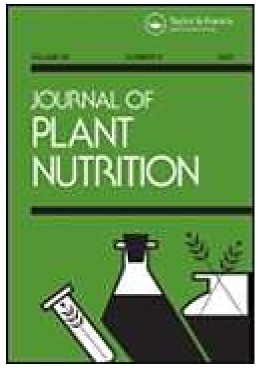

Effect of Delayed Emergence on Corn Grain Yields

Journal:	*Journal of Plant Nutrition*
Manuscript ID:	LPLA-2009-0479.R1
Manuscript Type:	Original Articles
Date Submitted by the Author:	27-Oct-2010
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Keywords:	Nitrogen < Macronutrients, Plant Physiology, Soil Fertility, Precision Agriculture, emergence, germination, Corn < Crops, maize

INTRODUCTION

Profit and the environment are important issues to corn producers. To maintain these at acceptable levels, yield should be optimized using modest amounts of agricultural inputs. It is well documented that crop stand is important in determining final grain yield (Evans and Fisher, 1999; Tollenaar and Wu, 1999). Crops with uniform stands have the advantage of producing higher grain yield under good growing conditions and management systems than crops with poor stands. Thus for farmers, replanting is an option to consider when stands are poor before further investing in fertilizer, herbicide and irrigation. One factor important in securing uniform stands is obtaining uniform emergence. Comprehensive work by Martin et al. (2005) found that on average, differences in corn grain yield from plant to plant were 2.8 Mg ha^{-1} (44 transects in 3 countries and 5 US States). Their findings in Argentina, Mexico, and the USA clearly showed that heterogeneity of plant stands and corn emergence are common, noted in the magnitude of average plant to plant yield differences.

Delayed emergence and complete failure of seed emergence are causes of uneven crop growth early in the season. This behavior can be attributed to irregular planting depth, seed quality, tillage, soil compaction, and limited moisture (Ford and Hicks, 1992; Dwyer et al., 1999; Diaz-Zorita et al., 2005; Gupta et al., 1988).

Alessi and Power (1971) observed that each 10 mm increase in planting depth delayed corn emergence for about 1 day at a constant temperature of 13.3 ^{o}C. They concluded that at least 68 growing degree days (GDD) with temperatures above 13.3 ^{o}C and adequate soil moisture are necessary to achieve 80% emergence in corn. A study by Triplet and Tesar (1960) showed that improved emergence of alfalfa (*Medicago sativa*

L.) seedlings was attributed to increased soil water and seed-contact as a result of increased planting depth from 0 to 2.5 cm and soil compaction.

Graven and Carter (1991) found that emergence rate strongly depends on corn seed quality. They observed a 4 to 6% decrease in emergence associated with medium and low seed quality, and that lower seed quality decreased emergence when fields were planted earlier. When planting date was delayed, seed quality did not have a significant effect on emergence. With low and medium quality seed they found a 1 day delayed emergence compared to high quality seed. Graven and Carter (1990) concluded that seed size and shape had an effect on emergence. They achieved higher emergence rates with large flat and small round seeds compared to large round and small flat seeds under temporal and moisture stress environments.

Delayed emergence and reduced plant populations are problems associated with corn production in conservation tillage (Lithourgidis et al., 2005; Drury et al., 1999). They also found that when soil moisture levels were sufficient, the emergence rate did not differ in conventional till and no-till systems. Similarly, Drury et al. (1999) reported that in no-till systems, emergence was reduced by 24% and subsequently corn grain yield was reduced by 9-17% compared with conservation tillage. Dry soil conditions, however, were associated with a 16% decrease in emergence in no-till corn. They found that there was no significant difference in delayed plants in reduced till and they noted that the presence of delayed plants did not reduce silage yield in no-till systems. Seedling emergence 2 to 3 weeks after planting was lower in no-till, compared to conventional till and reduced-till (Burgess et al., 1996).

Murungu (2003) found that seed priming (soaking seeds in water before planting) improved emergence and early growth in drying soils. Harris et al. (1999) also concluded that with seed priming, there was a direct benefit in faster emergence, better stands and a lower incidence of re-sowing. In a study conducted to assess the influence of delayed planting on emergence of corn seed coated with Temperature-Activated Polymer, Gesch and Archer (2005) found that emergence was delayed causing uneven stands and subsequent yield loss. This study demonstrates the deleterious effect of seed treatment on the emergence pattern of corn. Lindstrom et al. (1976) showed that a combination of factors including water potential, the lowering of soil temperature from 25 ^{o}C, and increasing planting depth decreased corn emergence. Helms et al. (1997) found that if soil water content is sufficient for germination and persists for 18 days after planting, emergence will not be reduced. Despite improved agricultural practices and land management, complete eradication of seed emergence related problems is still not achievable.

There have been numerous studies on the causes of delayed emergence but limited studies on the effect of delayed emergence on corn grain yields. Nafziger et al. (1991) found that delayed emergence can reduce grain yields of corn from 6 to 22%. Corn grain yields were reduced by 0.55 Mg ha^{-1} and 1.2 Mg ha^{-1} with planting dates delayed 7 and 14 days respectively (Ford and Hicks 1992). They also observed reduced yields when non-uniform (mixed) stands were simulated by planting corn plants at different distances within the row. Imholte and Carter (1987) found that delayed planting decreased yields in both conventional and no-till corn systems; the highest corn grain yields of conventional and no-till achieved when planting was completed by early May.

Many studies showed that delayed plant emergence reduced yield, thus in theory if each plant could be fertilized individually, it is possible to increase nitrogen use efficiency (NUE) and reduce the cost of fertilizer. This would also help to reduce the impact of N on the environment. By finding out how many days plant emergence is delayed, it is possible to identify which plants need to be fertilized and which ones do not. The current emphasis in variable rate application of nutrients especially N in corn requires by-plant emergence data. Limited research has been done that looked into delayed planting at the by-plant level. The objectives of this study were to determine corn grain yield reduction as a function of interplant competition arising from delayed emergence; and to evaluate yield levels in 3-plant sequences, with and without delayed emergence.

MATERIALS AND METHODS

Two experimental sites were established in the spring 2005: one near Perry, OK at the Lake Carl Blackwell irrigated research station, and one at Efaw Research Station (rainfed), near Stillwater, OK. The Lake Carl Blackwell research station soil series is a Pulaski fine sandy loam (fine sandy loam, coarse-loamy, mixed, nonacid, thermic Typic Ustifluvent) and Efaw Research Station has a soil series of Easpur loam (fine-loamy, mixed, superactive, thermic Fluventic Haplustoll). Results from composite pre-plant soil sample analysis at each site are reported in Table 1.

The experiment employed a randomized complete block design (RCBD) with 11 treatments and three replications. Each treatment was a combination of 0, 56 and 168 kg N ha^{-1} and a delayed emergence scenario of 0, 2, 5, 8, and 12 days delay. The treatment structure is reported in Table 2. Of the 11 treatments, Treatments 1, 2 and 7 were reference plots (no delay planting of all the seeds). In all remaining treatments, five 3-plant sequences (to simulate various delayed emergence scenarios) were established. Each plot consisted of a row that was hand planted with a border row on each side. In each of the delay emergence sequences, two seeds (adjacent plants) were planted at planting while a seed (middle plant) was planted in the middle of the two plants at a later date depending on the number of days set for delayed emergence. Row and plant configuration are illustrated in Figure 1. Border rows were planted on the same day on each side of the rows which contained the delayed plants at a similar population using two-row John Deere "MaxEmerge" seeding equipment (Deere & Company, Moline, Illinois). Treatment averages were generated from at least 9, 3-plant sequences at each site, each year.

