

Effects of Plant Population Density on Yield and Yield Components of Eight Isolines of cv. Clark (*Glycine max* L.)

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ABSTRACT

A field study was conducted to evaluate the agronomic response of eight isolines of cv. Clark on a clay loam soil (at Karaj-Iran, 35°48') to four plant population densities of 11.3, 18.5, 68.5, and 103.4 plants per square metre. Significant yield increase was obtained as a result of higher plant density. Differences among the cv. Clark isolines were significant ($p < 0.05$). Yield components such as numbers of branches, pods, and seeds per plant decreased linearly as population density increased. Adjustments in pods and seeds per plant resulted from altered branches per plant. The isolines which exhibit profuse branching (e.g. $E_1E_2E_3$, $E_1e_2E_3$, $E_1E_2e_3$) were capable of optimising yield when planted at low densities. The second dynamic factor that aided yield compensation by plant population density was greater total dry matter partitioning, which resulted in a significantly greater harvest index at the lower compared with the higher plant density. The results indicated that total biomass and crop growth rate were the major elements explaining the reduced yield compensation factors at higher plant population density. Plotting the fitted seed yield values against the number of dominant alleles showed the effect of the maturity genes on the response of seed yield to plant density.

Keywords: Branching, Dry matter partitioning, Harvest index, Soyabean.

INTRODUCTION

Determination of the optimal plant population density necessary for optimal yield is a major agronomic goal. Sowing at a seed rate that results in optimal plant population density may reduce seed costs, lodging, and ameliorate disease problems (Boquet and Walker, 1980). A Major factor influencing optimal seed rate for any particular environment is the genotype, and there is a little information concerning the study of genotype-density interaction.

Numerous studies have been conducted on the effect of production practices such as row spacing (Parkers *et al.*, 1982), plant population density (Goli and Olsen, 1983),

and cultivar (Boerma and Ashley, 1982) on soyabean seed yield. These studies demonstrate that sowing seeds in narrow, rather than wide rows frequently increases soyabean yields in many regions. Regardless of row width, and with increasing population density, plant components (stem length, pod and seed number and seed weight) were reduced by intra-row plant competition, but branch development was not affected (Boquet, 1990). Competition between crop plants can affect not only total yield, but also plant size and maturity (Bleasdale, 1984). Wilcox (1974) showed that height differences were associated with within-row spacing. Previous studies have indicated that the optimal plant population density for soyabean can vary from 30,000 to 500,000 plants

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ha⁻¹, depending on environmental and genetic factors (Parkers *et al.*, 1982; Wells, 1993).

The major hypotheses tested in this study were: (i) whether the impact of maturity genes on the agronomic response of cv. Clark isolines can be quantified; (ii) to examine the effects of genes on the asymptote yield, besides comparing yield-density relations (using the reciprocal equation); and (iii) to determine the optimum plant population density for soyabean genotypes grown at Karaj (Iran).

MATERIALS AND METHODS

Near-isogenic lines of soyabean cv. Clark differing in the three maturity genes of E_1/e_1 , E_2/e_2 , and E_3/e_3 (Bernard, 1971) constituted the experimental material used in this investigation. A split-plot design with plant densities as the main plots and eight isolines of cv. Clark as subplots was used in a randomised complete-block design with three replicates. Each experimental plot consisted of either four rows (spaced 50 cm apart) or eight rows (spaced 25 cm apart).

The experiment was conducted at the research farm of the Agricultural College of Tehran University at Karaj, Iran (Lat. 35°48' N, Long. 50°57' E; Alt. 1313 m). The soil was clay loam with a neutral reaction. After land levelling and furrow preparation, the plots were irrigated using a furrow irrigation method and subsequent irrigations were applied every seven days during plant development, up to two to three weeks before final harvest.

Recommended practices for insect and weed control were used. The sowing date was 1 May 1996. Seeds were sown by hand on an inter-row spacing of 0.5 and 0.25 m and with an intra-row spacing of 18, 11, 6, and 4 cm (Table 1) and the plot length was 3.0 m long. Plots were seeded in excess and hand-thinned at emergence two or three times, to get the desired plant densities.

The observations and plant samples were

Table 1. Average plant population density for different spacing between and within rows for the experiment with cv. Clark in 1996.

