Response of Corn to Uneven Emergence

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ABSTRACT

Uneven emergence of corn (*Zea mays* L.) may occur when soils are dry at the time of planting. This research was conducted in seven environments in Illinois and Wisconsin during a 2-yr period to measure the effect of uneven emergence on grain yield. Two hybrids (Pioneer Brand 3732 and 3615), chosen to represent differing responses to plant density, were hand planted in early May (E), 10 to 12 d after E (M), and 21 to 27 d after E (L) to produce various patterns of among-row and within-row unevenness. There was no consistent interaction of hybrid with emergence patten, and responses were quite consistent among environments. Across environments, uniform E, M, and L plantings produced 11.8, 11.1, and 10.4 Mg ha^{-1}, respectively. Uniform E rows bordered by M rows [E(M)] produced 11.4 Mg ha^{-1}, while the other among-row treatments E(L), M(E), L(E), and M(L) produced 12.2, 10.5, 7.9, and 11.8 Mg ha^{-1}, respectively. The within-row, repeating patterns of 3E:1M, 1E:1M, 3E:3M, and 1E:3M produced yields of 11.0, 10.7, 10.9, and 10.9 Mg ha^{-1}, respectively, while the 3E:1L, 1E:1L, 3E:3L, and 1E:3L treatments produced grain yields of 10.5, 9.2, 9.4, and 9.1 Mg ha^{-1}, respectively. Comparison of uneven within-row patterns with incomplete stands showed that in no case did the presence of late-emerging plants cause yield loss. While uneven emergence decreased yields, these data do not show a yield benefit to replanting in order to attain uniformity, with the possible exception of cases where one-half or more of the plants are delayed in their emergence by at least 3 wk.

The corn planting season in much of the Midwest has been relatively dry during the last half of the 1980s, with the result that a considerable area of corn has been planted into relatively dry soils. This has led in some instances to uneven emergence, in which a portion of the seed in a field germinates and emerges normally, while the remainder stays in dry soil until sufficient rain falls to enable it to germinate. Soil compaction, crusting, and herbicides also may affect rate of emergence, but marginal soil moisture and uneven distribution of that moisture by tillage operations are the primary causes.

If the delay in emergence of some of the corn plants is prolonged, then existing guidelines may be used to decide whether or not the field should be replanted (Johnson and Mulvaney, 1980), though continuing dry weather may hinder establishment of a replanted crop. If the existing stand is retained after rain has fallen to cause germination of the remaining seed, then plant sizes may vary substantially. Adjacent plants or rows of plants of unequal size have been found to affect yield when plant size differences were obtained by using corn hybrids that differed genetically in plant height (Pendleton and Seif, 1962).

The relationship between variability in plant size and the grain yield of individual plants within the same corn hybrid has generally been examined only for the natural variability found among plants within a stand (Daynard and Muldoon, 1983; Glenn and Daynard, 1974; Muldoon and Daynard, 1981). Other studies have examined the effect of management practices on such variability (Glenn and Daynard, 1974; Edmeades and Daynard, 1979). While variability among plants has been associated with yield loss (Glenn and Daynard, 1974), it is not clear from those studies whether plant size variability was due only to nongenetic factors, or whether there was in some cases a lack of genetic uniformity that led to confounding of height and inherent yielding ability of individual plants. Furthermore, such studies involved relatively small differences in size among plants, and so did not duplicate the degree of unevenness commonly observed when poor soil moisture delays emergence of some plants.

To decide whether to keep or to replant an unevenly emerged corn field, we must be able to assess the effect of the unevenness (both in time of emergence and in the proportion of delayed plants) on final grain yield. Another management decision is whether to destroy late-emerging plants if such plants will act as weeds by competing with other plants while producing little or no yield. This study was conducted to answer these questions by assessing the effects of uneven and incomplete emergence on grain yield of two corn hybrids.

