AN ABSTRACT OF THE THESIS OF

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Title: The Effect of Nitrogen Rates, Row Spacings and Population Densities on Yield and Ear Characteristics of Sweet Corn

Abstract approved: Harry J. Mack

The response of sweet corn *Zea mays* L. var. rugosa (cultivar 'Jubilee') to row spacing, nitrogen and population density at two planting dates was studied in a field experiment at the OSU Vegetable Research Farm in 1984. Variables included two row spacings, 75 cm and 90 cm, three nitrogen rates, 150, 200, 250 kg/ha, and seven plant population densities, 49,400; 55,575; 61,750; 67,925; 74,100; 80,275 and 86,450 plants/ha.

Population density showed a greater effect on yield (unhusked total and husked good), number of ears/plant, stalk diameter, ear weight, ear length, usable ear length, ear diameter and tip-filling of ears than did nitrogen rates and row spacing. Effects of row spacings and nitrogen rates were generally not significant. Total unhusked yield and yield of husked good ears increased 16 to 20% for the early planting and 22 to 24% for the late planting as plant density increased from 49,400 to 86,450 plants/ha. Ear weight of the first ear decreased 10% in the early planting and about 15% in the late planting as plant density increased from the

lowest to the highest. Although characteristics of second ears were affected by plant population density, their contribution was only 3-16% of the total yield. Longer ears and higher ear weights were associated with the lower plant densities. Stalk diameter was reduced, plants were taller, and average number of ears per plant was reduced at higher densities. No significant interactions between the variables studied in the experiment were observed on any of yield or plant and ear characteristics measured.

Effect of Nitrogen Rates, Row Spacings and
Population Densities on Yield
and Ear Characteristics of Sweet Corn

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Introduction

Oregon is a leading state in the U.S. in sweet corn production for processing, ranking third after Minnesota and Wisconsin. More than 16,000 hectares (40,000 acres) are harvested annually with a value to growers of about 25 million dollars. There has been a trend over the past few years to increase plant population densities to the presently used 55,000 to 65,000 plants/ha. Additionally, there has been an increased acreage of sweet corn planted in 75 cm rows compared to 90 cm rows.

Another trend in recent years in the Oregon sweet corn processing industry has been an increase in the whole ear pack of corn (cob corn). Adequate and more uniform length of ears is more critical for best efficiency, recovery and economics in processing than when kernels are removed from the cob.

The research reported here was conducted to obtain more information on the effects of a range of plant population densities, two row spacings and three nitrogen rates on yield and ear characteristics of sweet corn. Emphasis was given to effects of these variables on ear characteristics, especially ear length, related to production of cob corn.

Review of Literature

Nitrogen

Nitrogen is the major nutrient necessary for corn growth and development. Aldrich *et al*. (1975) and Stoskopf (1981) reported that adequate nitrogen is especially important during pollen-silk structure formation because it is the period when the corn plant has a high protein requirement and uses energy to produce mature pollen, cob and kernels.

Pierre *et al*. (1966) reported that N utilization during silking and ear formation was very high and therefore nitrate was transported or utilized from the leaves and seemed to be low in the leaves. Krautz *et al*. (1984) noted that if nitrate content of the leaves is low this would indicate that the plant has a severe N deficiency. He also reported changes in nitrogen content of the leaves due to season and growth. Alvaro *et al*. (1972) reported that nitrogen fertilization during the flowering stage prolongs the grain filling period and results in more assimulate accumulation in the grain, increasing its size.

Luckwill (1965) suggested that there is a reciprocal relationship between N metabolism and endogenous hormones. However, not only do these hormones control a certain phase of protein synthesis and degradation but also auxin and cytokinins are nitrogen containing compounds whose production is inevitably linked with N metabolism of the plant. Roberts *et al*. (1969) reported that under favorable conditions nitrogen increased the capacity of a given leaf area to produce grain rather than increasing the leaf area per plant.

Increased yields from nitrogen application have been reported by Andrew et al. (1963), Mack (1972), Malzer et al. (1978), Moss and Mack (1977), Peterson and Ballard (1953), and Jordan et al. (1950). Increases in yield were primarily due to increase in ear size and number of ears. Aldrich et al. (1966) found that higher yield and longer ears were due to nitrogen fertilization when adequate amount of P and K are available in the soil. They also found that lodging was associated with heavy ears obtained by adding nitrogen. Moss (1974) found that several ear characteristics such as ear weight, ear size, and length of ear are affected by N fertilizer. His work showed a 44% increase in ear weight when nitrogen was increased from 0 kg/ha to 244 kg/ha. In their five year experiment on sweet corn in highly fertile soil, Vittum et al. (1959) reported no significant increase in average ear weight, gross yield or ears/plant resulted from adding nitrogen. Mengel and Kirkby (1982) reported that nitrogen deficiency can reduce the number of grain per ear in cereals. Smith et al. (1964) reported a decrease in poorly filled ears of sweet corn and a delay in maturity when nitrogen was used. Swezey and Turner (1962) reported an increase in leaf N content by using the nitrification inhibitor nitapyrin. Also Warren et al. (1975) found an increase of nitrogen content of the grain by using nitrapyrin. Lueking et al. (1983) found that nitrapyrin increased the K content of the leaf and NH_4-N remained higher in the soil for six weeks. Malzer and Rondall (1976) in their work on a nitrification inhibitor (terrazol) suggested that the nitrification inhibitor may be effective in maintaining nitrogen in the ammonium form for a longer period, but it may not necessarily increase yield.

Row Spacing and Plant Arrangement

Specific information about the effect of row spacing on yield and yield components is limited. However, Griffith (1973) in his study on field corn (*Zea mays* L.) reported an increase in yield of an early hybrid (at a given plant population density) with 81 cm row spacing compared to the 102 cm row spacing. This agreed with the finding by Stivers *et al*. (1972) who reported 75% increase in yield with 51 cm row spacing and 44% increase with 76 cm compared with 102 cm. A three percent increase in yield by using narrow rows of 46 cm compared with 96 cm was reported by Hunter *et al*. (1970). Bailey (1941) found that narrower row spacing decreased the number of usable ears, ear weight, and also delayed maturity. Plants were taller in narrow rows than in wider rows. Whitaker *et al*. (1969), when testing two hybrids of field corn, reported that average grain yield from pioneer 321 was higher from 49,400-59,280 plants/ha with 75 cm row width while United Hagie 152A had the highest yield at 59,280 plants/ha with a 90 cm row width. The highest yield from both occurred at 49,400-59,280 plants/ha at a row width of 75 cm or more. Denmead *et al*. (1962) suggested that close spacing increased the energy available to the crop for photosynthesis. Giesbrecht (1969) when testing four row spacings

65, 95 and 100 cm) reported that row spacing did not affect but it was the increased plant population density that led ,tantial increase in grain yield.

lson and Roberts (1963) in their experiment comparing 56 :m row spacings at 44,213 plants/ha found that 56 cm was in average yield. Parks et al. (1965) using five row (45, 60, 76, 90 and 100 cm) and four plant densities ,640; 37,000; and 44,460 plants/ha), reported that d was at 44,460 plants/ha at the 45 cm row spacing. Brown et al. (1970), Hoff and Mederski (1960), and Lutz et al. (1971) all reported an increase in yield with equidistance planting. Mack (1972) found that 30 x 30 cm equilateral triangular spacing gave the highest yield of usable corn.

Effect of Plant Population Density on Yield

Several investigators have reported an increase in corn yield from increasing plant population density (Andrew, 1967; Chipmen and Mackay, 1960; Colville, 1962; Colville and McGill, 1962; Donlan and Christopher, 1952; Dungun et al., 1958; Freyman et al., 1972; Moss, 1974; Moss and Mack, 1979; Nelson, et al. 1967). Other investigators also found the same relationship between increasing plant population density and yield (Baker et al., 1970; Dolan and Christopher, 1952; Freyman et al., 1972; Giesbrecht, 1969; Russel, 1968). Whitaker et al. (1969) when testing two hybrids of field corn reported that grain yield was higher when plant population density increased and also dry matter for both hybrids increased linearly when population density increased from

29,640 to 69,160 plants/ha. Brown et al. (1970) in their work on field corn (Zea mays L.) obtained about 300 kg/ha increase in yield by increasing plant population density from 27,000 to 62,000 plants/ha (102 cm rows). Lutz et al. (1971) stated that yield was usually higher as row width decreased (increasing population density) and late maturing varieties gave higher yield when planted at medium and high population density. Norden (1966) found a positive curvilinear relationship between plant population density and yield, and negative linear relationship between plant density and yield per plant.

Bleasdale (1966) reported that the increase in dry matter yield due to an increase in plant population density was not always continuous, but reached a point where further increase in plant population led to a decrease in yield. This agreed with results of Colville and McGill (1962), Nelson et al. (1967), Richard et al. (1971), and Whigham and Wooly (1974), who found a reduction in yield of corn as plant densities increased over the optimum.

