of the delayed plant was slightly lower (Figure 1). For 2010 LCB 1, 2010 LCB 2, and 2007 LCB 2, for each day delay in planting, the

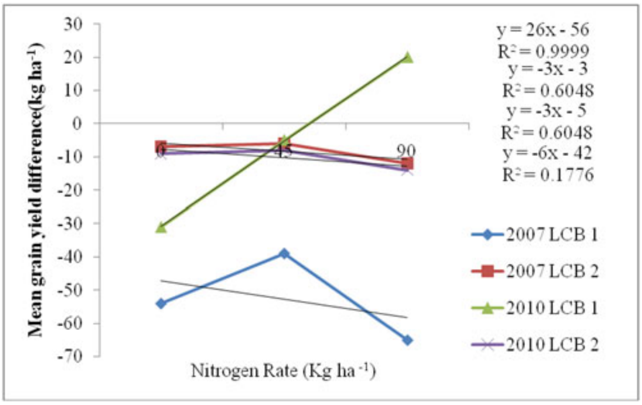

FIGURE 2 Influence of application of sidedress nitrogen fertilizer at 0, 45, 1nd 90 kg ha^{-1} on grain yield of the delayed plant compared to the earlier planted neighboring plants, at Lake Carl Blackwell (LCB), 2007 and 2010 cropping seasons.

delayed plant was depressed in yield by 20 kg ha^{-1}, 12 kg ha^{-1} and 8 kg ha^{-1} respectively.

Overall, these findings indicated that, with the exception of 2007 LCB 1, delaying planting by more than 7 days resulted to a decrease in yield of the delayed plant. This could be attributed to the inability of the delayed plant to compete for sunlight, nutrients, and moisture with the earlier established plants; hence reduction in yield. Efficient N and moisture use by the plant and the ability to capture solar radiation for photosynthetic process is crucial for growth and yield production.

Application of side dress N application to the delayed plants led to a general decline in grain yield, with the exception of 2010 LCB 1 (Figure 2). This could have been due to poor response to side dress N by the delayed plant, which resulted from an underdeveloped root system. Early planted plants have more established root systems than the late planted; hence their efficiency to take up nutrients and moisture is high (Weiner, 1990). For all the sites and cropping seasons, interaction between the number of days delayed after planting and nitrogen application was not significant ($P<0.05$). This suggests that application of the side dress N fertilizer regardless of the rate applied did not improve the growth and development of the delayed plant.

Mean Grain Yield: Delayed Planting

Depending on the cropping season and the location, mean corn grain yield was affected differently with each delay in planting. The results for 2007 and 2010 cropping seasons at LCB 1 and 2 are presented in Table 2 and Figure 3. In 2007 at LCB 1, mean corn grain yield recorded was thelowest compared to other locations and cropping seasons. The yield ranged from

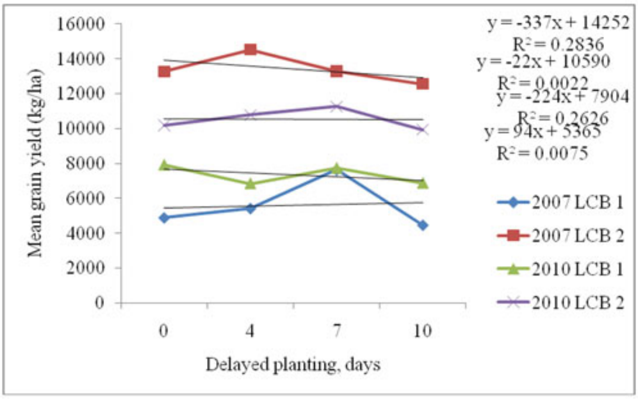

FIGURE 3 Effect of delaying planting corn by 0.4, 7 and 10 days on mean grain yield during 2007 and 2010 cropping seasons at Lake Carl Blackwell, sites 1 and 2.

4464 kg ha^{-1} to 7630 kg ha^{-1} when planting was delayed by 10 and 7 days, respectively (Table 2). For this particular site and cropping season, grain yield increased by 94 kg ha^{-1} with each delay in planting (Figure 3), contrary with past findings (Nafziger et al., 1991), that delayed planting leads to a decrease in yields.

The highest grain yield was recorded in 2007 LCB 2, which ranged from 12,559 to 14,525 kg ha^{-1} (Table 2). Each day delay in planting resulted in a 337 kg ha^{-1} yield decline (Figure 3). In the 2010 cropping season at LCB 1 and 2, each day delay in planting contributed to a 224 kg ha^{-1} and 22 kg ha^{-1} mean corn yield decrease, respectively. In general, regardless of the cropping season and site, delayed planting for up to 7 days, did not contribute to a sizeable yield reduction. However, delaying for 10 days led to a modest decline in yields; an indication that, delaying planting for this period of time did not have a substantial negative impact on the overall grain yield and would not necessitate replanting. This finding is in agreement with what (Nafziger et al., 1991) determined, that <2 weeks delay in planting only contributed to 6 to 7% reduction in grain yield, irrespective of the percentage of the plants delayed. Their study concluded that, while earlier planted plants (#1 and #3) will not make up for the yield loss of the delayed plants, replanting will not increase yield potential unless more than half of the plants were delayed by three or more weeks. However, in a separate study by Liu et al. (2004) it was established that plants neighboring delayed plants can partially offset yield losses of the delayed plants, and plants located near the gaps in the row are able to compensate for the gaps; hence reducing the negative impact delayed planting will have on the mean grain yield. These findings assist in explaining the results obtained in this study.