The corn hybrid "33B51" (Pioneer Hi-Bred International Inc., Johnston, IA) was planted late March or early April at a seeding rate of 73779 seeds ha^{-1}. With corn planted at 76.2 cm row spacing, the distance between plants was 17.8 cm. Equal inter-row spacing is essential for the analysis of this experiment; therefore the middle row containing the delay emergence scenarios was planted by hand. To maintain a uniform depth of 5 cm and plant spacing of 17.8 cm, a special tool was made from 1.0 cm square tubing. Bolts were positioned 3.8 cm deep, every 17.8 cm along the tube. This was then used to create uniform depth in the soil and ensuring specific planting points for each of the seeds (Figure 2).

The two preplant nitrogen fertilizer rates (56 and 168 kg ha^{-1}) were applied broadcast before planting using urea (46-0-0). Bicep Lite II Magnum® Syngenta

(Greensboro, North Carolina) was applied preplant at a rate of 2338 ml ha^{-1} to control broadleaf and grass weeds at each site.

For each of the 3-plant sequences, each plant was harvested and bagged separately. In each plot, three of the five 3-plant sequences were selected for harvest. Each bag was individually weighed wet, dried in an air forced oven at 66 ^{o}C and weighed again for moisture determination. Percent moisture was determined by taking the wet weight minus the dry weight and dividing by the wet weight. Grain yield for all treatments was adjusted to 15.5% moisture.

Grain yield depression was determined as the difference of average grain yield of non-delayed plants and the yield of delayed plants for each delayed emergence treatment. Percent yield of the delayed plant was determined as the ratio of the yield of the delayed plant and the average yield of non-delayed plants multiplied by 100. Data was subjected to statistical analysis using the General Linear Models (GLM) procedure in SAS (2002).

RESULTS AND DISCUSSION

The main effect of treatment on corn grain yield was significant at $p<0.05$ for both years at both locations. Even though planting depth, method of planting, and seed cover/compaction were held constant, there were minor discrepancies in emergence. Data was not collected documenting exact day of emergence for all 3-plant sequences that comprised individual treatments, but the large number of sub-sets collected was expected to deliver accurate estimates of the average yield, yield depression, and percent of maximum grain yield.

Averaged over years, grain yields decreased when the middle plant of the 3-plant sequence was delay planted 2, 5, 8, and 12 days, by 3, 10, 19 and 25%, respectively (Table 3). For the rainfed site, average grain yields decreased when the middle plant in the 3-plant sequence was delay planted at 2, 5, 8, and 12 days, by 14, 25, 23, and 11%, respectively. In terms of percent yield reduction, the overall effects of delayed planting on resultant grain yields were greater where irrigation was not available.

Grain Yield by Plant of 3-Plant Sequence

Grain yields for each plant where plants 1 and 3 were planted at the same time, and plant 2 was delay planted by 2, 5, 8, and 12 days are reported in Figures 3-6 for Efaw and Lake Carl Blackwell, with 56 and 168 kg N ha^{-1} applied preplant in both 2005 and 2006, respectively. The standard error of the difference between two equally replicated means (SED) is reported on each graph (Figures 3-6). As expected, no differences in grain yield were found in the 3-plant sequence when planted on the same day at Efaw, 2005 for the 56 kg N ha^{-1} rate (Figure 3a). However, when delayed by 2 or more days, the middle plant had significantly lower yields, and the yield reduction exceeded 2.0 Mg ha^{-1}. These yield reductions were primarily due to a middle plant not producing when averaged over the 3-plant sequence. Lie et al. (2004) reported that plant emergence is a key factor in determining final corn grain yield. In their study they found that delaying planting until 1-2 leaf stage resulted in 4-8% yield reduction. It is important to note that there were also yield reductions in the adjacent plants when the middle plant was delay planted by 2, 5, and 8 days (compared to no delay). However, for the 12 day delay the middle plant had significantly lower yields but the adjacent plant yields tended to be higher than 2, 5, and 8 day delay in planting. This suggests that at 2, 5, and 8 days the middle plant competed with the adjacent plants, but for the 12 day delay there was less competition since adjacent plants yielded slightly more. If two plants are crowded, one being bigger and one being smaller, the smaller plant will likely compete less for sunlight and nutrients. In this case, the smaller plant will not be able to catch up resulting in a smaller ear at harvest (Nielsen, 2001).

At the 168 kg N ha^{-1} rate, at Efaw in 2005, results were highly variable, especially when noting the depression in yield for the middle plant when no delay was imposed (Figure 3b). It is likely that the 2, 5 and 8 delay could have increased yields because competition between plants was less. This may have been caused by the high seeding rate used at this rainfed site. In other words there was likely less competition between plants, at this high N rate, evidenced in the higher yields when compared to those at the 56 kg N ha^{-1} rate (Figure 3a versus Figure 3b).

Results for the Efaw site in 2006 at the 56 and 168 kg N ha^{-1} rates are reported in Figures 4a and b, respectively. Extreme temperatures were encountered throughout the season at this site, and as a result, yields were highly variable. In general, limited differences were noted for the 0, 2, 5, and 8 day delays at the 56 kg N ha^{-1} rate (Figure 4a). With a 12 day delay, the middle plant yielded significantly less than the adjacent plants. Furthermore, the two non-delayed plants for the 12 day delay tended to have higher yields when compared to the 0, 5, and 8 day delayed plantings. At the 168 kg N ha^{-1} rate, yields were higher and the separation of yields due to treatment was wider (Figure 4b). The more the middle plant was delayed the greater the yield reduction was when compared to the two non-delayed plants.

At LCB in 2005, similar results were observed as that reported at Efaw for the 56 and 168 kg N ha^{-1} rates (Figures 5a and b). However, at this site, there was no significant effect of delay planting for the 2 day delay at the 56 kg N ha^{-1} rate. With a 5 day delay, the middle plant had significantly lower yields compared with the 0 and 2 day delay (Figure 5a). At the 168 kg N ha^{-1} rate the 2 and 5 day delayed plants were not different from the 0 day delay treatment. By applying more N, the 5 day delay was in effect not different from the 0 and 2 day delay treatments, yet at the low N rate the yield decrease was notable (Figures 5a and b). This was not understood.

In 2006 at LCB the 56 and 168 kg N ha^{-1} rates (Figures 6a and b, respectively) resulted in highly variable treatment results. At the 56 kg N ha^{-1} rate, the 8 and 12 day delayed planting had lower yields for the middle plant. At the 168 kg N ha^{-1} rate, yields were higher, but more variable. The middle plants for the 8 and 12 day delayed planting tended to have lower yields while the adjacent plants had higher yields, similar to results for Efaw in 2005 and 2006. As was noted for Efaw in 2006, the severe heat contributed to the variable yield results at LCB. The high temperatures encountered during flowering resulted in incomplete pollination that further depressed final grain yields.