Inter-row spacing (cm)	Intra-row spacing (cm)	Actual Plant population density (plants/hectare) ^a
50	18	113000
50	11	185000
25	6	685000
25	4	1034000

^a Target population density was 450000-850000 plant/ha.

taken at random from each plot on a per unit area basis. Seed yield and other plant measurements were recorded as follows:

- Vegetative duration (R1)-days from sowing to the first open flower on the main stem.
- Reproductive duration (R1-R7)-days from first flowering to physiological maturity.
- Total crop duration (R8)-durations from sowing to harvest maturity.
- Plant height (cm)-from ground level to the tip of main stem at harvest maturity. (R8), recorded on 10 plants randomly selected from the two middle rows.
- Pod number-total number of pods per plant at R8.
- Branch number-number of primary branches on main stem per plant harvested at maturity (R8).
- Seeds per plant -total number of seeds per plant at R8.
- Total above-ground biomass (g/m²)-total biomass was determined from an air-dried sample (since the bulk of samples was huge they could not be dried in an oven) taken at harvest (all plants in 1 m²) from the two middle rows (in treatments with 50 cm row spacing) and the four middle rows (in treatments with 25 cm row spacing). These samples were then weighed before threshing and separating seed samples to obtain the plant dry matter. To these values, the weights of abscised leaves were added in order to estimate the total biomass.

Table 2. Effects of plant population density on seed yield and related parameters (mean of eight isolines of cv. Clark) in 1996.

Population density plants/m ²	Plant height cm	Branch	Pod	Seed	Seed yield	Total dry matter ^a g/m ²	Harvest index ratio	Crop growth rate g/m ² /day
		Numbers per plant						
11.3	80.6 ^c	5.8 ^a	73.7 ^a	161.0 ^a	304.3 ^b	1196.5 ^c	0.258 ^a	8.4 ^c
18.5	87.4 ^b	4.1 ^b	48.2 ^b	106.0 ^b	314.8 ^b	1301.6 ^c	0.245 ^{ab}	9.2 ^c
68.5	90.5 ^{ab}	1.1 ^c	15.2 ^c	30.8 ^c	336.4 ^b	1472.2 ^b	0.228 ^b	10.4 ^b
103.4	95.4 ^a	0.6 ^d	10.9 ^c	21.8 ^c	400.6 ^a	1753.0 ^a	0.226 ^b	12.1 ^a

Means within column that have the same letter are not significantly different (DMR test).

^a Total above-ground plant dry weight at R8 including fallen leaves.

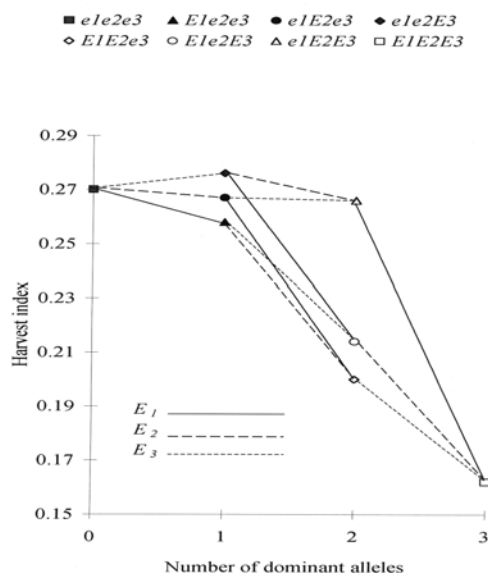
- Seed yield (gr/m²) -seed yields were determined from oven-dried samples. The pods from the plant samples described above were taken, oven-dried at 70°C for 48 hours until a constant moisture content of 10-15% was achieved, then threshed, cleaned with a wind blower, and weighed.
- Harvest index-harvest index at R8 obtained by calculating the seed/total above ground biomass ratio.

RESULTS AND DISCUSSION

Seed yields per unit area were maximised at the highest plant density treatment and, although significant differences for seed yield (g/m²) were detected, for comparisons with the highest population density (103.4 plants/m²) the trend was constant across all densities (Table 2). These results are in agreement with the findings of Cooper (1977) who stated that sowing seeds in narrow rows frequently increased soyabean yield. The increase in seed yield as well as in total dry matter per unit area (Table 2) with an increasing population density suggest that a greater utilization of resources might have been achieved in these treatments at higher densities, in agreement with the reports of Willey (1982). No interactions between plant population density and isoline for seed yield or dry matter were detected ($p > 0.10$).