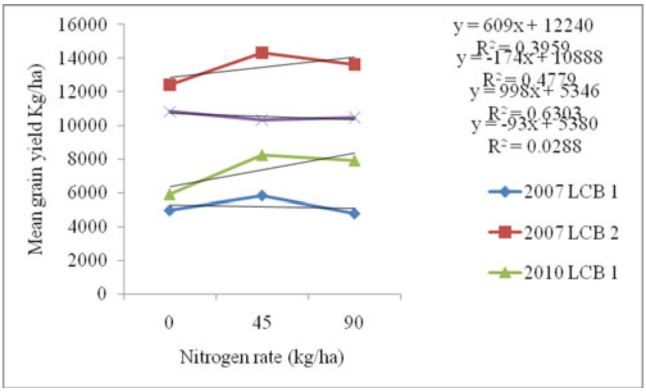

FIGURE 4 Effect of varrying nitrogen application on mean corn grain yield during 2007 and 2010 cropping seasons at Lake Carl Blackwell, sites 1 and 2.

Nitrogen Response

The results for corn response to side dress nitrogen (N) application in 2007 and 2010 cropping seasons, at LCB 1 and 2 are presented in Table 2 and Figure 4. Generally the results varied with location, implying that corn responded differently to fertilizer N application. This could be due to field variability that exists at low resolutions (Solie et al., 1996).

In 2007 at LCB 1, corn yield increased with N rate (40 kg N ha^{-1}). Grain yields however declined when the N rate was increased to 80 kg N ha^{-1} (Figure 4). During the cropping season, at LCB 2, for each increase in sidedress N applied, mean grain yield increased by 608 kg ha^{-1}. Mean grain yields as earlier recorded at LCB 1 dropped as well for LCB 2 to 13,633 kg ha^{-1}, at the 80 kg N ha^{-1} rate, and to 14327 kg ha^{-1} when 40 kg N ha^{-1} was applied (Table 2).

For 2010 LCB 1, mean corn yields were generally low. However,). the highest response to side dress N was recorded, with each increase in N rate applied, contributing to a 998 kg ha^{-1} mean corn yield increase. Nonetheless, with 80 kg ha^{-1}, a slight drop in yield was recorded (Figure 4). At LCB 2, a negative response to applied N was recorded as mean grain yields decreased by 174 kg ha^{-1} with each increase in N side dress applied (Figure 4).

These findings, with exception of 2010 LCB 2, indicated that mean grain yield increased with 40 kg N ha^{-1} side dress application and dropped when the rate was increased to 80 kg N ha^{-1}. This suggests that over cropping seasons and locations, 40 kg N ha^{-1} appeared to have been an optimum rate and beyond which mean grain yields declined. Nitrogen fertilization increases corn yield when N supply by soil is low (Wienhold et al., 1995; Sexton et al., 1996). Therefore, an excess application of N fertilizer beyond maximums will not lead to further increases. Instead, nitrate N is accumulated below the root zone, which can cause toxicity especially with in adequate soil

TABLE 3 Change in grain yield of the middle delayed plant compared to the average of the earlier planted neighboring plants as affected by delayed planting of 0, 4, 7 and 10 days and application of sidedress nitrogen (N) fertilizer at 0, 45 and 90 kg ha^{-1}, at Lake Carl Blackwell (LCB), OK in 2007 and 2010 cropping seasons

	Mean Square			
	2007		2010	
Source	LCB 1	LCB 2	LCB 1	LCB 2
Replication	1021	991	702	1194
Days delayed in planting	8456	851*	4098	2280*
Sidedress N rate	634	100	3413	275
Error	3145	280	3027	659
	Grain yield (kg ha^{-1})			
Delayed planting (days)				
0	−8	2	24	−2
4	−68	−3	26	4
7	−87	−12	−17	−12
10	−91	−22	−30	−34
Sidedress N rate (kg ha^{-1})				
0	−54	−7	−31	−9
40	−39	−6	−5	−8
80	−66	−12	20	−14
SED	46	14	45	21
N rate linear	ns	ns	ns	ns
N rate quadratic	ns	ns	ns	ns
DDP§ linear	ns	**	ns	**
DDP quadratic	ns	ns	ns	ns

§ Days delayed after planting.
$^{\delta}$ Not determined due to absence of data.
*, **significant at the 0.05, and 0.01 probability levels, respectively.
SED = standard error of the difference between two equally replicated treatment means.

moisture (Ludwick et al., 1976). Excess N in the soil is also susceptible to loss by other mechanisms such as plant loss as ammonia (NH_3), denitrification, surface runoff, leaching and volatilization (Raun and Johnson, 1999) thereby reducing NUE Table 3.