Wood and Rossman (1956) stated that the increase in yield from the increase in population density was due to increase in light interception and photosynthesis of the plant canopy. Pendleton et al. (1967) suggested that under field conditions corn leaves are not light saturated even at low rates of planting. Increasing stand density can increase leaf area index (LAI) which plays a crucial role in light interception. Excessive leaf area can reduce yield due to limitation of air circulation and CO_2

movement which can reduce the net assimilation rate (Stoskopf, 1981). However, by increasing populations that have a very high leaf area index, more shading occurs which may have a detrimental effect on yield (Williams et al., 1965). Yield reduction due to poor light environment has also been reported by Prine (1961). Nunez and Kamprath (1969) reported that grain yield of a corn plant is highly dependent upon plant population density, fertility level, as well as growth characteristics of the hybrid adapted to a certain area. He also reported that when plant population is high enough to develop competition between plants, an increase in plant density could cause a reduction in leaf area and yield per plant. Loomis et al. (1968) reported that the major limiting factors of the total seasonal yield seemed to be leaf area and its manner of display in addition to CO_2 supply. Loomis and Williams (1963) reported that optimum population and planting arrangement will be determined by genetic and environmental factors. Increasing yield by increasing LAI 3 to 4 times was reported by many investigators (Williams et al., 1968; Eik et al., 1966; Hoyt et al., 1962) and they suggested that yield increase was due to the increase in light interception by the plant canopy. They also reported that effective leaf area should intercept over 90% of the radiation. Brougham (1956) suggested that the "critical" leaf area is a point when 95% of the incoming light energy is intercepted. Duncan (1971) showed that theoretical increases in yield were achieved as leaf area index increased up to 4. Daynard et al. (1971) reported that yield was increased as plant population and LAI increased, however this increase was not continuous but reached a point when higher density and LAI caused reduction in grain yield. This may be due to shading the lower leaves or the manner in which leaf area was displayed (Williams et al. 1968). Hicks and Stucker (1972) stated that higher yield was expected if plant canopy was well distributed so as to increase light interception to the lower part of the plant canopy.

Vittum et al. (1959) found that high yield due to increase in population density was counteracted by smaller ear size and large number of ears which results in an increase in gross yield. This agreed with work by Enzie (1942) who found in an experiment on three sweet corn hybrids, Seneca Golden, Tender Gold, and Golden Cross, that increasing stand density per unit area coincided with reduction in ear quality and an increase in total yield. Mack (1972) reported 35-55% increase in yield of sweet corn as plant density increased from 29,000 to 128,000 plants/ha. However, this increase in yield coincided with 10-15% reduction in individual ear weight at the higher plant population density.

Ear Weight

A reduction in individual ear weight due to increase in plant population density was reported by the following: Huelson (1947), Lana (1956), Eddowes (1968), Rutger and Crowder (1967), Stickler (1964), and Whitaker et al. (1969). Andrew et al. (1963) in their five year experiment on field corn reported that ear weight consistently decreased from .18 to .12 kg as population density increased from 32,123 to 54,362 plants/ha. Lang et al. (1956)

obtained ears with average weights of .32 kg at a population density of 9,884 plants/ha to .13 kg at 59,300 plants/ha. Evans *et al*. (1960) noticed that the average weight of unhusked ears was significantly lower when plant population density was 37,000 plants/ha than that at 18,000 plants/ha. Mack (1972), Moss and Mack (1979), and Vittum *et al*. (1959) found a decrease in individual ear weight and an increase in yield with increasing plant population density.

Ear Length

Kiesselbach (1950) reported that corn ears reach their maximum length three weeks after fertilization and four weeks before maturity. He also reported a reduction in ear length (about 14%) during the maturing process might take place if the plant is exposed to moisture stress or unfavorable conditions during the critical period of the growth. Bailey (1941) found that ear size and length of ear would increase if the plant feeding area increased (distance between plants increased). Freyman *et al*. (1972), Moss (1974), and Moss and Mack (1979) found a decrease in ear length with increasing plant population densities.

Tip-fill

Bercel and Efthimescu (1973) reported that stress imposed by temperature of about 90°F during tasseling and pollination speeded the growth of the reproductive parts and resulted in higher kernel abortion and poorly filled ears. Classen and Shaw (1970) found that water and nitrogen stress imposed during 75% silking was responsible for a large reduction in the number of developed kernels. Voladarski and Zineuch (1960) stated that drought stress can reduce the number of grains per ear.

Pierre et al. (1966) reported that boron deficiency may cause poor tip-filling. Berger et al. (1957) observed that boron can prevent blank stalks and barren ears. They reported that boron deficiency did not occur each year on the same field but was more related to unfavorable climatic conditions. Furthermore, since boron is an immobile element in the plant, it should be continuously supplied. Marsh and Sheive (1940) concluded that boron should be within the optimum range in the corn plant because of its effect on calcium metabolism.

Plant height

Fleming and Wood (1967), Giesbrecht (1969), Huelsen (1947), and Stringfield and Thatcher (1947) reported that plant height increased with increasing plant population density. Stoskopf (1981) stated that increasing plant population density can cause poor light penetration to the lower part of the plant canopy and under reduced light an actively growing stem causes the cells to elongate. Moss (1974) found that maximum plant height was obtained when plant population density increased from 91,367 to 190,376 plants/ha. Kiesslebach (1950) reported that the corn plant reached its maximum height about nine weeks after emergence with a growth rate of about 4.79 cm per day. Norden (1966) reported a 5% increase in plant height when population density increased from 12,350 to 61,750 plants/ha. Colville and McGill

(1962), and Dungan _et al_. (1958) found that at higher plant population densities, stalk and ear height were taller.

Materials and Methods

A field experiment was conducted in 1984 at the Oregon State University Vegetable Research Farm, Corvallis. The experimental site was in alfalfa for four consecutive years prior to 1984. The soil was deeply plowed and harrowed in the spring so organic material from the previous crop was well mixed in the soil. Fertilizer was banded at planting at a rate of 56 kg N, 74 kg P, and 47 kg K/ha. Additional nitrogen was side dressed to achieve rates listed below. The insecticide Dyfonate 10G at 9 kg/ha was broadcast and incorporated into the soil before planting. Chemical weed control was acomplished by a mixture of Lasso and atrazine 80W (5.63 liters + 2.47 kg). Weeds that developed later in the season were hand removed. Sprinkler irrigation was supplied every 10 to 15 days as needed for adequate growth.

The experiment included seven plant population densities: 49,400; 55,575; 61,750; 67,925; 74,100; 80,225; and 86,450 plants/ha; three nitrogen rates: 150, 200, 250 kg/ha; and two row spacings, 75 and 90 cm, in two planting dates, 5/16/84 and 6/18/84.

The design of the experiment was a split-split plot with three replications. Two row spacings were main plot, three nitrogen rates were sub-plots and seven population densities were sub-sub-plots. All were randomly assigned. The two planting dates were treated as separate experiments. A prolific sweet corn cultivar, 'Jubilee' which produces more than one ear per plant, was used.

The early planting was made on May 16 and was harvested on September 6-7 while the late planting was made on June 18 and was harvested September 24. At harvest, the first (upper) and second (lower) ears were kept separate.

Measurements taken at harvest were: yield of total unhusked ears and of husked, usable (good) ears for all densities in the early planting but for only three densities (49,400; 67,925; and 86,450 plants/ha) in the late planting.

Measurements of individual ear characteristics of husked, good ears were: ear weight, total ear length, usable length (cob corn), ear diameter and tip-fill. These were made on first (top) and second (bottom) ears at all densities in the early planting and all densities for the first ear in the late planting but only for the three densities listed above in the late planting.

Total ear length was measured from the base to the tip (end) of the ear while usable length was measured after trimming the base and tip of the ear to simulate processor requirement for cob corn. Ear diameter was measured 50 mm above the base of the ear. Tip-fill was evaluated on a scale of 1 to 5 with 1 being very poor tip-fill and 5 being excellent tip-fill or full development of kernels at the tip or end of the ear. Tip-fill scores were assigned by the same person to assume uniform grading.

Plant height and diameter of stalk at harvest were measured in the first planting only at two densities, 49,400 and 86,450 plants/ha.

Results and Discussion

Effect of nitrogen on yield and ear characteristics

Yield

There was no significant effect of nitrogen rates on the total yield of unhusked ears or on husked good ears for both early and late planting dates (Tables 1, 2). However, in the early planting, yield at 150 kg N/ha tended to be higher than at 200 and 250 kg N/ha and the latter gave the lowest yield. In the late planting, yield at the 200 kg N/ha rate was higher than that at 150 and 250 kg N/ha rates, although the difference was not statistically significant. Lowest yield was at 150 kg N/ha.

Number of ears per plant

The F test did not reveal any significant effect of the nitrogen on number of ears for the early and late planting when both first and second ears were included. However, if only second ears are included, there was a trend for N to increase number of second ears in the early planting. At the lowest plant population density (49,400 plants/h) total good second ears increased from 9,000 ears/ha to 15,710 ears/ha as nitrogen rates increased from 150 to 250 kg/ha (data not shown). The trend for N to increase number of second ears was not evident at the high population densities.

Plant height and stem diameter

Neither plant height nor stem diameter were significantly affected by nitrogen rates, although there was a slight decrease in plant height as nitrogen rates increased from 150 to 250 kg/ha (Table 4). The same trend was evident for stem diameter. There was a greater effect on plant height and stem diameter because of change in population densities rather than change in nitrogen rates.

<u>Ear weight</u>

Nitrogen application over 150 kg/ha showed no significant effect on first and second ear weight of the early planting or first ear of the late planting. But ear weight of the second ear for the late planting was significantly affected by nitrogen application (Table 5). About 10% increase in average ear weight was found as nitrogen rates increased from 150 to 250 kg N/ha. Ear weight was the lowest at the nitrogen rate of 200 kg/ha.

<u>Total ear length and usable ear length</u>

Neither total ear length nor usable ear length of the first and second ear of the early and late planting was significantly affected by increasing nitrogen application over 150 kg/ha. Still, nitrogen application tended to increase ear length and usable length of the first ear for the early and late planting. Second ear length and usable length was higher at 250 kg/ha for both dates (Table 6). Nitrogen at 200 kg/ha did not show a uniform effect on the second ear length and usable length.

<u>Ear diameter</u>

No significant effect for nitrogen application over 150 kg/ha on ear diameter of the first ear for both dates was found. However the F test revealed a significant effect for nitrogen application on ear diameter of second ear for both early and later planting (Table 7). At the late planting 200 kg/ha gave 28% decrease in second ear diameter than at 150 and 250 kg N/ha, while at the early planting a nitrogen rate of 250 kg/ha increased second ear diameter about 2-5% when compared to 150 and 250 kg N/ha rates.