The crop growth rate (CGR) pattern differed so little for lower plant population densities (i.e. for 11.3 and 18.5 plants/m²) because of similar total dry matter in these

two treatments (Table 2). This study showed that greater CGR and total biomass could be achieved through more plants with increasing plant population density. However, the harvest index declined progressively with an increase in plant population density (Table 2). This result is in agreement with the report of Wilcox (1974) who observed a general decrease in harvest index with soyabean cultivars under equidistant spacing as the plant population increased from 2.5 to 58.2 plants/m². Buttery (1969) also observed a decrease in harvest index with increasing population using cv. Harosoy-63 at 4, 8, 16, and 32 plants/m².

**Figure 1.** Richards diagram (Richards, 1941) showing harvest index variation among eight isolines of cv. Clark grown at four plant population densities in 1996.

**Table 3.** Seed yield and related parameters of eight isolines of cv. Clark (mean of four plant population densities) in 1996.

Isoline	Vegetative duration Days	Reproductive duration Days	Seed yield	Total dry matter* g/m ²	Harvest index ratio	Crop growth rate g/m ² /day
e ₁ e ₂ e ₃	41.0 ^f	62.4 ^e	303.8 ^{bc}	1127.0 ^d	0.270 ^a	9.0 ^{bc}
E ₁ e ₂ e ₃	56.5 ^d	65.4 ^e	401.7 ^a	1536.3 ^{ab}	0.258 ^a	11.1 ^a
e ₁ E ₂ e ₃	47.2 ^e	70.6 ^b	366.8 ^{ab}	1373.6 ^{bcd}	0.267 ^a	10.2 ^{ab}
e ₁ e ₂ E ₃	41.1 ^f	70.4 ^b	391.3 ^a	1429.4 ^{bc}	0.276 ^a	10.6 ^{ab}
E ₁ E ₂ e ₃	73.6 ^b	63.7 ^d	299.6 ^{bc}	1500.7 ^{abc}	0.200 ^b	9.8 ^{abc}
E ₁ e ₂ E ₃	69.3 ^c	65.6 ^e	258.6 ^c	1251.4 ^{cd}	0.214 ^b	8.3 ^c
e ₁ E ₂ E ₃	47.6 ^e	75.2 ^a	410.2 ^a	1504.4 ^{abc}	0.267 ^a	10.6 ^{ab}
E ₁ E ₂ E ₃	76.8 ^a	65.2 ^c	280.3 ^{bc}	1725.6 ^a	0.162 ^c	10.5 ^{ab}

Means within column that have the same letter are not significantly different (DMR test).

* total above-ground plant dry weight at R8 including fallen leaves.

The vegetative (plant height and number of branches per plant) and reproductive yield (number of pods and seeds per plant) components were affected by plant population

A highly significant correlation between the number of branches per plant with both pods and seeds per plant ($r = 0.88$, $p < 0.01$) was recorded.

Table 4. Plant height, number of branches, pods and seeds per eight isolines of cv. Clark (mean of four plant population densities) in 1996.

Isoline	Plant height cm	Branch	Pod Numbers per plant	Seed
e ₁ e ₂ e ₃	54.1 ^e	1.7 ^f	34.9 ^{ab}	64.2 ^c
E ₁ e ₂ e ₃	89.9 ^c	3.1 ^{bcd}	40.0 ^a	87.9 ^{ab}
e ₁ E ₂ e ₃	74.5 ^d	2.7 ^{cde}	37.3 ^{ab}	80.6 ^{abc}
e ₁ e ₂ E ₃	71.4 ^d	2.2 ^{ef}	36.4 ^{ab}	82.5 ^{abc}
E ₁ E ₂ e ₃	113.3 ^b	3.5 ^b	41.0 ^a	91.4 ^a
E ₁ e ₂ E ₃	93.8 ^c	3.2 ^{bc}	30.2 ^b	70.1 ^{bc}
e ₁ E ₂ E ₃	86.7 ^c	2.6 ^{de}	41.3 ^a	92.2 ^a
E ₁ E ₂ E ₃	124.0 ^a	4.2 ^a	34.9 ^{ab}	70.5 ^{bc}