CONCLUSIONS

The yield of the delayed plant (#2) consistently decreased with each day delay in planting. For 2007 LCB 1, 2007 LCB 2, 2010 LCB 1, and 2010 LCB 2, yields decreased by 27, 8, 20, and 12 kg ha^{-1} for each planting day delay, respectively. Generally, the delayed plants did not respond to side dress N application, although a slight decrease in yield was noted with each additional N rate. The overall grain yield was not significantly reduced by delayed planting enough to warrant replanting. However, across seasons and locations, mean grain yield almost always resulted in a yield decrease when planting was delayed by 10 days. This demonstrated the ability of the earlier established plants to partially compensate for the decreased grain yield as a result of delayed planting. Therefore replanting plants delayed by 10 days may not be necessary since grain yield potential will not be increased. However, over all locations and years, the mean grain yield decrease of the delayed plant versus neighboring plants for each day delay was 122 kg ha^{-1}. Side dress application contributed to an increase in yield by 609 and 998 kg ha^{-1} for 2007 LCB 1 and 2010 LCB 1, respectively. The 40 kg N ha^{-1} N rate seemed to have been an optimum rate across seasons and sites, and beyond this yield generally declined.

ACKNOWLEGDMENTS

The authors would like to thank; Kevin Waldschmidt, Mondini Millor, Natasha Macnack, Anne Raun, Katharine Raun, and Caio Torres for their support during data collection, processing and analysis.

REFERENCES

Benson, G. O. 1990. Corn replants decisions: A review. *Journal of Production Agriculture* 3:180–184.

Blacklow, W. M. 1974. Simulation model to predict germination and emergence of corn (*zea mays* l.) In an environment of changing temperature. *Crop Science* 13: 604–608.

Finck, C. 1997. Keep the planter pass sacred. *Farm Journal* 121: 16–18.

Ford, J. H., and D. R. Hicks. 1992. Corn growth and yield in uneven emerging stands. *Journal of Production Agriculture* 5: 185–188.

Hayhoe, H. N., and L. M. Dwyer. 1990. Relationship between percentage emergence and growing degree days for corn. *Canadian Journal of Soil Science* 70: 493–497.

Liu, W., M. Tollenaar., G. Stewart, and W. Deen. 2004. Response of corn grain yield to spatial and temporal variability in emergence. *Crop Science* 44: 847–854.

Ludwick, A. E., J. E. Reuss, and E. J. Langin. (1976). Soil nitrates following four years continuous corn and as surveyed in irrigated farm fields of central and eastern Colorado. *Environmental Quality* 5: 82–86.

Nafziger, E. D., P. R. Carter, and E. E. Graham. 1991. Response of corn to uneven emergence. *Crop Science* 31: 811–815.

Nielsen, R. L. 1998. Tips to make corn more profitable. West Lafayette, IN: Agronomy Department, Purdue University. Nielsen, R. L. 2001. Stand establishment variability in corn [online]. Available at: http://www.agry.purdue.edu/ext/pubs/AGRY-91-01_v5.pdf (accessed 1 December 2003).

Raun, W. R., and G. V. Johnson. 1999. Improving nitrogen use efficiency for cereal production. *Agronomy Journal* 91: 357–363.

Schmidt, J. P., A. J. Dejoia, R. B. Ferguson, R. K. Taylor, R. K. Young, and J. L. Havlin. 2002. Corn yield response to nitrogen at multiple in-field locations. *Agronomy Journal* 94: 798–806.

Schneider, E. C. and S. C. Gupta. 1985. Corn emergence as influenced by soil temperature, matric potential and aggregate size distribution. *Soil Science Society of America Journal* 49: 415–422.

Sexton, B. T., J. F. Moncrief, C. J. Rosen, S. C. Gupta, and H. H. Cheng. 1996. Optimizing nitrogen and irrigation inputs for corn based on nitrate leaching and yield on a course textured soil. *Journal of Environmental Quality* 25: 982–992.

Solie, J. B., W. R. Raun, R. W. Whitney, M. L. Stone, and J. D. Ringer. 1996. Optical sensor based field element size and sensing strategy for nitrogen application. *Trans. ASAE* 39: 1983–1992.

Stibbe, E., and R. Terpstra. 1982. Effect of penetration resistance on emergence and early growth of silage corn in a laboratory experiment with sandy soil. *Agricultural Research Organization, Institute of Soils and Water, Bet Dagan Israel* 2: 143–153.

Weiner, J. 1990. Asymmetric competition in plant population. *Trends in Ecology and Evolution* 5: 360–364.

Wienhold, B. J., T. P. Trooien, and G. A. Reichman, (1995). Yield and nitrogen use efficiency of irrigated corn in the Northern Great Plans. *Agronomy Journal* 87: 842–846.