Tip-fill

Increasing the nitrogen rate from 150 to 250 kg/ha had no significant effect on ear tip-fill scores except for the second ears of the late planting. The tip-fill scores for the second ears of the late planting were much lower than for the others. Because of this low score there would appear to be very little usable corn for processing (Table 7).

Discussion

It is not obvious why the effect on yield and ear characteristics of 200 and 250 kg/ha rates of nitrogen, compared to 150 kg N/h were not consistent. In some cases, higher rates of N application tended to increase yield, but in others the intermediate rate of N produced lowest yield. Because of previously cropping the experimental area in alfalfa for four or five years, yield response from nitrogen would not be likely. Moss and Mack (1979) found that additional N above 56 kg/ha had little further influence on ear weight, ear length or total marketable ear yields. Vittum _et al_. (1959) found no yield response of sweet corn from adding nitrogen to a highly fertile soil. In the present study, nitrogen did not appear to be limiting yield, even at the highest population densities since there was no significant N x density interaction.

Effect of row spacing on yield and ear characteristics

Yield

There was no significant effect of row spacing on total unhusked yield or on husked good ear yield for both planting dates. However, in the early planting yield of total unhusked and husked good ear tended to be higher at the 90 cm row spacing than at 75 cm at lower population densities and higher at 75 cm row spacing than for 90 cm at the highest population densities (Table 8). However, this trend did not result in a significant row spacing x population density interaction.

Ear weight

Row spacing had no significant effect on ear weight of first and second ears for both planting dates (Table 9). Ear weights of first ears were higher than for second ears. Ear weights on the late planting were lower than in the early planting.

Ear length and usable length

The F test revealed no significant effect for the row spacing on total length and usable length for the first and second ears of the early and late planting (Table 10). Although there was no significant effect in 75 cm rows there was a trend for reduced total length and usable length of second ear for both early and late planting at the higher densities. Length of second ears was less than for first ears and total and usable length of both first and second ears were usually less in the late planting than in the early planting.

Ear diameter

Data in Table 11 indicate row spacing had no significant effect on ear diameter of the first and second ear in early and late plantings. Average diameter of the second ear was about 20% less than for the first ear (mean of both row spacings) in the first planting and 35% less when the same comparison is made in the second planting.

Tip-fill

There were no significant effects for the row spacing on tip-fill of first and second ears of the late planting or the second ear of the early planting. Still, first ear tip-filling of the early planting was significantly increased (at the .05 level of significance) at the narrow spacing (Table 12). However, second ear tip-fill for the early and late planting showed greater improvement at the wider spacing but both probably would not be acceptable by the processor.

Discussion

The non-significant effect of row spacing on yield and ear characteristics was expected due to the fact that the differences between the two row spacings in the experiment were not very great (only 15 cm). However, there was a trend for yield to increase about 10-15% at the higher plant population densities, while the increase on the average was 3-5%. Results agree with Brown *et al.* (1970), Denmead *et al.*; Geisbrecht (1969); Griffith (1973); Hunter *et al.* (1970); Hoff and Medereski (1960); and Parks *et al.* (1965)

who reported slightly higher yields at narrower spacing and higher densities.

Effect of plant population density on yield, plant and ear characteristics

Yield

Significant increases in unhusked total yield of about 16%, and yield of husked good ears of about 21% were obtained in the early planting as plant population density increased from 49,400 to 86,450 plants/ha. Likewise, in the late planting increasing plant density from the lowest to the highest increased yield 22% for total unhusked yield and 24% for the yield of husked good ears (Fig. 1). The regression analysis for yield of total unhusked ears and husked good ears vs. plant population density showed a curvelinear relationship with R^2s (coefficient of determination) at 0.916 and 0.951, respectively (Figs. 2,3).

First ear

The F test for the split-split plot design revealed a significant effect of plant population density on the yield of total unhusked and husked good ears for both early and late plantings (at the two levels of significance .01 and .05) (Figs. 4,5,6,7). Increases of 27% and 28% in the yield of total unhusked ears and husked good ears, respectively, were obtained as population density increased from 49,400 to 86,450 plants/ha in the early planting (Figs. 4,5). Similarly an increase of 31% in both yield of total unhusked and husked good ears was found as plant density increased from the lowest to the highest at the late planting (Figs. 6,7).

Second ear

Plant population density showed a significant impact on the yield of second ears for both early and late plantings. Yield of second ears was higher at the lower densities than at the higher densities. However, yield of second ears was much less than yield of first ears and only constituted from 3 to 17% of the total yield (Figs. 4,5,6,7).

Number of ears per plant

As population density was increased from 49,400 to 86,450 plants/ha, the average number of ears per plant was significantly reduced in both plantings (Figs. 8,9). The range was from 1.5 ears/plant at the lower plant population density to 0.975 ears/plant at the highest population in the early planting. In the late planting, the respective range was 1.3 to 1 ear/plant. Also, the regression analysis showed that plant population density was highly responsible for the change in the number of ears per plant (R^2 0.986 and 0.956 for early and late planting, respectively).

Plant height and stem diameter

Plant height was not significantly different between the two population densities that were compared in the early planting date 49,400 vs. 86,450 plants/ha. However, plants at the higher density were 7.5 cm taller than for the low density. Stem diameter was significantly lower (about 10%) at 86,450 plants/ha than at 49,400 plants/ha (data not shown). Although measurements were made for only two populations in the early planting, results agreed with others who have found that height is increased and stem diameter decreased as densities are increased (Fleming and Wood, 1967; Giesbrecht, 1969; Huelsen, 1947; Moss, 1974; Rutger and Crowder, 1967; and Stringfield and Thatcher, 1947).

Ear weight

Increasing the plant population density significantly reduced average ear weight of both first and second husked good ears for the early and late plantings (.01 and .05 level of significance) (Fig. 10). Reduction in average ear weight for the early planting was 9% for the first ear and 33% for the second ear as plant density increased from 49,400 to 86,450 plants/ha. Similarly, first and second ears of the late planting showed reductions of 9% to 50%, respectively, as population density increased from the lowest to the highest. The regression analysis indicated a high negative correlation between plant density and average ear weight (Figs. 11,12,13,14).

Total ear length and usable ear length

Total length and usable length for the first and second ears of the early and late plantings were significantly affected (at the .05 and .01 level of significance) by increasing plant population density from 49,400 to 86,450 plants/ha (Figs. 15,16). Total ear length of the first ear in the early planting was reduced 5% when the highest is compared to the lowest density. A reduction in the total and usable ear length of 30 and 35% respectively for the second ear of the early planting was found when the lowest and the highest populations are compared. Similarly, total and usable ear length of the first ear of the late planting were reduced about 4 and 8%, respectively, as plant density increased from the lowest to the highest. Regression analysis of ear length and usable length of the first and second ear (Figs. 17,18,19,20,21,22) show a linear negative relationship between plant population density and ear length and usable length of the early planting (first and second ear with R^2 equal to 0.965 and 0.850, respectively). Similarly, the second ear of the late planting also showed a linear correlation between plant density and ear length with an R^2 of 0.999, while for the first the exponential equation with an R^2 of 0.98 fits the relationship. Usable length of the first ear of the early planting showed linearly negative correlation with plant population density with R^2 of 0.865, while the first ear of the late planting showed a curvilinear relationship with R^2 of 0.958.

Ear diameter

Second ears of early and late plantings were significantly affected by increasing plant population density from 49,400 to 86,450 plants/ha, but population density did not affect diameter of first ears of both planting dates (Fig. 23). Diameter of ears was measured approximately 5 cm from the base of the ear so that part of the first ear was less highly affected by change in population density than if diameter measurements had been made toward the tip of the ear. The regression analysis also showed higher coefficient of determination of second ear of the early and late planting than on the first ear of both dates (Figs. 23,24,25,26,27).

Tip-fill

Plant population density showed a significant effect on tip-fill of first and second ears of both planting dates (at .01 and .05 level of significance) (Fig. 28). As population density was increased from lowest to highest level there was a reduction in tip-filling of about 8-13% on the first ears and 8% on the second ears of the early planting. This reduction was 8% and 51% for the first and second ears of the late planting, respectively. A logarithmic curve with a coefficient of determination $R^2 = 0.82$ had a better fit when regression analysis was made on the first ear of the early planting. A polynomial regression, third degree, fit for the relationship of tip-fill and population for the first ear of the late planting (Figs. 28,29,30).

Discussion

Total yield of sweet corn was increased about 20 to 25% in the two plantings as population density was increased from 49,400 to 86,450 plants/ha. These results are in agreement with other investigators: Brown et al. (1970), Coville (1962), Freyman et al. (1972), Moss (1974), Moss and Mack (1979) and Vittum et al. (1959).

Although potential yield increases are determined by genetic, environmental and grower management practices, it appears that western Oregon growers could increase plant populations over the presently used 55 to 65,000 plants/ha to 80 to 85,000 plants/ha to achieve increases in yield. However, these yield benefits would need to be evaluated against changes which would occur in number, weight, and other characteristics of individual ears, especially those uses for specific processed products. Of particular interest to processors are factors affecting usable ear length and diameter of ears for whole ear or cob packs. General specifications are to trim both ends of each ear and then to obtain two Cobetts of 76 mm length each or one cob of 140 mm length. The cultivar 'Jubilee' usually produces two usable ears per plant under non-competitive plant population pressure and develop or fills the primary (top) ear first and then diverts the excess amount of photosynthate to the second ear. When total amount of photosynthate is limiting, which occurs under more competition or crowded conditions and reduced light penetration, size of second ears is reduced markedly or they do not develop at all, and first (top) ears are limited in size and kernel fill at the tips. These relationships of population density effects on individual ear characteristics in the present study are manifested in change in ear weight, ear diameter, total and usable ear length and tip-fill scores. Some of these changes have also been reported by Freyman et al. (1972), Moss and Mack (1979) and Vittum et al. (1959).