MATERIALS AND METHODS

Similar experiments were conducted in 1986 and 1987 at Urbana, IL, on a Drummer silty clay loam (fine-silty, mixed, mesic Typic Haplaquoll), at Monmouth, IL, on a Muscatine silt loam (fine-silty, mixed, mesic Aquic Hapludoll), at Arlington, WI, on a Plano silt loam (fine-silty, mixed, mesic Typic Argiudoll), and in 1987 only at DeKalb, IL, on a Drummer soil. In the Illinois locations, P and K were applied according to soil tests, such that these elements were not limiting. At Arlington, soil test levels of P and K were adequate, but starter fertilizer was applied at the rate of 22-10-19 kg N-P-K ha^{-1} in 1986 and 12-23-47 kg N-P-K ha^{-1} in 1987. Soybean [*Glycine max* (L.) Merr.] was the previous crop in all cases. All N was applied before planting as anhydrous NH_3 at 243 and 202 kg N ha^{-1} at Urbana and Monmouth, respectively, and as NH_4NO_3 at 269 and 168 kg N ha^{-1} at DeKalb and Arlington, respectively.

Weeds were controlled with a combination of herbicides, cultivation, and hand weeding. At Urbana and Monmouth, 1.1 kg ha^{-1} of atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and cyanazine (2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile) were applied preplant, along with 4.7 kg ha^{-1} of butylate [bis(2-

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Abbreviations: E, early; M, middle (10–12 d after E); L, late (21–27 d after E).

Table 1. Corn planting dates and monthly rainfall totals for the seven environments.

	Environment						
	Arlington 1986	Arlington 1987	DeKalb 1987	Monmouth 1986	Monmouth 1987	Urbana 1986	Urbana 1987
Planting date							
Early (E)	03 May	30 Apr	01 May	02 May	30 Apr	05 May	30 Apr
Middle (M)	15 May	12 May	13 May	13 May	11 May	15 May	12 May
Late (L)	28 May	26 May	23 May	23 May	21 May	26 May	22 May
Rainfall							
	mm						
May	53	119	119	147	178	69	80
June	106	15	71	113	134	109	127
July	118	102	124	185	33	119	199
August	273	125	391	81	214	36	127

methylproply)carbamothioic acid *S*-ethyl ester] at Urbana and 3.4 kg ha^{-1} of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] at Monmouth. In 1987, an additional application of 1.1 kg ha^{-1} of bentazon [3-(1-methylethyl)-1*H*-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] was made after emergence. At DeKalb, 2.8 kg ha^{-1} of alachlor [2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide] was used along with 2.0 kg ha^{-1} of atrazine and 2.2 kg ha^{-1} of cyanazine. Herbicides used at Arlington were cyanazine and alachlor, each at 2.2 kg ha^{-1}.

Two corn hybrids (Pioneer Brand 3732 and 3615) were used, based on company literature and personnel describing these as similar in maturity, but different in their response to plant population: 3732 is described as having a relatively fixed ear size, while ear size of 3615 will increase readily if plant population is low. Hybrid was assigned to main plots of a randomized complete-block design with three replicates. Planting treatments were assigned to subplots, each consisting of three rows 6.1 m in length, with rows spaced 0.76 m apart.

In each experiment, planting was done on three dates (early = E, middle = M, late = L), with 10 to 14 d between dates (Table 1). Plants were spaced 0.2 m apart, for a full-stand plant population of 64 580 plants ha^{-1}. The center row of each plot was planted by hand, and thinned to 1 plant hill^{-1} after emergence. The outside rows were machine planted, then thinned and replanted as appropriate. Three of the 20 planting treatments consisted of uniform plantings on each date. An additional five treatments were designed to simulate row-to-row unevenness, with uniform plantings within each row. These were E-planted center rows with M or L border rows, designated as E(M) and E(L), respectively; M- or L-planted center rows with E borders, M(E) and L(E), respectively; and M-planted center rows with L-planted borders M(L).