Grain Yield Depression

Grain yield depression is reported as a function of planting delay in days for Efaw and Lake Carl Blackwell in 2005 and 2006 in Figures 7-8, respectively. At Efaw in 2005 (Figure 7a) the grain yield depression increased significantly as planting was delayed from 2 to 12 days. As has been noted, the delayed planting was used to simulate delayed emergence. At this site in 2005, when the middle plant was delayed 5 days, grain yield reduction was estimated to exceed 2.4 Mg ha^{-1} predicted by the linear relationship (Figure 7a). With 8 and 12 day delay, the grain yield depression exceeded 3.0 Mg ha^{-1}, for both N rates. Interestingly, these values are very similar to that reported by Martin et al. (2005) concerning "average" plant to plant yield differences (2.8 Mg ha^{-1}) from corn fields all over the world.

In 2006 at Efaw (Figure 7b), corn grain yield depression as a function of delayed planting was actually greater for both N rates, noting the increased slope when compared to the 2005 data (Figure 7b versus Figure 7a). However, for 2006, limited differences were noted between the 2 and 5 day delay planting (Figure 7b). This trend was generally similar for the 56 and 168 kg N ha^{-1} rates.

At LCB in 2005, the grain yield depression was highly significant as a function of planting delay, more obvious than that observed at the other sites and/or years (Figure 8a). This was partly due to the increased yield levels recorded at LCB in 2005. However, in 2006, the effect of planting delay on grain yield depression was less significant, partly due to the lower yields encountered in this heat stressed year (Figure 8b). Over both sites and years, for each day of delay emergence (estimated using delayed planting), grain yield depression could be expected to exceed 0.225 Mg $ha^{-1}day^{-1}$ using the slope components reported at each site (Figures 7-8).

Percent of Maximum Corn Grain Yield

The percent of maximum corn grain yield expressed as a function of planting delay for Efaw and Lake Carl Blackwell, in 2005 and 2006 is reported in Figures 9-10, respectively. At Efaw in 2005, the percent of maximum grain yield was reduced by 3 and

15% at the 56 and 168 kg N ha^{-1} preplant rates, respectively when the middle plant was planted 2 days later (Figure 9a). Percent of maximum corn grain yield continued to decline gradually when the delay went from 2 to 8 days. By the 12 day delay, grain yields were significantly reduced beyond that seen for the 2, 5, and 8 day delayed planting (Figure 9a). This relationship between percent of maximum corn grain yield and planting delay was much clearer at Efaw in 2006, whereby a distinct linear relationship was observed, and similar for both N rates (Figure 9b). For the 12 day delay, the percent of maximum corn grain yield declined to less than 20% of the average of the two adjacent plants (Figure 9b).

At LCB in 2005 grain yields declined significantly in a linear fashion as planting was delayed from 2 to 12 days (Figure 10a). However, there was a trend for limited yield reduction when the middle plant was only 2 days late in emerging. With a 5 day delay, the percent maximum corn grain yield was estimated at 21 and 24% less than the 2 day delay (Figure 10a). In general, limited differences due to the fertilizer N rate were found at this site. In 2006 at LCB there were varying results due to the severe heat stress encountered from July 14 to August 18 (temperature exceeded 37°C days) (Figure 10b). Despite the heat stress, the linear relationship of percent of maximum corn grain yield expressed as planting day delays, were similar to that noted in 2005 (Figures 10a and b).

CONCLUSIONS

Delayed planting to simulate delayed emergence was used in this experiment to determine the adverse effects on final corn grain yield. When comparing 3-plant sequences, the results show that delayed emerging plants result in decreased corn grain yields. Over both sites and years, data showed that when corn plants were delay planted 5 days or more, there was almost always a significant yield reduction. When the middle plant was delayed by 2, 5, and 8 days, it continued to compete with the two non-delayed plants. With a 12 day delay, the middle plant competed less with the two non-delayed plants and the latter tended to have higher by-plant yields. Results from this study will assist in improving by-plant N fertilization by knowing how much by-plant corn grain yields will be reduced for each day delay in emergence. This information will in turn be used to estimate N removal based on yield level (or projected yield decrease) based on how much each plant is or is not delayed versus neighboring plants. Over all sites and years, for each day delay in emergence (one out of every 3 plants), corn grain yields decreased 0.225 to 1.379 Mg ha^{-1} day^{-1}.

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Table 1. Initial surface (0-30 cm) soil test results at Efaw and Lake Carl Blackwell (LCB), OK.

Location, depth (cm)	K mg kg^{-1}	P mg kg^{-1}	NH_4-N mg kg^{-1}	NO_3-N mg kg^{-1}	Total Nitrogen g kg^{-1}	Total Carbon g kg^{-1}	pH
Efaw S., 0-15	99	22	9	3.5	0.72	10.69	5.05
Efaw S., 15-30	76	17	16	4.3	0.65	10.23	5.71
Efaw N., 0-15	105	20	17	3.2	0.64	10.93	6.15
Efaw N., 15-30	76	19	11	3.7	0.57	9.09	6.56
LCB, 0-15	144	45	28	4.3	0.77	9.87	5.63

NH_4-N and NO_3-N – 2 M KCL extract; P and K – Mehlich-3 extraction; pH – 1:1 soil:deionized water

1 Table 2. Treatment structure employed at Lake Carl Blackwell, and Efaw, 2005 and 2006
2 evaluating delayed planting on resultant corn grain yields.

Treatment No.	Delay in planting	N rate, kg ha^{-1}
1	All 3 plants planted on the same day	0
2	All 3 plants planted on the same day	56
3	Middle plant planted 2 days late	56
4	Middle plant planted 5 days late	56
5	Middle plant planted 8 days late	56
6	Middle plant planted 12 days late	56
7	All 3 plants planted on the same day	168
8	Middle plant planted 2 days late	168
9	Middle plant planted 5 days late	168
10	Middle plant planted 8 days late	168
11	Middle plant planted 12 days late	168

Table 3. Treatment, preplant N, Days delay, planting, Mean grain yields (kg ha^{-1}) for Efaw, Lake Carl Blackwell, 2005

Treat-ment	Preplant N, kg ha^{-1}	Days Delay Planting	*Mean grain yields Mg ha^{-1}*					
			Efaw			*LCB*		
			2005	2006	Avg.	2005	2006	*Avg.*
1	0	0	4.10	4.01	4.05	15.58	2.15	*8.86*
2	56	0	9.08	6.33	7.71	16.07	5.02	*10.54*
3	56	2	5.83	7.44	6.64	16.81	3.69	*10.25*
4	56	5	6.23	5.22	5.73	15.25	3.90	*9.58*
5	56	8	6.65	5.27	5.96	13.61	3.55	*8.58*
6	56	12	7.11	6.71	6.91	11.17	4.62	*7.90*
7	168	0	9.65	11.53	10.59	15.13	5.48	*10.30*
8	168	2	11.31	9.14	10.22	16.12	6.40	*11.26*
9	168	5	11.56	10.72	11.14	16.36	5.64	*11.00*
10	168	8	11.58	10.24	10.91	11.68	7.00	*9.34*
11	168	12	10.48	9.33	9.90	11.67	6.16	*8.92*
SED			*1.05*	*2.05*		*1.18*	*1.14*	