Duncan (1984) suggested that in corn, competition for light reduces per plant yield unless some other requirement is severely limiting. Furthermore, for field corn, he states "as the number of plants in a planting pattern increases, the distance between plants decrease and the crowding value (all of interplant competition for yield-related needs) increases at an increasing rate. At lower than the maximum-yield population, adding more plants overcompensates for the lowered grain yield per plant due to the increased crowding. Above some population, however, the effect of rapidly increasing crowding due to the close plant spacing cannot be offset by the yield of the added plants and again yield per unit area beyond this point decreases as plant population continue to increase." In the present study populations were not high enough to produce diminished yields of ears per unit area. Moss (1974) assigned an arbitrary minimum weight of 220 grams for marketable ears (husked) and found that marketable yields were increased to about 76,800 plants/ha, then leveled off and dropped rapidly above 110,000 plants/ha.

Table 1. The effect of nitrogen rates on unhusked and husked good yield of first and second ears, early planting date.

	Unhusked total MT/ha			Husked good MT/ha		
Nitrogen kg/ha	First ear	Second ear	Total	First ear	Second ear	Total
150	28.87	2.69	31.83	21.76	1.25	23.01
200	28.32	2.28	30.60	21.60	1.07	22.67
250	26.09	2.79	28.88	19.76	1.34	21.10

Means of 7 population rates, 2 row spacings, and 3 replications.

There were no significant differences in nitrogen rate means.

Table 2. The effect of nitrogen rates on unhusked and husked good yield of first and second ears, late planting date.

	Unhusked total MT/ha			Husked good MT/ha		
Nitrogen kg/ha	First ear	Second ear	Total	First ear	Second ear	Total
150	22.30	1.94	24.24	15.16	1.02	16.80
200	22.61	2.10	24.71	16.41	0.91	17.32
250	22.91	1.61	24.52	15.71	0.95	16.65

Means of 3 population rates, 2 row spacings, and 3 replications.

There were no significant differences in nitrogen rate means.

Table 3. The effect of nitrogen rates on ear number per plant in the two planting dates.

	Early planting N rates kg/ha			Late planting N rates kg/ha		
Population density plants/ha	150	200	250	150	200	250
49,400	1.35	1.59	1.54	1.24	1.39	1.26
55,575	1.48	1.36	1.29			
61,750	1.32	1.21	1.29			
67,925	1.24	1.18	1.27	1.08	1.10	1.10
74,100	1.19	1.18	1.18			
80,275	1.15	1.06	0.88			
86,450	1.15	1.06	0.88	1.05	1.02	0.99
Average of N rates	1.26	1.23	1.19	1.12	1.17	1.12

Means of 3 replications and 2 row spacings.

There were no significant differences on nitrogen rate means.

Table 4. The effect of nitrogen rates on plant height and stem diameter, early planting.

	Plant height (cm) N rates kg/ha			Stem diameter (mm) N rates kg/ha		
Population density plants/ha	150	200	250	150	200	250
49,400	283	271	272	21.67	21.84	21.41
86,450	286	281	280	20.33	20.05	20.06
Average of N rates	284	276	276	21.00	20.94	20.74

Means of 2 row spacings and 3 replications.

There was no significant difference in nitrogen rate means.

Table 5. The effect of nitrogen rates on ear weights of first and second ears, early and late plantings.

Population density plants/ha	Early planting						Late planting					
	Ear weight grams						Ear weight grams					
	First ear			Second ear			First ear			Second ear		
	Nitrogen rates kg/ha						Nitrogen rates kg/ha					
	150	200	250	150	200	250	150	200	250	150	200	250
49,400	309	303	313	220	228	228	245	254	255	187	176	199
55,575	314	305	304	237	219	203	260	256	258			
61,925	294	297	307	235	229	231	247	249	260			
67,925	295	295	302	187	197	199	238	232	232	153	95	142
74,100	286	291	298	184	188	209	240	244	246			
80,225	280	280	292	105	151	211	246	241	246			
86,450	281	272	290	212	138	101	222	229	237	77	106	118
Average of N rates	294	292	300	197	193	197	242	244	247	139*	126*	153*

Means of 2 row spacings and 3 replications

There was no significant difference in means except (*) significant at .05 level.

Table 6. Effect of nitrogen rates on total ear length and usable ear length, early and late plantings.

	Ear length mm							
	Early planting				Late planting			
	Total		Usable		Total		Usable	
N kg/ha	First ear	Second ear	First ear	Second ear	First ear	Second ear	First ear	Second ear
150	197	163	150	106	188	62	142	37
200	199	162	153	108	189	44	141	26
250	200	169	155	110	189	66	143	41

There was no significant difference in nitrogen rate means.

Table 7. Effect of nitrogen rates on ear diameter and tip-fill, early and late plantings.

	Ear diameter mm				Tip-fill[z]			
	Early planting		Late planting		Early planting		Late planting	
N kg/ha	First ear	Second ear	First ear	Second ear	First ear	Second ear	First ear	Second ear
150	49	39	47	14	4.2	2.8	3.8	1.0
200	49	38*	47	10*	4.1	2.8	3.9	1.0
250	48	40	47	14	4.2	2.8	3.8	1.5

[z] Tip-fill scores: 1=poor, 5=excellent.

Menas of 7 population rates, 2 row spacings, and 3 replications (for the second ear late planting means come from 3 population rates, 2 row spacings, and 3 replications).

There was no significant difference in nitrogen rate means except (*) at the .05 level.

Table 8. Effect of row spacing on total yield of unhusked and husked good ears for the early and late planting.

	Yield mt/ha							
	Early planting				Late planting			
	75 cm		90 cm		75 cm		90 cm	
	Total unhusked	Husked good	Total unhusked	Husked good	Total unhusked	Husked good	Total unhusked	Husked good
49,400	26.90	19.05	27.57	19.08	22.58	14.64	20.96	13.67
55,575	27.45	19.63	29.59	20.95				
61,750	29.09	21.28	30.39	21.47				
67,925	30.38	21.76	32.08	22.67	24.32	16.09	23.24	15.98
74,100	32.32	23.97	31.91	22.98				
80,225	34.14	25.52	28.41	20.40				
86,450	34.34	25.02	30.32	23.16	28.20	18.69	27.62	18.47
Row spacing means	30.66	22.32	30.04	21.53	25.03	16.47	23.94	16.04

Numbers are mean of three replication and three nitrogen levels.

There was no significant difference in row spacing means.

Table 9. Effect of row spacing on ear weight of early and late planting.

	Ear weight grams							
	Early planting				Late planting			
	First ear		Second ear		First ear		Second ear	
Population density	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm
49,400	313	304	227	224	259	243	189	169
55,575	309	306	223	217	262	254		
61,750	300	299	237	226	250	254		
67,925	296	298	197	191	238	230	120	134
74,100	288	289	191	198	246	242		
80,225	289	279	144	168	244	245		
86,450	283	278	104	197	227	231	57	114
Row spacing means	296.9	293.3	189	203	246.6	242.7	122	139

There was no significant difference in row spacing means.

Means of 3 nitrogen rates and 3 replications.

Table 10. Effect of row spacing on ear length and usable length for early and late planting.

Population density plants/ha	Ear length mm															
	Early planting								Late planting							
	First ear				Second ear				First ear				Second ear			
	Total		Usable		Total		Usable		Total		Usable		Total		Usable	
	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm
49,400	204	203	155	155	182	184	130	129	192	192	149	148	183	166	113	104
55,575	202	202	156	156	183	184	117	119	192	192	148	147				
61,750	201	201	156	156	188	188	133	125	188	191	142	145				
67,925	200	200	154	152	176	174	105	110	187	189	142	139	122	146	75	89
74,100	196	197	150	152	159	163	107	105	186	188	140	139				
80,225	196	195	151	146	124	145	76	93	186	188	138	140				
86,450	194	192	144	151	92	160	59	106	186	186	135	137	63	121	37	70

There was no significant difference in row spacing means.

Means are 3 nitrogen rates and 3 replications.

Table 11. Effect of row spacing on ear diameter of the early and late planting.

Population density plants/ha	Ear diameter mm							
	Early planting				Late planting			
	First ear		Second ear		First ear		Second ear	
	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm
49,400	49	49	43	43	49	47	41	36
55,575	49	49	43	43	48	47		
61,750	49	49	43	43	47	48		
67,925	49	49	43	41	47	46	27	31
74,100	49	49	38	37	47	47		
80,225	48	48	27	32	47	46		
86,450	48	48	24	39	47	46	20	26
Row spacing means	49	49	37	40	47	47	29	31

There was no significant difference in row spacing means.

Means are 3 nitrogen rates and 3 replications.

Table 12. Effect of row spacing on tip-filling of first and second ears in early and late plantings.

	Early planting				Late planting			
	First ear		Second ear		First ear		Second ear	
Population density plants/ha	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm	75 cm	90 cm
49,400	4.60	4.20	3.22	3.33	4.00	3.88	2.88	2.77
55,575	4.44	4.33	3.44	3.00	4.00	4.11		
61,750	4.22	4.11	3.66	3.33	3.88	4.00		
67,925	4.00	4.22	2.33	2.33	3.77	3.44	2.00	2.22
74,100	4.11	4.11	2.77	2.55	3.77	3.77		
80,225	4.00	3.77	2.22	2.55	3.89	3.89		
86,450	4.00	4.00	1.60	2.77	3.55	3.66	1.00	1.77
Row spacing means	4.20	4.11	2.75	2.83	3.84	3.82	1.96	2.25

There was no significant difference in row spacing means.

Means are 3 nitrogen rates and 3 replications.