Means within column that have the same letter are not significantly different (DMR test).

density (Table 2) and isolate significantly ($p < 0.05$) (see Table 4). The shortest plants (80.6 cm) with the most branches (5.8), seeds (161) and pods (73.7) per plant (Table 2) were produced at the lowest densities (11.3 plants/m²). Although plant height increased with an increase in plant population density, the number of branches per plant decreased markedly ($p < 0.05$) and was greatest at the lowest plant density (Table 2). The number of pods and seeds per plant was greatly reduced by increasing the plant density (Table 2). These results are in agreement with the study by Boquet (1990) who noted that an increase in plant population density increased stem length and decreased all other soybean plant yield components.

Yield differences among genotypes with different maturity genes or different growing durations could have occurred owing to differences in canopy photosynthesis (CGR), partitioning or the duration of seed filling (Egli, 1988). In this experiment, the greater CGR and total biomass among the cv. Clark isolines revealed that the genotypes with longer vegetative and reproductive durations (see Table 3) efficiently balanced the time available for growth between producing vegetative structure and the maximum partitioning of assimilates to yield.

The cv. Clark isolate e₁E₂E₃ provided the highest seed yield (Table 3), although this was not significantly greater than the yields of E₁e₂e₃, e₁e₂E₃, and e₁E₂e₃. The isolate

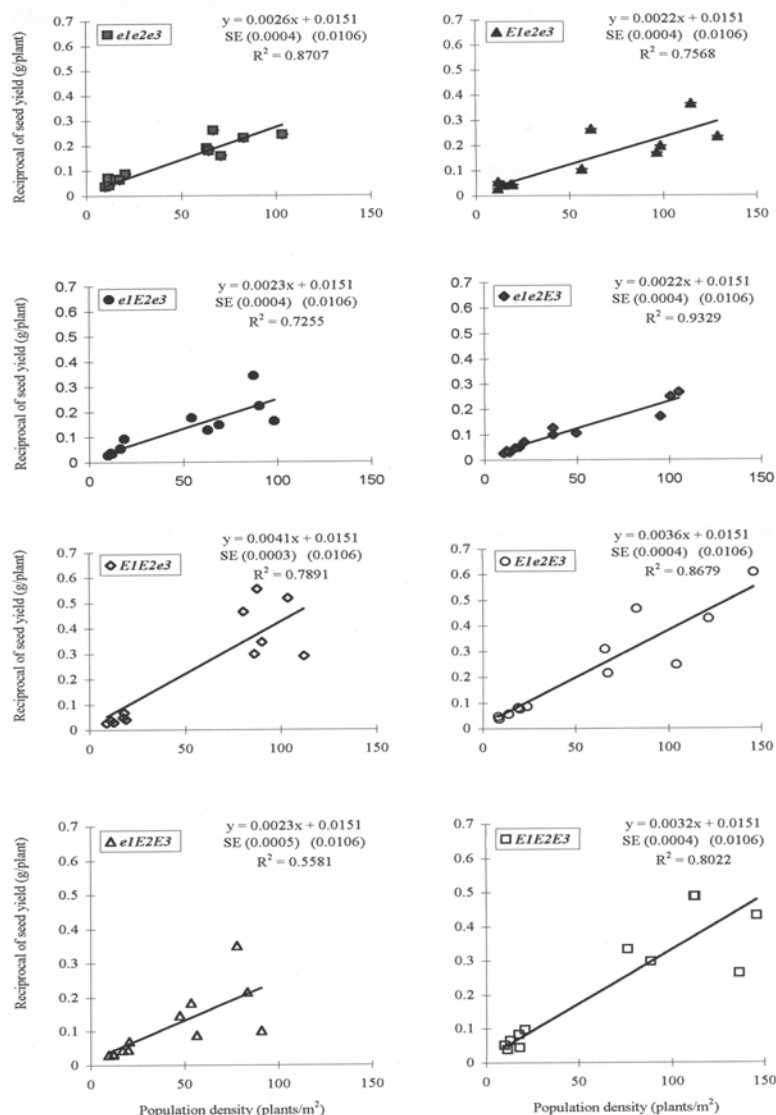


Figure 2. Relationship between plant population density and reciprocal of seed yield per plant among eight isolines of cv. Clark grown at four population densities in 1996.