SED – standard error of the difference between two equally replicated means

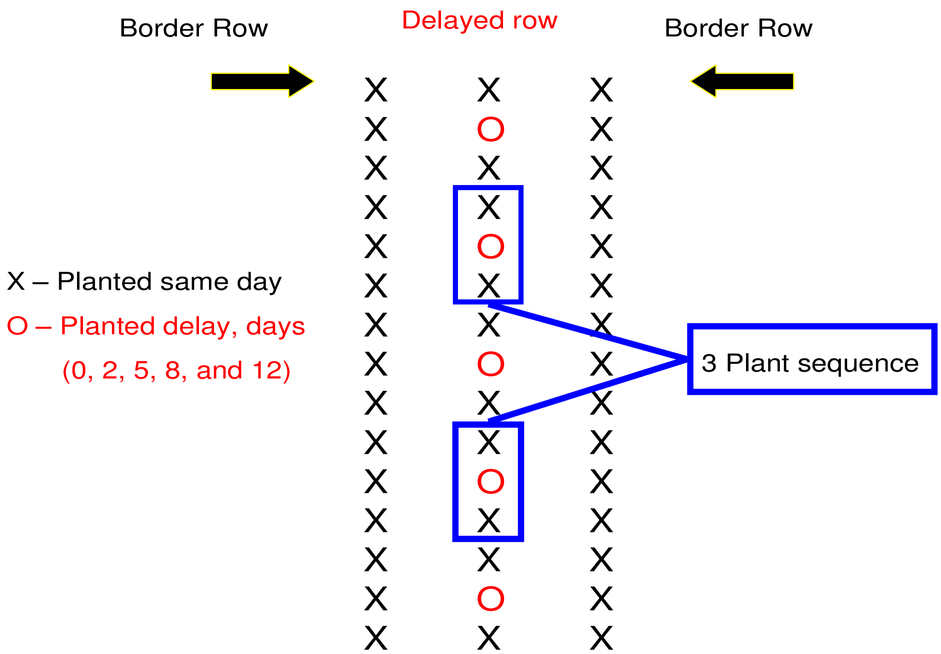

Figure 1. Schematic diagram illustrating a single plot whereby the center row had 5, 3-plant sequences between two border rows. Each treatment was replicated three times, thus, 15, 3-plant sequences were used to determine each treatment average.

Figure 2. Planting device constructed to establish fixed depths, and distances between plants for all sites, 2005-2006.

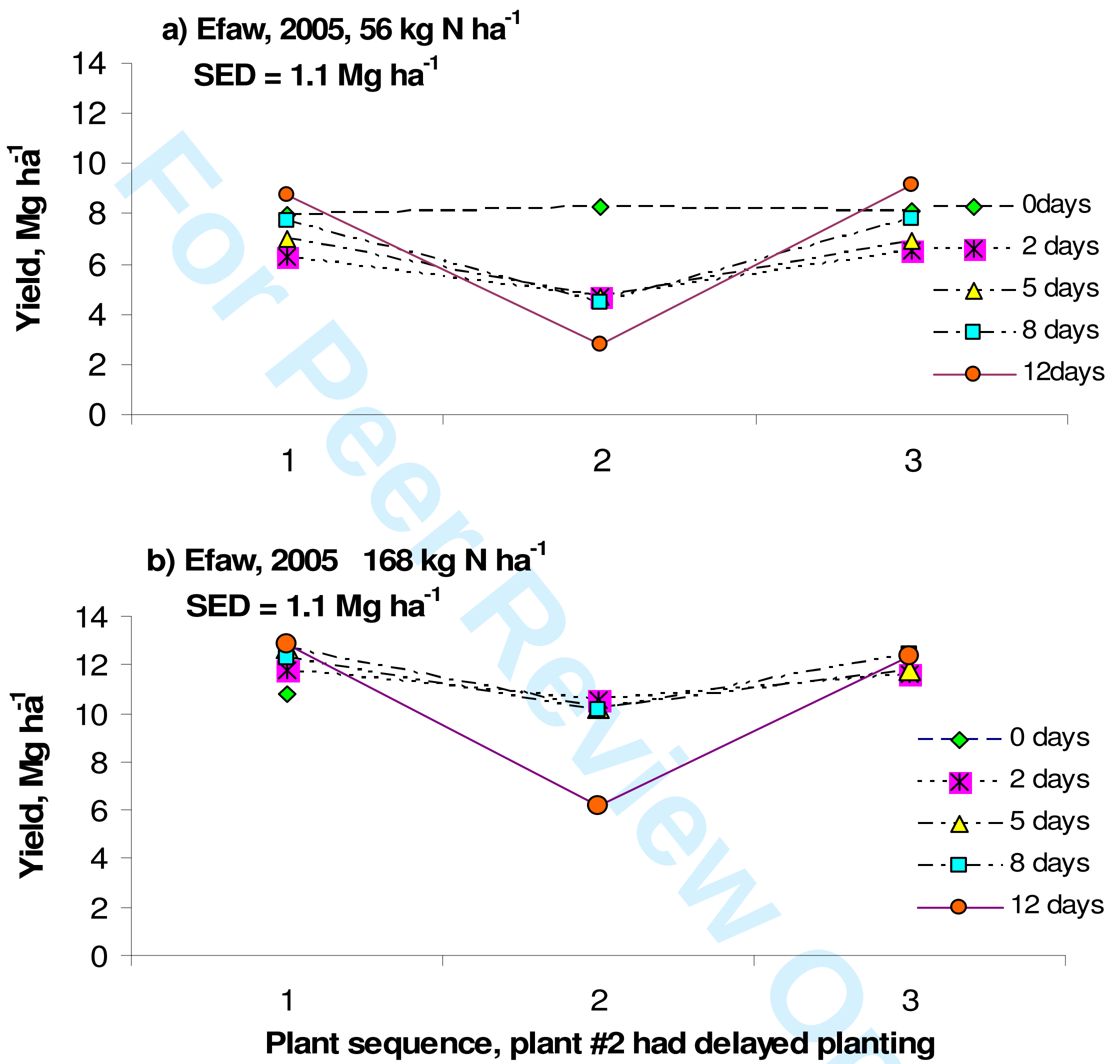

Figure 3. Three plant sequence where plant #2 (middle plant) was planted 0, 2, 5, 8, and 12 days later, at Efaw in 2005 with a preplant applied N rate of 56 kg ha^{-1} (a); and 168 kg ha^{-1} (b). Each point represents the average of nine plants repeated in these 3-plant sequences.