In the remaining 12 treatments, center rows were planted on the early dates to establish three subplots of each of four patterns, which were repeated down the row: 3 E plants, 1 skip; 1 E plant; 1 skip; 3 E plants, 3 skips; and 1 E plant, 3 skips. The skips in one set of these patterns were filled in on each of the M and L planting dates, and the third set was not planted, thus producing incomplete stands. These 12 treatments were designated 3E:1M, 1E:1M, 3E:3M, 1E:3M, 3E:1L, 1E:1L, 3E:3L, 1E:3L, 3E:1S, 1E:1S, 3E:3S, and 1E:3S, where S refers to a skipped (missing) plant in the final stand. Border rows were thinned and replanted as necessary to correspond with the center row.

Plants heights (to the top leaf collar) were measured during grainfill, with plants of different age in the same plot measured separately. Plots were hand harvested in late September to mid-October. In all treatments except for 3:3 patterns, 3.2 m of row were harvested (16 plants in the full stands), keeping the ears from the different planting dates separate where appropriate. In the treatments with 3:3 patterns, 3.6 m of row were harvested to give a full complement of plants from the different dates. Weight and moisture content of the grain were taken. Data were subjected to analysis of variance, and LSD values for means separation were calculated according to McIntosh (1983).

RESULTS AND DISCUSSION

With few exceptions, growing season rainfall was near normal for these seven environments (Table 1). Though overall yields differed among environments (Table 2), yields reflected the favorable growing conditions and generally were high (Table 3). Dry June weather at Arlington in 1987 probably caused some yield loss in that environment, but yields of the uniform E treatment in all of the environments exceeded 10 Mg ha^{-1}. The two hybrids produced similar yields; though 3615 yielded significantly more than did 3732 across environments, this difference was only 0.17 Mg ha^{-1}, or <2%. The environment × hybrid interaction also was significant (Table 2), due primarily to two environments: 3732 yielded ≈0.5 Mg ha^{-1} more than 3615 at Arlington in 1986, and the yield advantage of 3615 was unusually large (1.1 Mg ha^{-1}) at Monmouth in 1987. Yield differences between the two hybrids were consistently small in the other five environments (data not shown). There appears to be no consistent pattern of differential response of these two hybrids to environment.

While the planting date response of the uniformly planted hybrids varied some among environments (Table 3), the overall response generally was similar to that reported from similar environments (Johnson and Mulvaney, 1980). Across environments and hybrids, the yield decrease in the M planting (10–12 d after the optimum date) was 0.69 Mg ha^{-1}, or ≈6%, while the L planting, which represents a delay averaging ≈22 d (Table 1), produced 1.44 Mg ha^{-1}, or

Table 2. Analysis of variance of grain yield (Mg ha^{-1}) of two corn hybrids planted in seven environments with different patterns of uneven emergence.

Source	df	Mean squares
Environment (Env)	6	24.79**
Replicates/Env	14	0.61
Hybrid (Hyb)	1	6.03*
Hyb × Env	6	6.72**
Error a	14	0.75
Treatment (Trt)	19	111.44**
Env × Trt	114	2.87**
Hyb × Trt	19	1.49**
Env × Hyb × Trt	114	0.44
Error b	532	0.43

*,** Significant at $P = 0.05$ and 0.01, respectively.

≈12% less yield than the uniform E planting (Table 3). The difference between M and L uniform plantings did not conform to this trend at Arlington in 1987 or at Monmouth in 1986, while the difference between uniform E and M plantings did not follow the general pattern at Urbana in 1987. These exceptions are quantitatively minor, and have no readily apparent explanation.

Across environments and hybrids, E rows bordered by M rows [Treatment E(M)] yielded significantly less than did the uniform E planting (Table 3). That is, M plants in uniform rows provided more interference with adjacent rows than did E plants in uniform rows. This greater interference may have been associated with the fact that M border rows generally were taller than E center rows (Table 4). The effect of E border rows on M center rows was, however, not consistent with this explanation; this M(E) treatment yielded less than the uniform M treatment (Table 3). Perhaps shading of the center row was the important factor in the E(M) treatment, while moisture competition was more important in the M(E) treatment. In any case, the yield loss to be expected when row segments differ to this degree in time of emergence vary with the proportion of the field representing these two treatments, E(M) and M(E), but the yield from an equal mixture of the two would be nearly equal to the yield from a uniform M planting, and thus would not indicate that the field should be replanted.