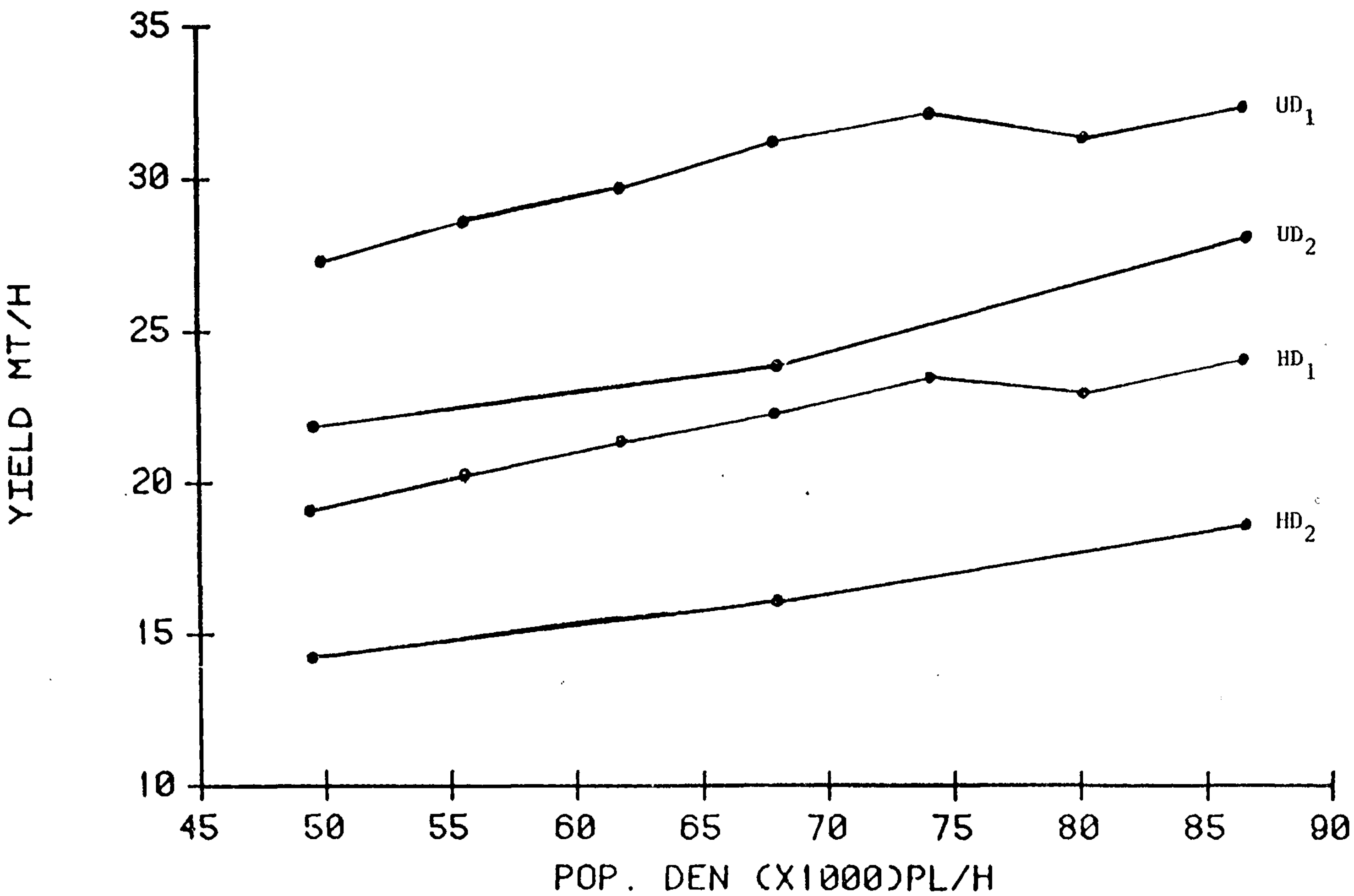
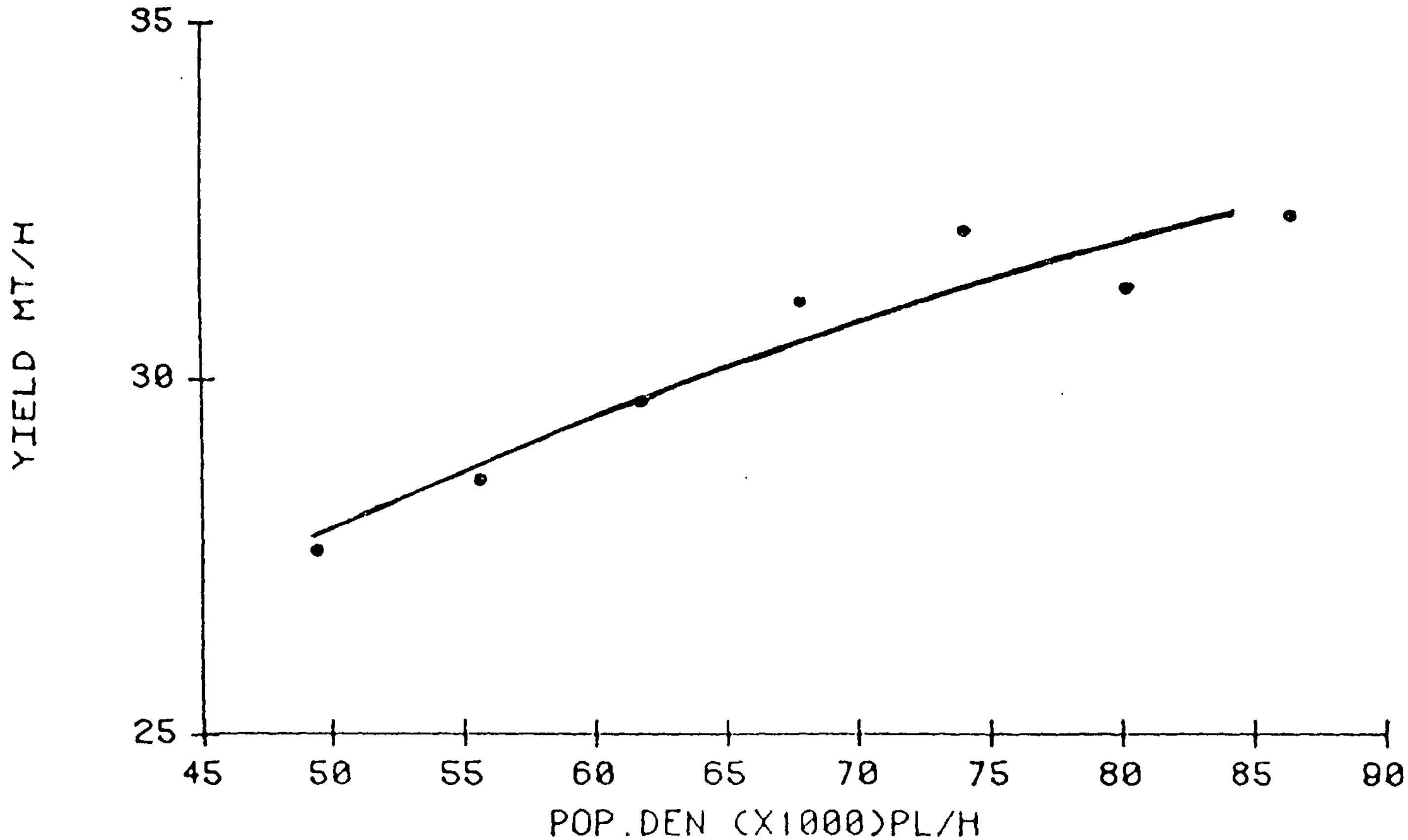


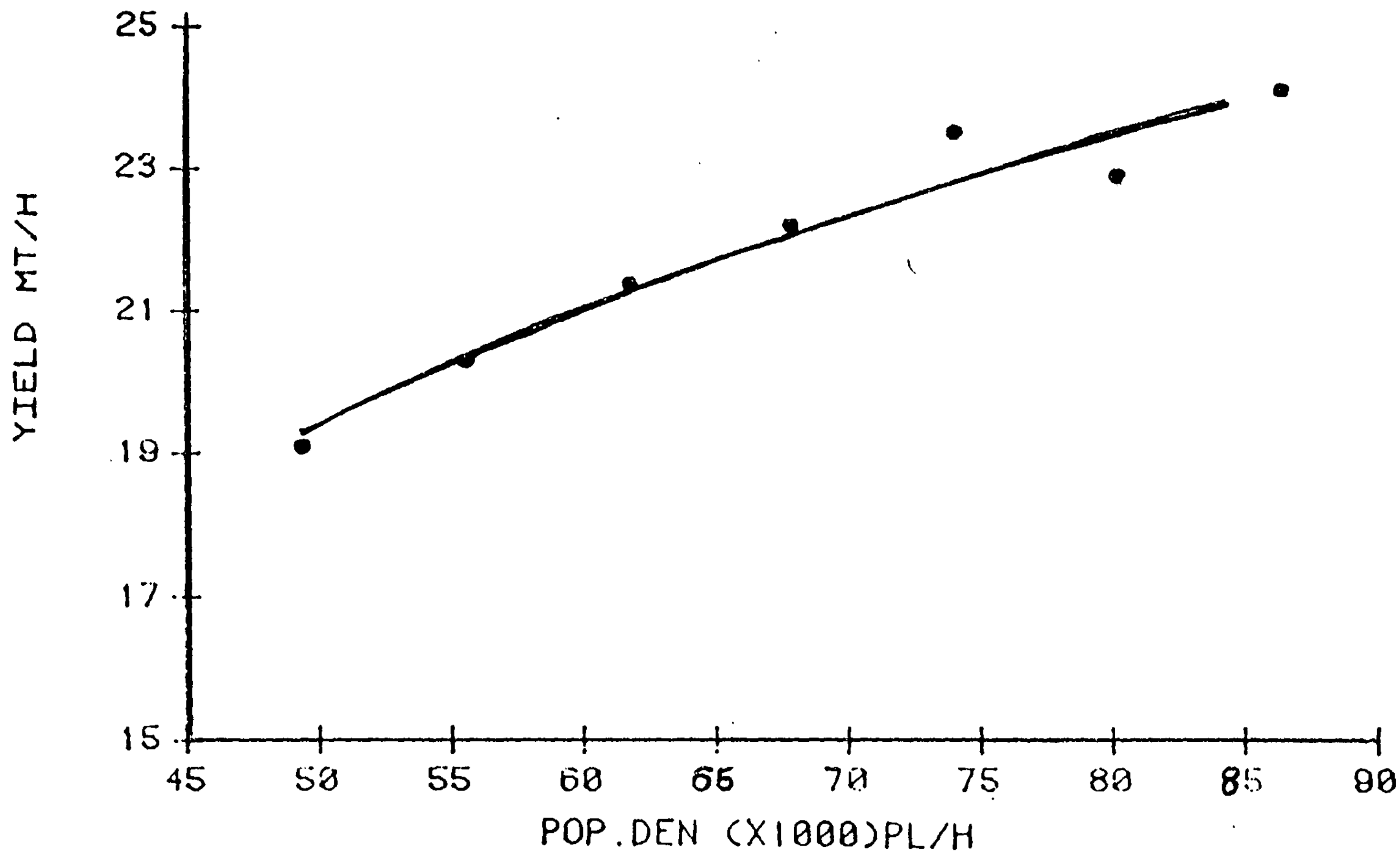
Figure 1. Effect of population density on yield of total unhusked (U) and husked (H) of the early (D_1) and late (D_2) planting.