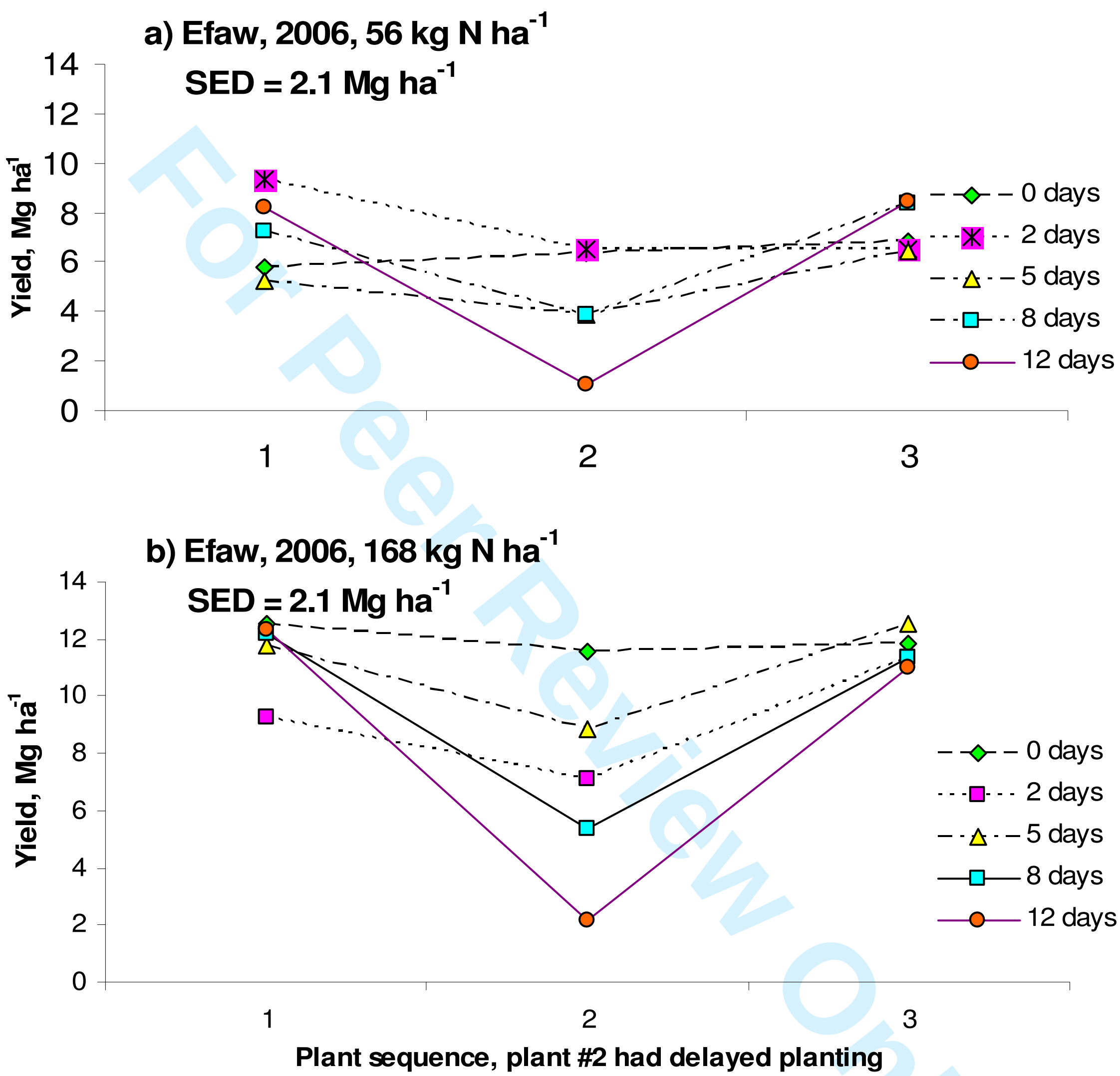

Figure 4. Three plant sequence where plant #2 (middle plant) was planted 0, 2, 5, 8, and 12 days later, at Efaw in 2006 with a preplant applied N rate of 56 kg ha^{-1} (a); and 168 kg ha^{-1} (b). Each point represents the average of nine plants repeated in these 3-plant sequences.

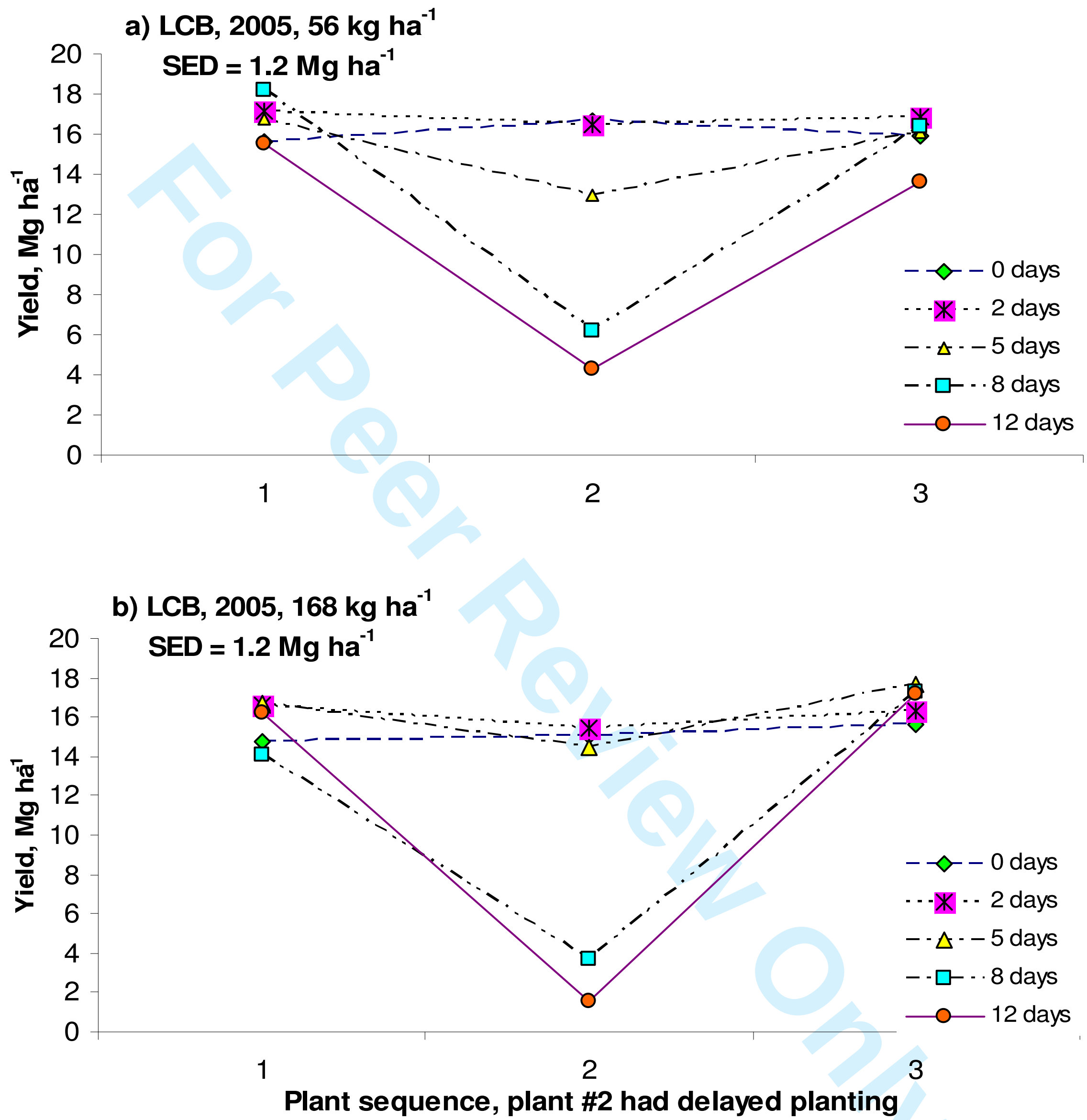

Figure 5. Three- plant sequence where plant #2 (middle plant) was planted 0, 2, 5, 8, and 12 days later, at Lake Carl Blackwell (LCB) in 2005 with a preplant applied N rate of 56 kg ha^{-1} (a); and 168 kg ha^{-1} (b). Each point represents the average of nine plants repeated in these 3-plant sequences.