When the center row of E plants was bordered by L plants [treatment E(L)], its yield was greater than in the uniform E planting (Table 3), indicating that the

Table 4. Plant height as affected by uneven emergence. Data are averages of two corn hybrids across seven environments.

Treatment†	Height of plants by planting date		
	Early (E)	Medium (M)	Late (L)
	cm		
Uniform E	211	–	–
Uniform M	–	221	–
Uniform L	–	–	230
E(M)	205	218	–
E(L)	205	–	220
M(E)	210	220	–
L(E)	208	–	218
M(L)	–	220	228
3E:1M	209	210	–
1E:1M	207	210	–
3E:3M	206	210	–
1E:3M	205	218	–
3E:1L	209	–	177
1E:1L	208	–	193
3E:3L	206	–	200
1E:3L	201	–	214
3E:1S	210	–	–
1E:1S	207	–	–
3E:3S	207	–	–
1E:3S	199	–	–
LSD (0.05)	2	3	5

† E = early May planting, M = 10 to 12 d later than E, L = 21 to 27 d later than E and S = plant skipped. E(M) = uniform E rows bordered by M rows, etc. 3E:1M = within-row repeating patterns of 3 E plants: 1 M plant, etc.

Table 3. Grain yield of corn in seven environments, and of two hybrids across environments, as affected by uneven and incomplete emergence.

Treatment†	Environment							Hybrid		
	Arlington 1986	Arlington 1987	DeKalb 1987	Monmouth 1986	Monmouth 1987	Urbana 1986	Urbana 1987	3732	3615	Mean
	Mg ha^{-1}									
Uniform E	12.38	10.36	11.76	12.56	11.77	12.16	11.61	11.64	11.96	11.80
Uniform M	11.17	9.97	11.32	11.03	11.27	11.11	11.87	11.16	11.05	11.11
Uniform L	10.80	10.06	11.16	11.28	10.24	9.71	9.30	10.32	10.40	10.36
E(M)	11.60	9.97	11.67	11.58	11.61	12.57	11.08	11.75	11.13	11.44
E(L)	11.08	10.28	12.77	12.16	13.87	13.03	11.83	12.31	11.99	12.15
M(E)	11.48	9.43	10.67	10.45	9.63	10.45	11.65	10.41	10.67	10.54
L(E)	10.33	8.55	7.90	8.59	5.58	8.00	6.11	8.06	7.67	7.87
M(L)	10.95	10.36	12.32	11.64	13.06	11.77	12.33	11.75	11.80	11.77
3E:1M	10.80	10.08	11.34	11.38	11.13	11.51	10.96	10.75	11.30	11.03
1E:1M	10.77	10.02	10.84	10.94	10.28	11.24	10.63	10.58	10.76	10.67
3E:3M	11.08	9.65	11.13	11.35	11.17	11.28	10.81	10.79	11.06	10.93
1E:3M	10.93	9.77	10.95	10.90	11.12	11.37	11.06	10.60	11.14	10.87
3E:1L	10.99	9.47	10.39	11.25	10.56	10.76	10.51	10.16	10.97	10.56
1E:1L	10.43	9.00	8.94	10.30	8.73	9.52	8.00	9.14	9.41	9.27
3E:3L	10.42	9.03	9.29	10.73	8.85	9.29	8.31	9.15	9.69	9.42
1E:3L	10.09	9.22	8.82	10.43	8.91	9.40	7.09	9.15	9.13	9.14
3E:1S	9.48	8.40	10.70	11.07	11.07	10.88	10.31	10.02	10.53	10.27
1E:1S	9.05	7.94	7.79	8.59	8.57	7.92	8.32	8.14	8.49	8.31
3E:3S	8.75	7.32	8.05	7.97	8.17	8.32	7.94	7.85	8.30	8.07
1E:3S	5.37	4.65	5.57	5.70	6.01	5.92	5.83	5.75	5.41	5.58
Mean	10.40	9.18	10.17	10.50	10.08	10.31	9.78	9.97	10.14	10.06
LSD (0.05)	0.62	0.70	0.90	0.64	0.93	0.68	0.72	0.40		0.28
CV, %	5.20	6.65	7.66	5.33	8.02	5.71	6.42			6.49