$E_1E_2E_3$ with the greatest dry matter (g/m²) produced one of the lowest seed yields per unit area, and not surprisingly, therefore, the lowest harvest index (Table 3). Mean dry matter accumulation among the isoline tended to increase with later maturity. Earlier maturity (e.g. $e_1e_2e_3$) with the shortest vegetative and reproductive durations produced consistently less biomass than other genotypes (Table 3). The relationship between seed yield and dry matter production among genotypes was both strong and linear

($r = 0.73$, $p < 0.0001$), implying that dry matter production was the basis of genotypic differences in seed yield.

Similarly, harvest index tended on average to be greater in the earlier-maturing genotypes, and lower in the later-maturing genotypes (Richards diagram, Fig.1). Those isolines with the maturity gene E_1 (e.g. isoline $E_1e_2e_3$), E_2 (e.g. isoline $e_1E_2e_3$), E_3 (e.g. isoline $e_1e_2E_3$), the isolines with E_2 and E_3 combined (e.g. isoline $e_1E_2E_3$), and the isoline with all three recessive maturity



genes (i.e. $e_1e_2e_3$ ■) provided together the higher harvest indices (Fig.1, Table 3). Schapaugh and Wilcox (1980) reported that the harvest index was lower in late-maturing genotypes, which is in accordance with the results seen here (see Fig.1, isoline $E_1E_2E_3$). Therefore, selection of genotypes that would maintain a high harvest index at high plant population densities should help to maximise yields with these soyabean Clark isolines.

The isoline $E_1E_2E_3$ had more branches (4.2) per plant and the tallest plants (124 cm), whereas the isoline $e_1E_2E_3$ provided the highest numbers of pods (41.3) and seeds (92.2) per plant (Table 4). Branching capacities varied among the isolines ($p < 0.05$). Genotypes with longer vegetative duration (Table 3) (such as. $E_1E_2E_3$, $E_1E_2e_3$, $E_1e_2E_3$, and $E_1e_2e_3$) had greater branching ability (Table 4).

To determine the relationship between seed yield and plant population density, the reciprocal equation ($1/w = a + bp$) proposed by Wiley and Heath (1969) was used, where w = the yield per plant, P = the number of plants per unit area and a and b are constants. These reciprocal relationships were linear (Fig. 2). Estimates of the intercept (a) from zero did not vary significantly among isolines ($p > 0.10$) whereas estimates of the slope (b) varied significantly ($p < 0.01$) among the isolines (Fig. 3).

The response of the Clark isolines $e_1e_2e_3$ ■, $E_1e_2e_3$ ▲, $e_1E_2e_3$ •, $e_1e_2E_3$ ◆ and $e_1E_2E_3$ △ were very similar (Figs 2 and 3). The isolines $E_1E_2e_3$ ◇, $E_1e_2E_3$ ○, and $E_1E_2E_3$ □ were also more or less similar in response to plant population density but gave lower seed yields (Fig. 2), and had significantly steeper slopes (Fig. 3).

In biological terms, the optimum plant density for an asymptotic curve can be defined as the minimum plant population that achieved the maximum yield (willey, 1982). In this study, to find optimum plant population density among various Clark isolines certain assumptions were made:

i) plant establishment or germination ability in the field was 78%, and

ii) weight per seed was 0.146 gram.

Based on these two assumptions, the seed weight was translated into plant per square metre using the equation that, 2.6 g of seed requires to establish 1 plant m^{-2} . Finally, to acquire the optimum plant population density the gradient of seed yield (g/m^2) was plotted against plant population density (Fig. 4).

Those isolines with 120-140 days total crop durations, namely $E_1e_2e_3$, $e_1e_2E_3$, $e_1E_2e_3$, $e_1E_2E_3$ and $e_1e_2e_3$, provided the higher fitted seed yields compared with the isolines with very longer durations (Fig. 4).