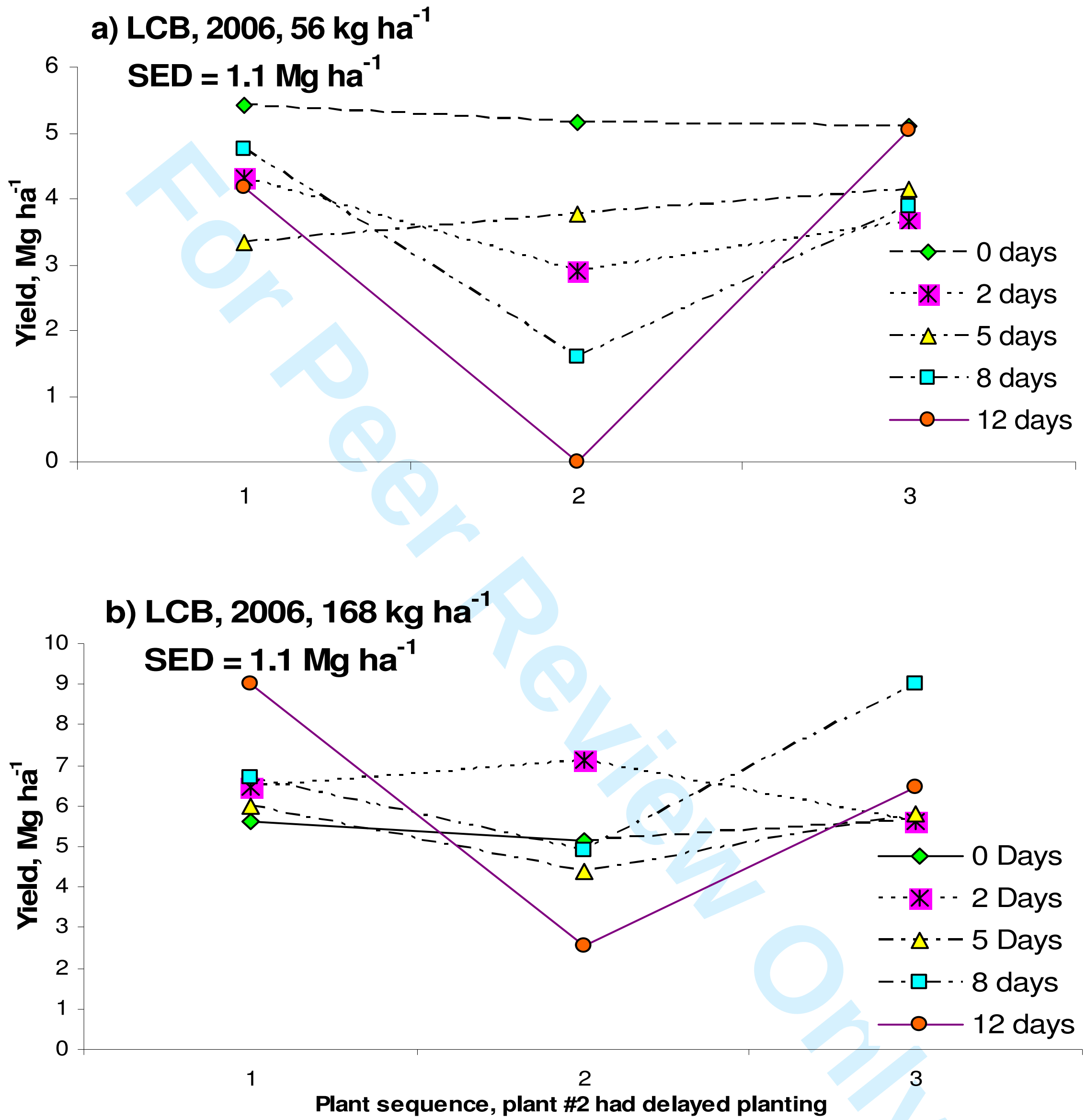

Figure 6. Three- plant sequence where plant #2 (middle plant) was planted 0, 2, 5, 8, and 12 days later, at Lake Carl Blackwell (LCB) in 2006 with a preplant applied N rate of 56 kg ha^{-1} (a); and 168 kg ha^{-1} (b). Each point represents the average of nine plants repeated in these 3-plant sequences.