† E = early May planting, M = 10 to 12 d later than E, L = 21 to 27 d later than E and S = plant skipped. E(M) = uniform E rows bordered by M rows, etc. 3E:1M = within-row repeating patterns of 3 E plants: 1 M plant, etc.

competition provided by a row of L plants to the adjacent row was less than that provided by E or M plants. This lower level of competition by L plants was also shown in the M(L) treatment, where the center M row yielded more than in the uniform M treatment. The L(E) treatment, where a uniform L row was bordered by E rows, yielded substantially less then did the uniform L treatment, even though the height of L plants in the uniform planting was greater than that of E border rows in the L(E) treatment (Table 4). This lends support to the hypothesis that competition for moisture was the primary component of competition in these treatments. The two environments with below-average yields for the L(E) treatment were Monmouth in 1987, when July rainfall was very low, and Urbana in 1987, when July rainfall was high, but occurred mostly near the end of the month. The yield of the L(E) treatment was above average at Arlington in 1986, when July and August rainfall was very high. When segments of row differ to this extent in emergence time, the effect on yield is heavily dependent on the proportion of the overall stand that is delayed; these results show that, if one-half of the stand is delayed to this extent, the yield (i.e., [E(L) + L(E)]/2) will be close to that of the uniform L treatment, and that replanting should be considered only if the proportion of late-emerging row segments (bordered by early-emerging plants) exceeds 50%.

The treatments that included E and M plants in the same row (E:M treatments) produced yields that were surprisingly similar (Table 3). Across environments and hybrids, the 3E:1M treatment yielded more than the 1E:1M treatment, but this difference was only ≈3%. These four treatments yielded only slightly less than the uniform M treatment, but ≈10% less than the uniform E treatment. This yield depression caused by uneven emergence is in agreement with previous reports that nonuniformity in plant size is associated with yield loss (Glenn and Daynard, 1974; Muldoon and Daynard, 1981). While this degree of within-row unevenness caused yield loss, it does not appear that replanting to produce a uniform stand at that time would be expected to produce much increase in yield, regardless of the proportion of plants that are delayed.

As the proportion of E plants in E:M increased, the grain weight per plant of E plants rose gradually before decreasing in the uniform E treatment, while the grain weight per M plant decreased steadily (Fig. 1). The decrease in weight per M plant was nearly compensated by the larger number of M plants, resulting in the similar yields for these four treatments.

In the E:L treatments, with L plants planted an average of 22 d later than E plants, the effect of uneven emergence on yield was substantial (Table 3). Across environments and hybrids, the yield of the 3E:1L treatment, while 11% lower than the yield of the uniform E treatment, was similar to the yield of the uniform L treatment; replanting to obtain a uniform stand in such a case is not indicated. When the proportion of L plants was >25%, however, the yields dropped below that of the uniform L treatment: the 1E:1L, 3E:3L, and 1E:3L treatments yielded 10.5, 9.3, and 11.8% less, respectively, than the uniform L treatment, and >20% less than the uniform E treatment.