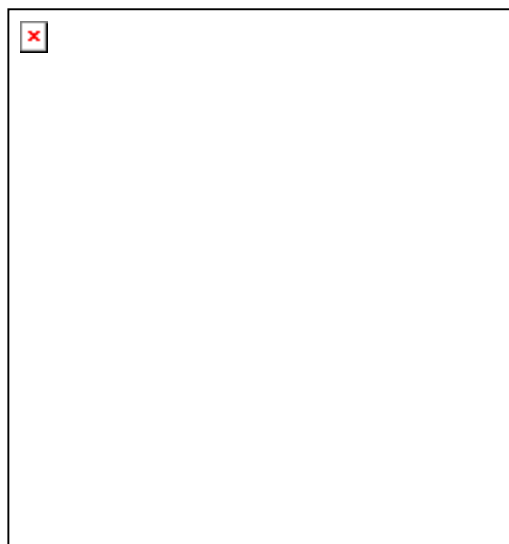


Figure 3. Relationship (fitted) between plant population density and seed yield among eight isolines of cv. Clark in 1996.

The latter isolines, namely $E_1E_2e_3$, $E_1e_2E_3$, and $E_1E_2E_3$, provided the lower fitted seed yields. Presumably they did not have sufficient time to complete their life-cycles since the prevailing growing season in the Karaj region lasts usually for 150 days and, hence, were harvested following premature senescence. The isolines with a single dominant allele E_1 (e.g. $E_1e_2e_3$), E_2 (e.g. $e_1E_2e_3$), and E_3 (e.g. $e_1e_2E_3$) had the highest fitted seed yield, whereas the isoline without dominant alleles (e.g. $e_1e_2e_3$) provided the medium fitted seed yield (Fig. 4). The isoline $e_1E_2E_3$ (Clark) was well adapted and gave one of

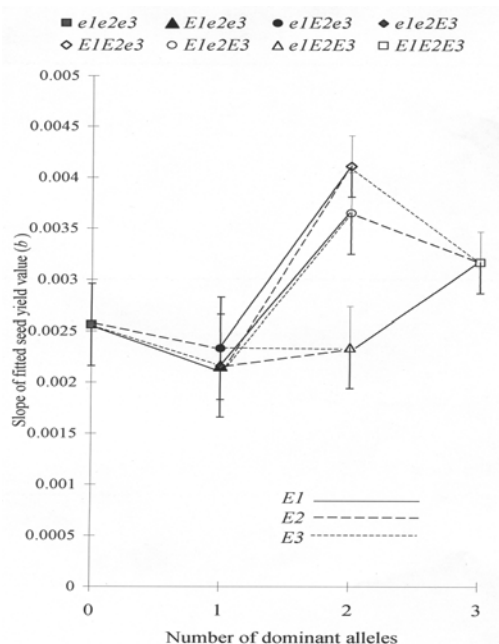


Figure 4. Richards diagram (Richards, 1941) showing slope of fitted seed yield values as affected by the maturity genes in the cv. Clark background in 1996 (Vertical bars represent ± 1 standard error, $p < 0.01$).

the highest fitted seed yields (g/m^2).

The optimum population density for achieving the best seed yield can be anywhere from 45 to 85 plants per metre square (Fig. 5). This approximates closely to the actual optimal plant population density in the Karaj region followed for soyabean production (i.e. 40 to 60 plants/ m^2). Overall, the optimal plant population density was higher for those isolines with a single dominant allele. For example, the optimal density for $E_1e_2e_3$ $\blacktriangle$ is 85 plants/ m^2 (Fig. 5) owing to their comparatively limited branching (see Table 4). On the other hand, the isolines with longer-growing periods such as $E_1E_2E_3$, $E_1E_2e_3$, and $E_1e_2E_3$, (Table 3); more branches per plant (see Table 4), and a bigger crop canopy need fewer plants per unit area to achieve maximum seed yield. $E_1E_2e_3$ $\diamond$, for example, requires 45 plants/ m^2 to achieve optimal seed yield (Fig. 5).