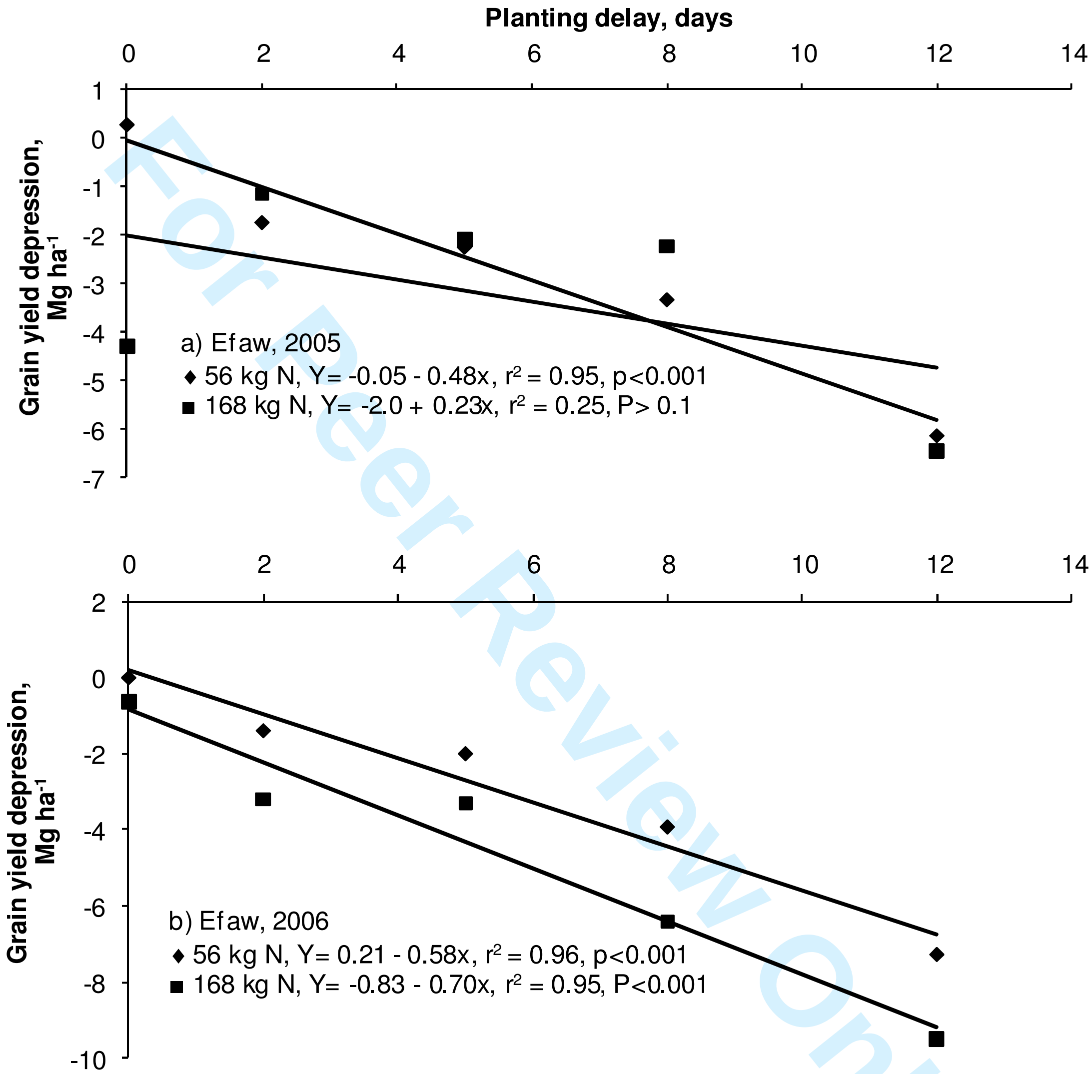

Figure 7. Corn grain yield depression when the middle plant was delayed 0, 2, 5, 8, and 12 days at Efaw in 2005 (a) and 2006 (b).

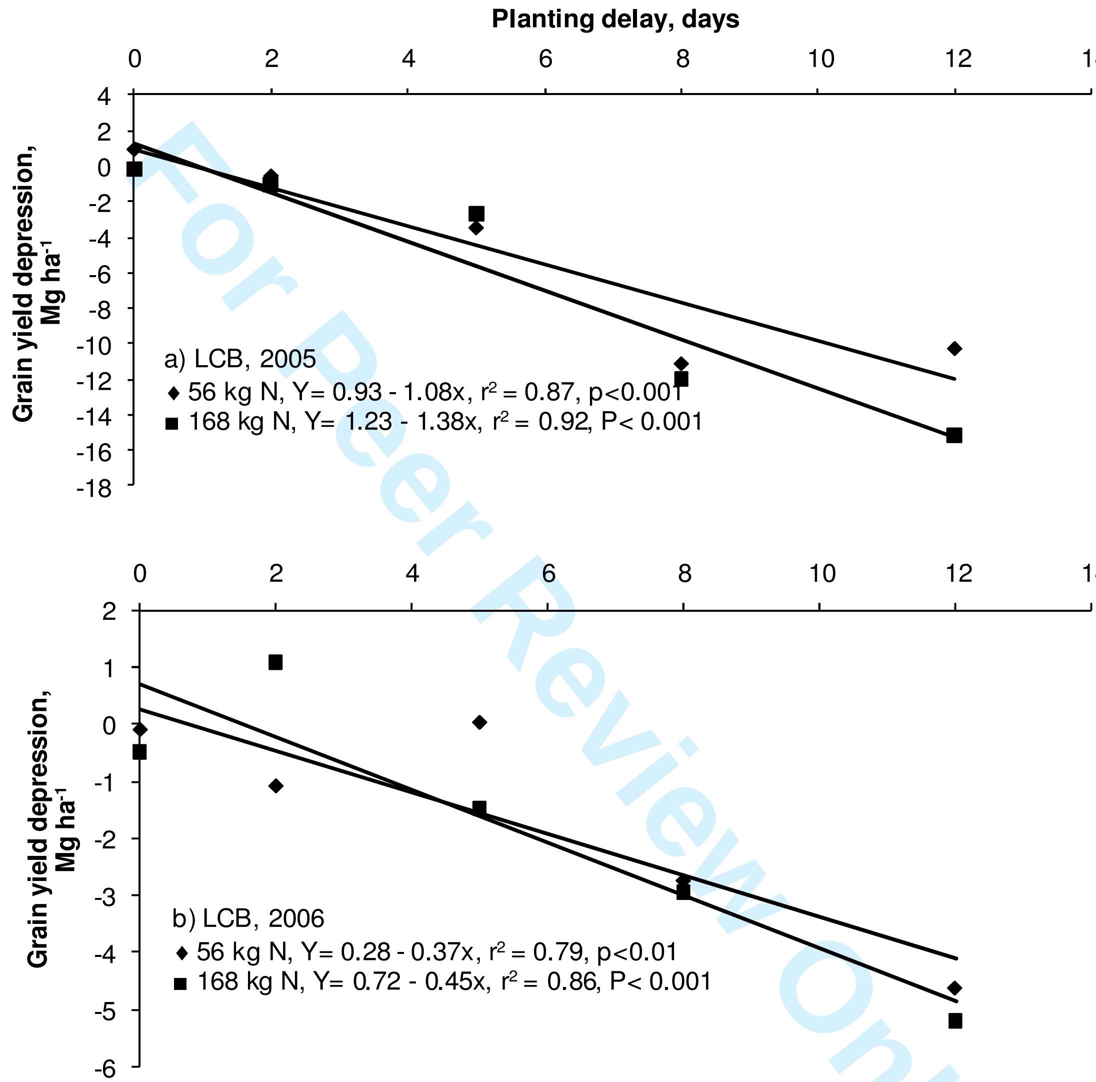

Figure 8. Corn grain yield depression when the middle plant was delayed 0, 2, 5, 8, and 12 days at Lake Carl Blackwell (LCB) in 2005 (a) and 2006 (b).