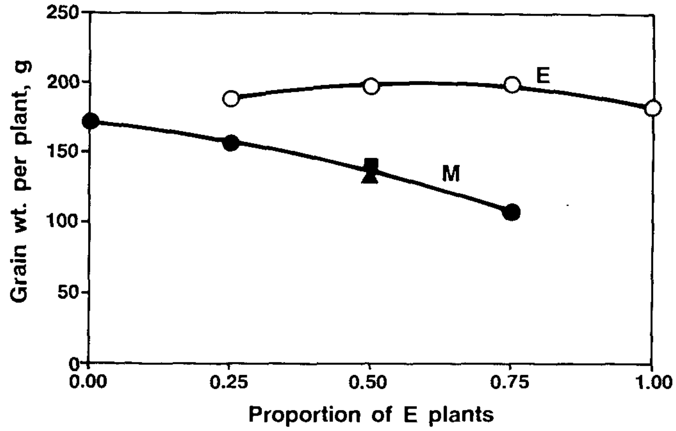

Fig. 1. Grain weight per plant of early (E) and middle (M) emerging plants in uniform plantings and in within-row mixtures. Data are averages of two hybrids and seven environments. The solid triangle and square at 0.05 E plants represent the yields per M plant in the 1E:1M (1E plant to 1M plant) and 3E:3M patterns, respectively, and the line is drawn through the mean of these two points. The yields of the E plants in these two treatments were virtually identical, and are presented as one point (open circle) for clarity.

At the Arlington location, the E:L treatments produced higher yields, relative to uniform E treatments, than in the Illinois environments (Table 3). This may have been due to slower growth of E plants due to cooler temperatures early in the season, resulting in less size difference between E and L plants early in the season. While the chance to increase yields by ≈10% may indicate replanting with this degree of unevenness, the decision will depend on replanting costs and, perhaps more importantly, on whether soil conditions favor the establishment of a uniform stand at replanting time.

The yield per E plant in E:L treatments remained relatively constant as the proportion of E plants increased, though the yield per plant in the uniform E treatment was less than that of the E plants in E:L treatments (Fig. 2). The yield per L plant decreased rapidly as the proportion of E plants increased, however, dropping by >80% from the uniform L planting to the 3E:1L treatment. Increasing barrenness accounted for some of this decrease. While differences among environments were large, barrenness of L plants, averaged across environments and hybrids, increased from <2% in the 1E:3L treatment to >50% in the 3E:1L treatments. The 1E:1L treatment also had ≈29% barren L plants, while only 15% of the L plants were barren in the 3E:3L treatment, reflecting the lower E:L plant interaction in the 3:3 pattern. Height of L plants in the E:L treatments also reflected their competitive disadvantage; plant height decreased steadily as the proportion of E plants increased (Table 4). One environment that provided an exception to this trend was Arlington in 1986, where L plants were taller than E plants in all E:L treatments (data not shown), reflecting the high summer rainfall at that location.

Comparison of the E:M and E:L treatments with the stand loss (E:S) treatments shows that, regardless of the pattern of emergence, in no case did the presence of late-emerging plants cause a yield decrease. Late plants did not always contribute to yield (all of the L

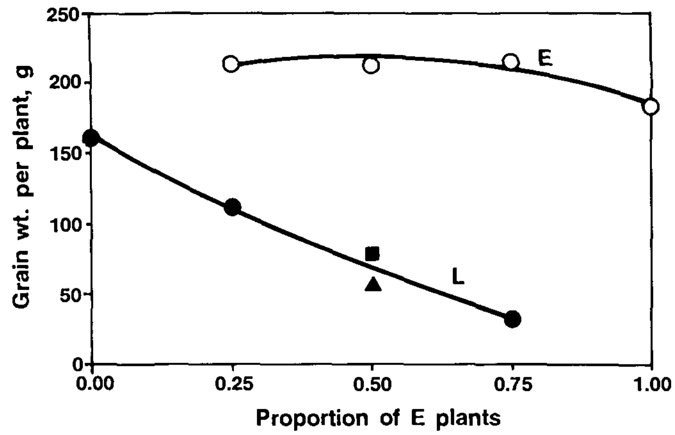

Fig. 2. Grain weight per plant of early (E) and late (L) emerging plants in uniform plantings and in within-row mixtures. Data are averages of two hybrids and seven environments. The solid triangle and square at 0.05 E plants represent the yields per L plant in within-row repeating patterns of 1E:1L (1E plant to 1L plant) and 3E:3L patterns, respectively, and the line is drawn through the mean of these two points. The yields of the E plants in these two treatments were virtually identical, and are presented as one point (open circle) for clarity.