$Y = -5.5779 + 8.56 \times LN(X)$

$R^2 = .916$

Figure 2. Effect of population density on total unhusked yield of the early planting.



$Y = -14.52 + 8.675 \ LN(X)$

$R^2 = .951$

Figure 3. Effect of plant population density on yield of husked good ears in the early planting.

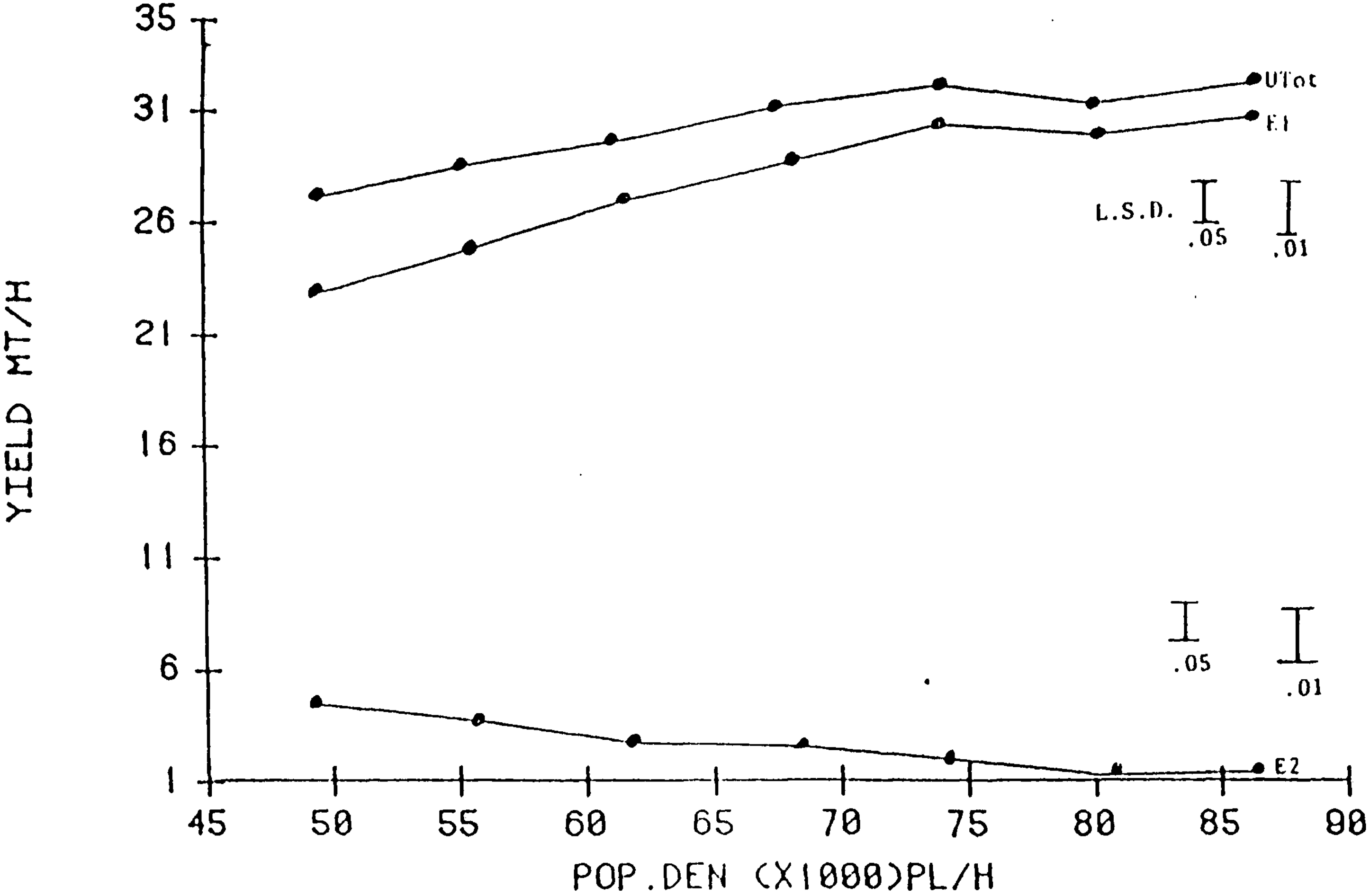


Figure 4. Effect of plant population density on yield of unhusked total (UTot), first ear (E1), and second ear (E2) in the early planting.

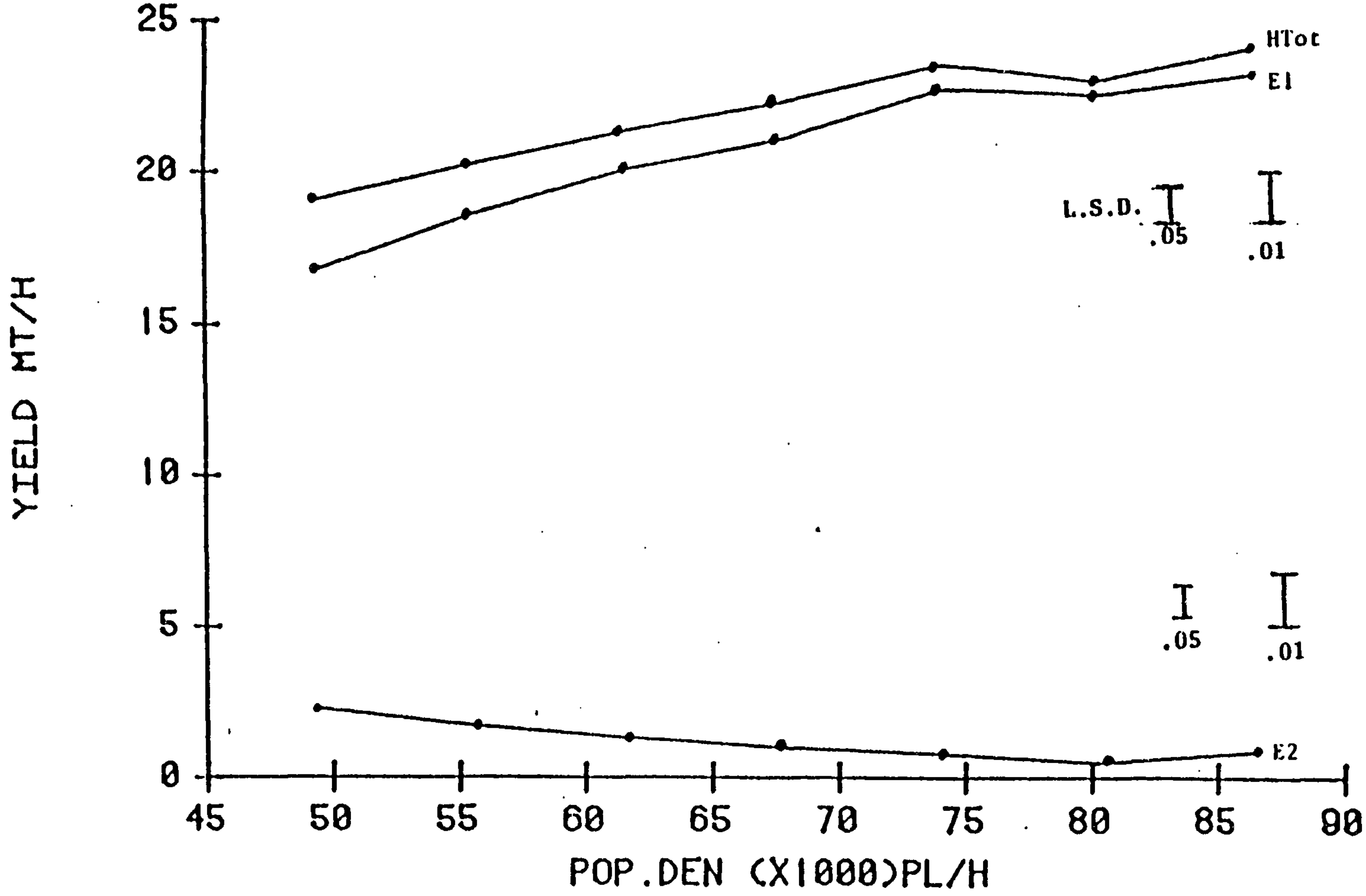


Figure 5. Effect of plant population density on yield of husked good total (HTot), first ear (E1), and second ear (E2) in the early planting date.