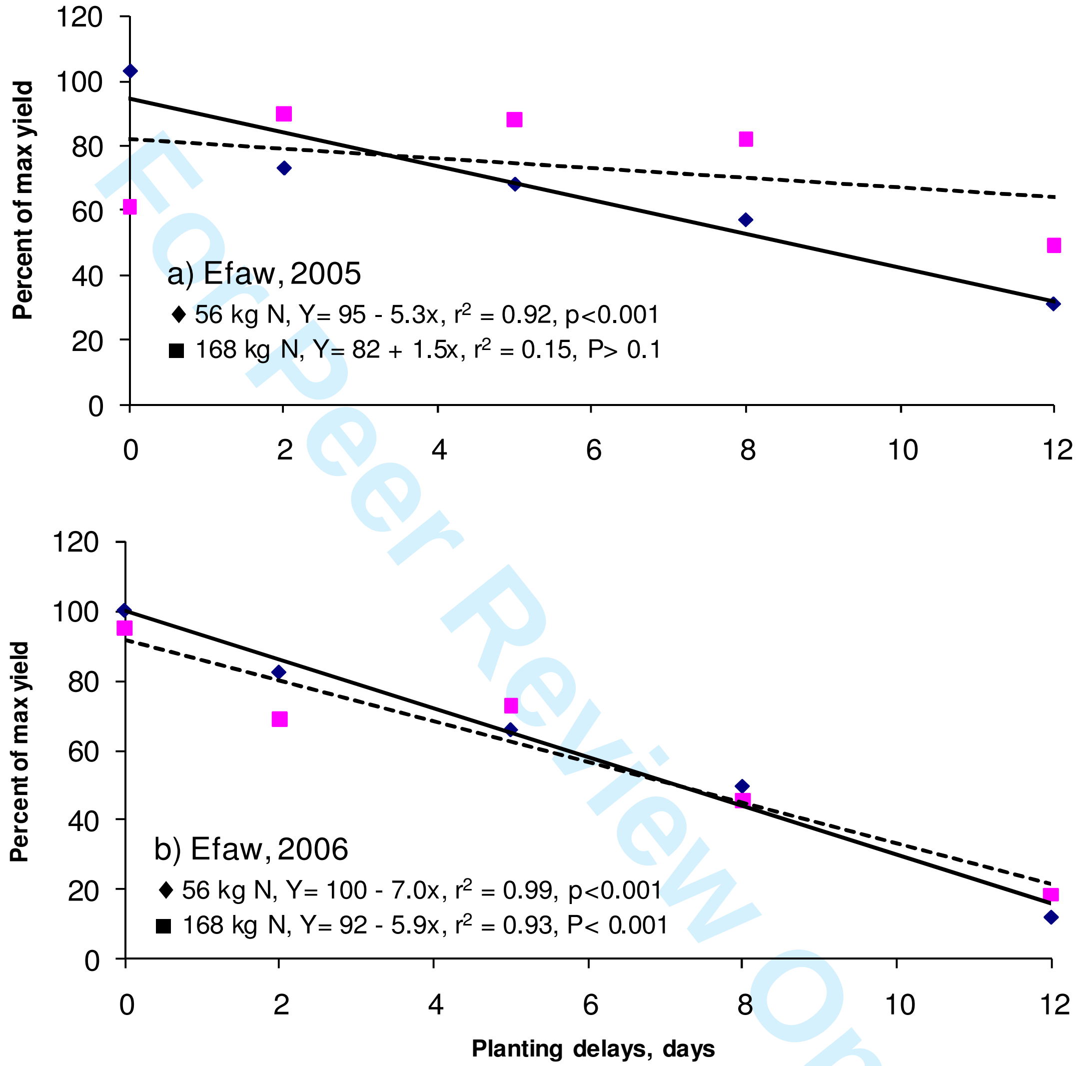

Figure 9. Three-plant average when the middle plant was delayed 0, 2, 5, 8, and 12 days expressed as percent of maximum corn grain yields at Efaw in 2005 (a) and 2006 (b) at 56 kg ha^{-1} and 168 kg ha^{-1} preplant N rates.

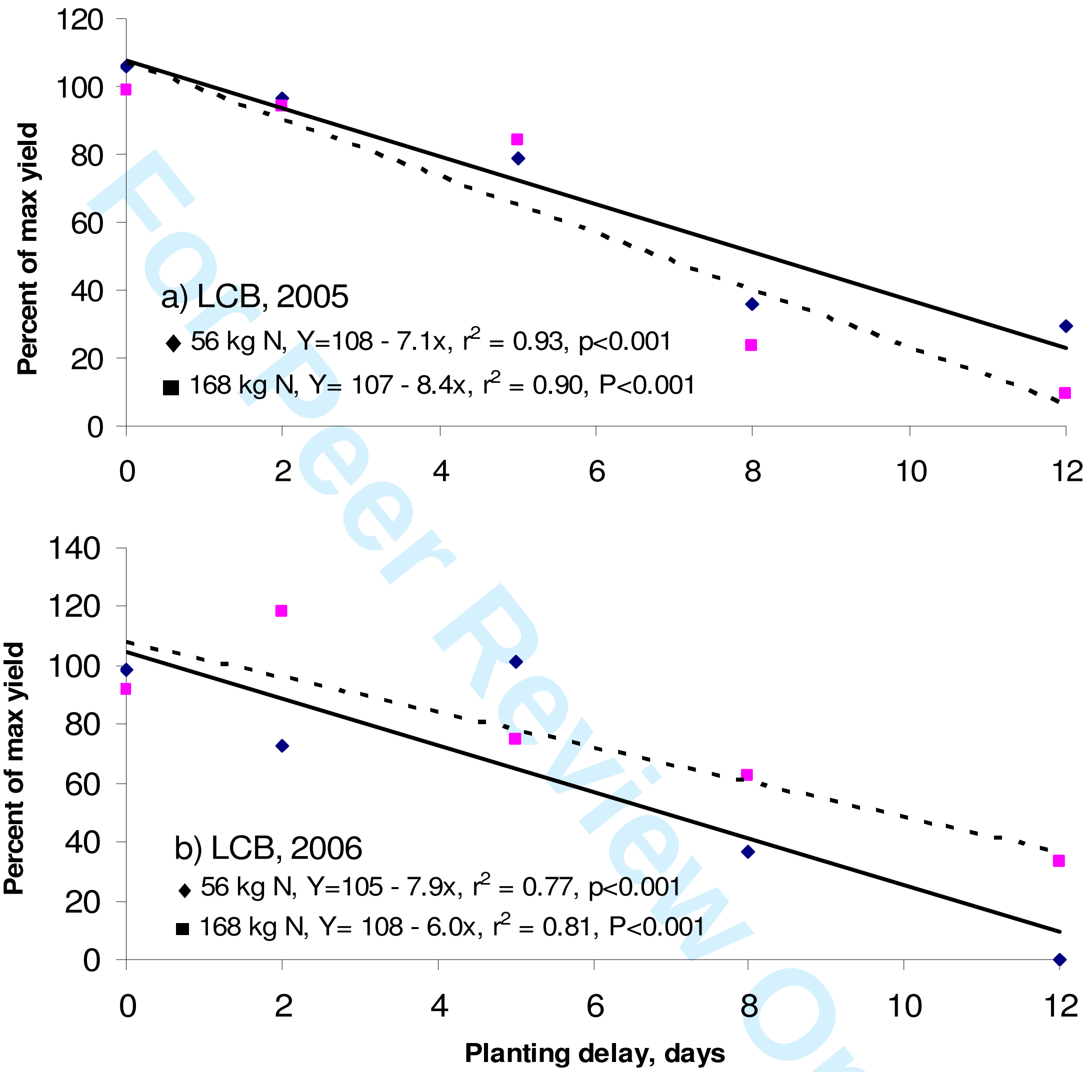

Figure 10. Three-plant average when the middle plant was delayed 0, 2, 5, 8, and 12 days expressed as percent of maximum corn grain yields at Lake Carl Blackwell (LCB) in 2005 (a) and 2006 (b) at 56 kg ha^{-1} and 168 kg ha^{-1} preplant N rates.