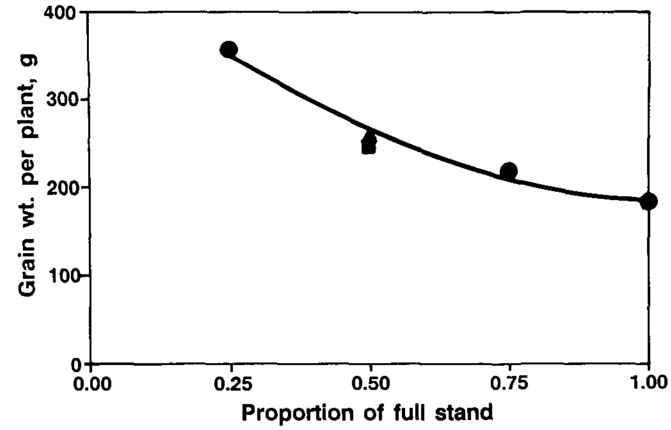

Fig. 3. Grain weight per plant of early (E) plants as affected by plant population. The triangle and square at 0.50 E plants represent the within-row repeating pattern of 1E:1S (1E plant to 1 skipped (S) plant) and 3E:3S patterns, respectively, and the line is drawn through the mean of these two points.

plants in the 3E:1L treatments at Monmouth in 1987 were barren), but the yield of the 3E:1L treatment was not significantly less than that of the 3E:1S treatment in any of the environments, and was significantly greater across environments and hybrids (Table 3). This is somewhat surprising, since barren plants would seem to act as weeds, but these results show that care should generally be taken to protect even those plants that emerge quite late.

In the E:S treatments, grain weight per plant decreased sharply as the proportion of full stand rose from 0.25 to 0.5, then declined more slowly, in a linear fashion (Fig. 3). The near doubling of the grain yield per plant when the plant population dropped to 25% of full stand caused a yield loss of only ≈50% in this treatment (Table 3). With a more uniform intrarow plant spacing, the 1E:1S treatment yielded slightly more than the 3E:3S treatment. Since the two hybrids were chosen based on their differential ability to compensate for low plant population, we expected that the hybrids would differ in response to the E:S treatments. This did not occur; the yield of 3615, which was chosen as having a greater ability to increase ear size at lower plant populations, was slightly lower than that of 3732 at the lowest plant population.

There was a significant interaction between hybrid and treatment, though this interaction accounted for a fairly small portion of the total variance (Table 2). There was, however, no clear-cut structure to this interaction. The slight yield superiority of 3615 compared with 3732 was observed in most of the treatments, with the major exceptions in the E(M), E(L), L(E), and 1E:3S treatments. Perhaps 3732 could be considered as slightly better able to take advantage of decreased competition, but the evidence for this is not strong. With only two hybrids in this study, conclusions about hybrid responses to changes in competition must be narrow. It is apparent, though, that in this case the effort to choose hybrids based solely on their putative response to changes in competition did not produce the expected effect.

Though we think that the response to uneven emergence may be affected by hybrid, including hybrid maturity, plant population, and soil water availability, these results provide guidelines to help manage this problem when it occurs in a field. If the difference in emergence times of plants in an unevenly-emerged field is <2 wk, the unevenness is likely to cause some yield loss, but this loss will probably not be large enough to justify replanting to produce a uniform stand. If emergence delays for some plants approach 3 wk, then replanting may produce yield increases of ≈10% if the proportion of delayed plants exceeds 25%. Whether this yield increase will justify the added cost of replanting will depend on both the cost of replanting and on whether conditions in the replanted field are conducive to establishment of a uniform stand.

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