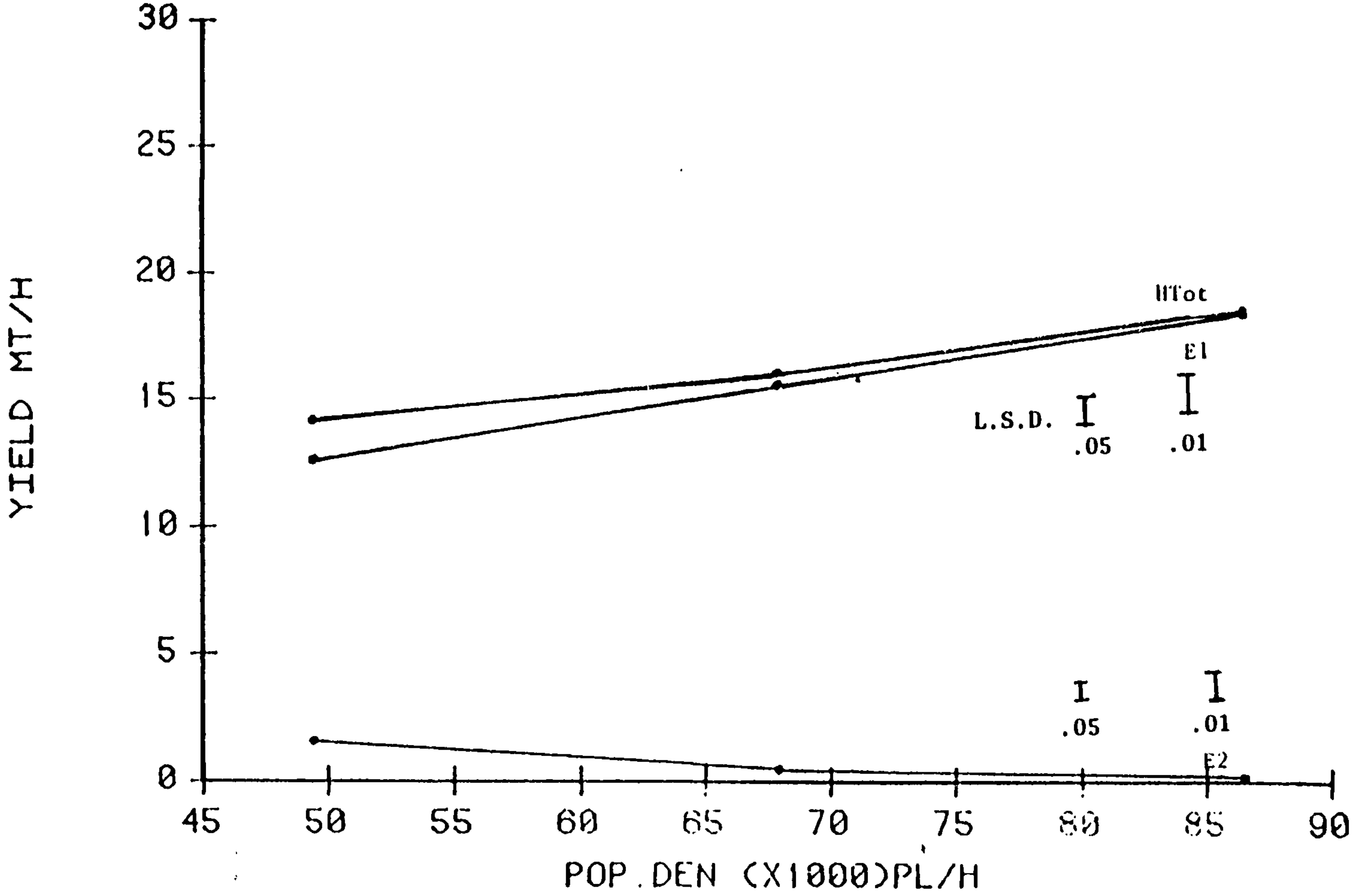


Figure 6. Effect of population density on husked good yield total (HTot), first ear (E1), and second ear (E2) in the late planting.

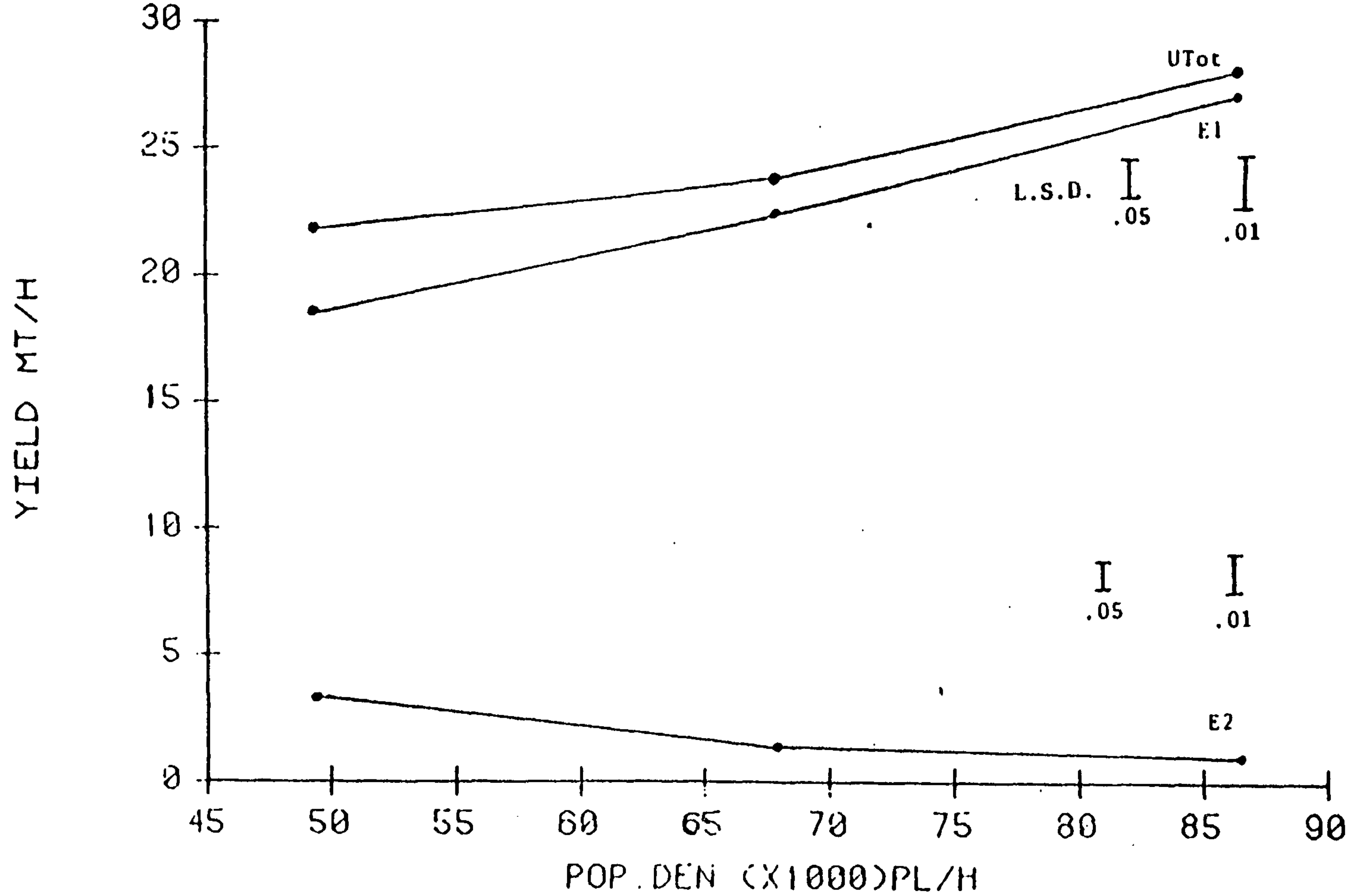
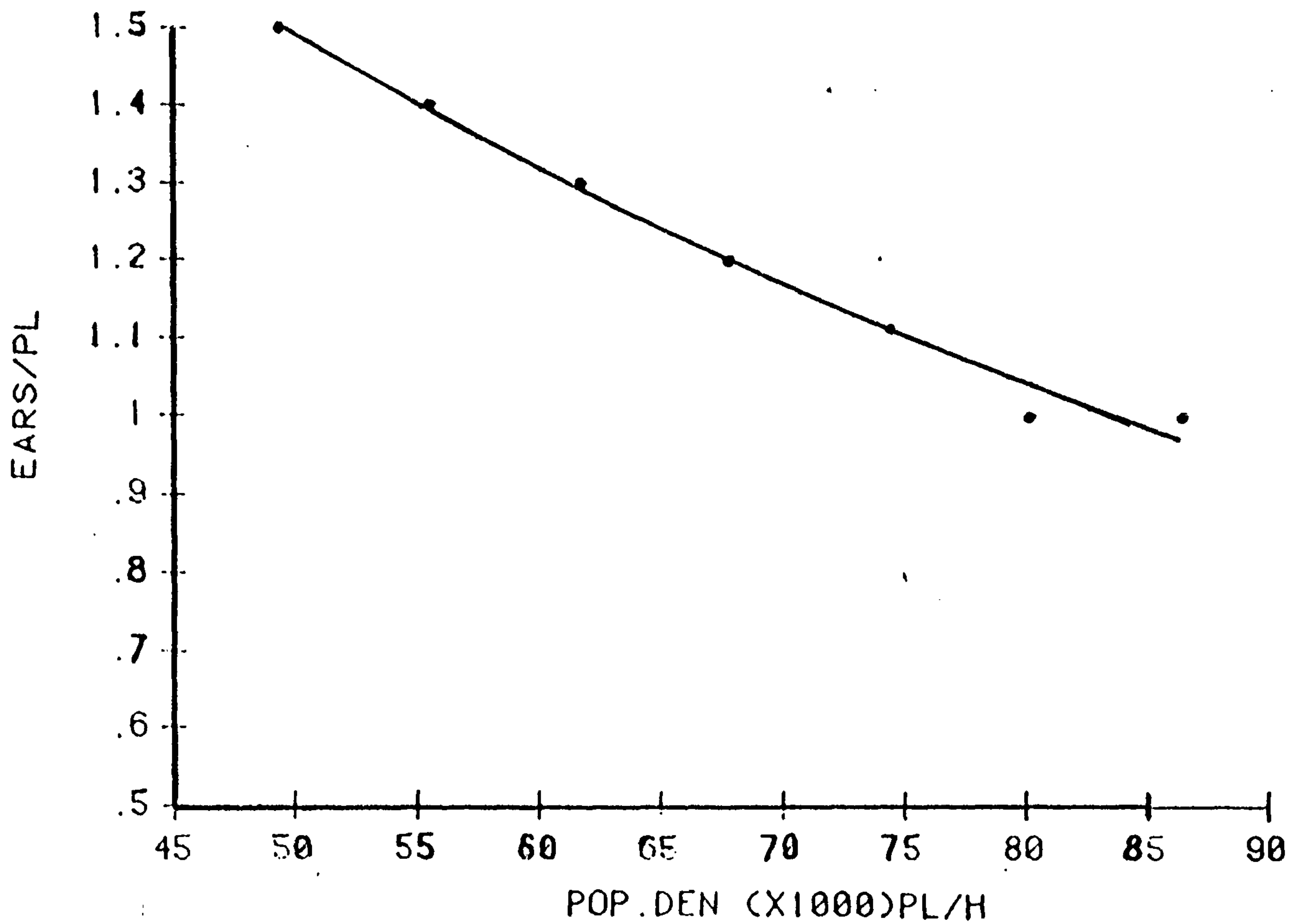