In conclusion, the results presented here indicate that adjustments in yield per unit area by changing plant population density

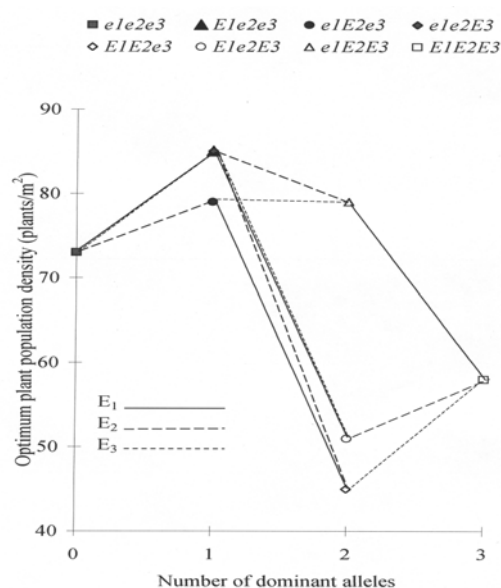


Figure 5. Richards diagram (Richards, 1941) showing optimum plant population density as affected by the maturity genes in the cv. Clark background in 1996. (the method of estimating the optimum density is described in the text).

were partially controlled by changes in yield compensation factors, such as the number of branches, pods and seeds per plant (see Table 2). This partially accounted for harvest index ratio (HI) and crop growth rate (CGR) among the cv. Clark isolines (e.g. the highest seed yield, HI and CGR were recorded for $E_1e_2e_3$ and $e_1E_2E_3$, see Table 3).

The partitioning of assimilates between the vegetative and reproductive plant parts of cv. Clark isolines during flowering and pod set could be related to the number of pods and seeds per plant, as well as seed yield. The isolines $E_1e_2e_3$ and $e_1E_2E_3$, for example, showed the highest number of pods and seeds per plant (see Table 4). The negative relationship between vegetative duration and CGR ($r = -0.54$, $p > 0.10$) and, on the contrary, the positive relationship between reproductive period and CGR ($r = 0.24$, $p < 0.01$) indicate that the Clark isolines balanced the durations between the vegetative phase for producing vegetative dry matter and the reproductive phase for the partitioning of assimilates into seed yield components. There was a significant inverse linear



relationship between the numbers of branches, pods, and seeds per plant and CGR for each genotype (see Table 4), which agrees with Egli's study.

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اثرات تراکم بوته بر عملکرد و اجزاء عملکرد هشت ایزولاین سویا رقم کلارک (*Glycine max* L.)

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چکیده

برای ارزیابی واکنش زراعی هشت ایزولاین سویا رقم کلارک در چهار تراکم مختلف کاشت (۱۱/۳، ۱۸/۵، ۲۸/۵ و ۱۰۳/۴ بوته در متر مربع) یک بررسی مزرعه‌ای در کرج-ایران (عرض جغرافیایی ۳۵°۴۸') برگزار شد. افزایش معنی دار عملکرد دانه سویا در نتیجه تراکم زیادتر بوته حاصل گردید. تفاوت بین ایزولاین‌های سویا (رقم کلارک) نیز معنی دار بود ($P < 0.05$). اجزاء عملکرد مثل تعداد شاخه، غلاف و

تعداد بذر در بوته با افزایش تراکم بوته کاهش خطی نشان داد. تعدیل تعداد غلاف و بذر در بوته ناشی از تغییرات تعداد شاخه در بوته بود. ایزولاین‌هایی که پرشاخه بودند (مثل $E_1E_2E_3$, $E_1e_2E_3$ و $E_1E_2e_3$) در تراکم بوته کم قادر به بهینه‌سازی عملکرد شدند. دومین عامل دینامیکی که به اجزاء عملکرد در تراکم‌های مختلف کمک نمود تقسیم بیشتر ماده خشک بود، که منجر به شاخص برداشت بالاتر و معنی‌دار در تراکم‌های کم نسبت به تراکم زیاد گردید. نتایج نشان داد که ماده خشک کل و نرخ رشد ارقام مورد بررسی سویا عناصر عمده‌ای بودند که عوامل کاهش دهنده اجزاء عملکرد را در تراکم زیاد بوته توجیه می‌کرد. ترسیم خط برازش میزان عملکرد دانه در مقابل تعداد آلل‌های غالب ایزولاین‌های مختلف بیانگر اثرات ژنهای رسیدگی در واکنش به اثرات تراکم بوته بر عملکرد دانه سویا را نشان داد.