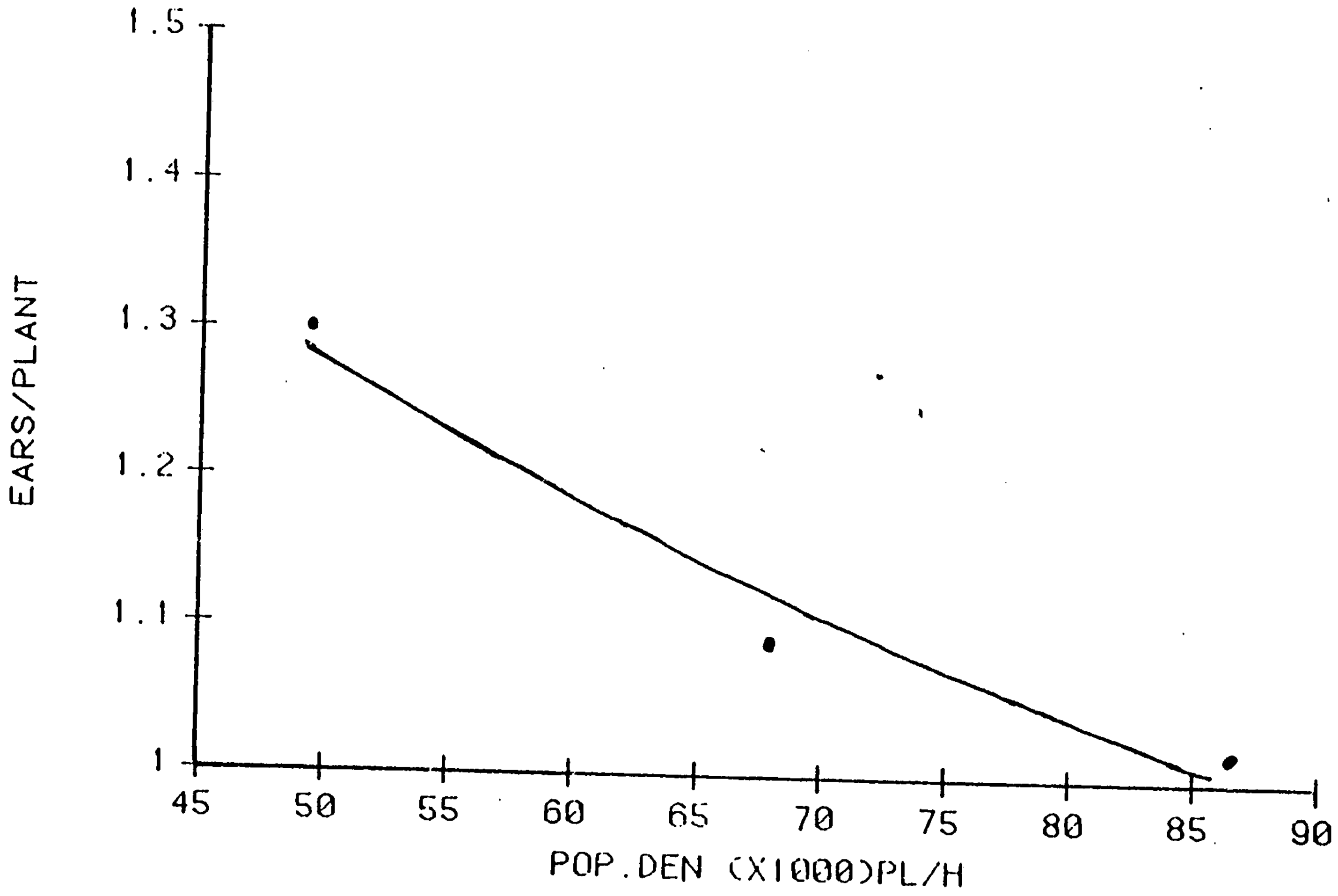
Figure 7. Effect of population density on unhusked yield total (UTot), first ear (E1), and second ear (E2) in the late planting.



$Y = 5.27 - .965 \, LN(X)$

$R^2 = .986$

Figure 8. Effect of population density on ears/plant in the early planting.



$Y = .568007\ LN(X) + 3.26659$

$R^2 = .956$

Figure 9. Effect of population density on ears/plant in the late planting.

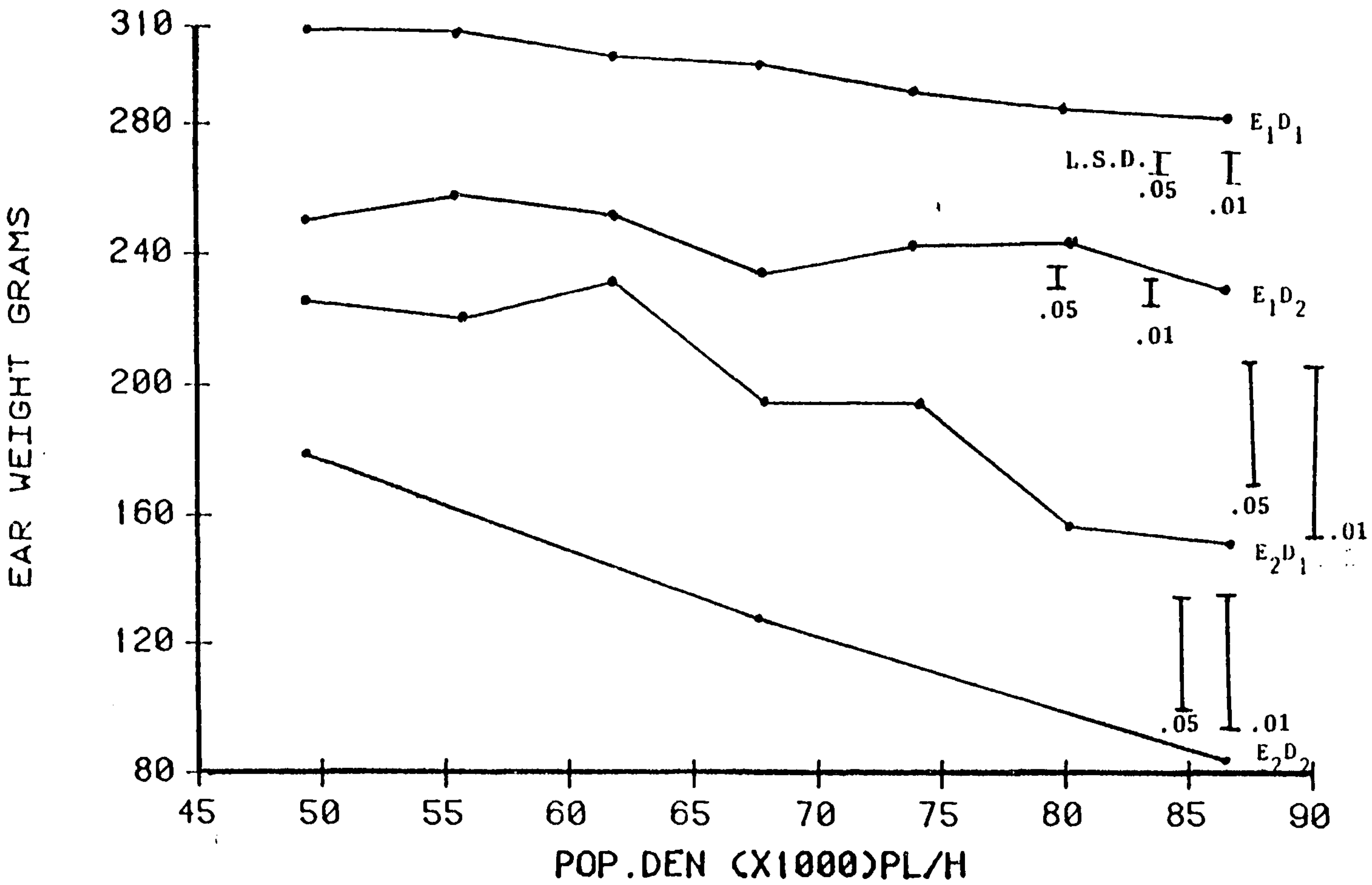
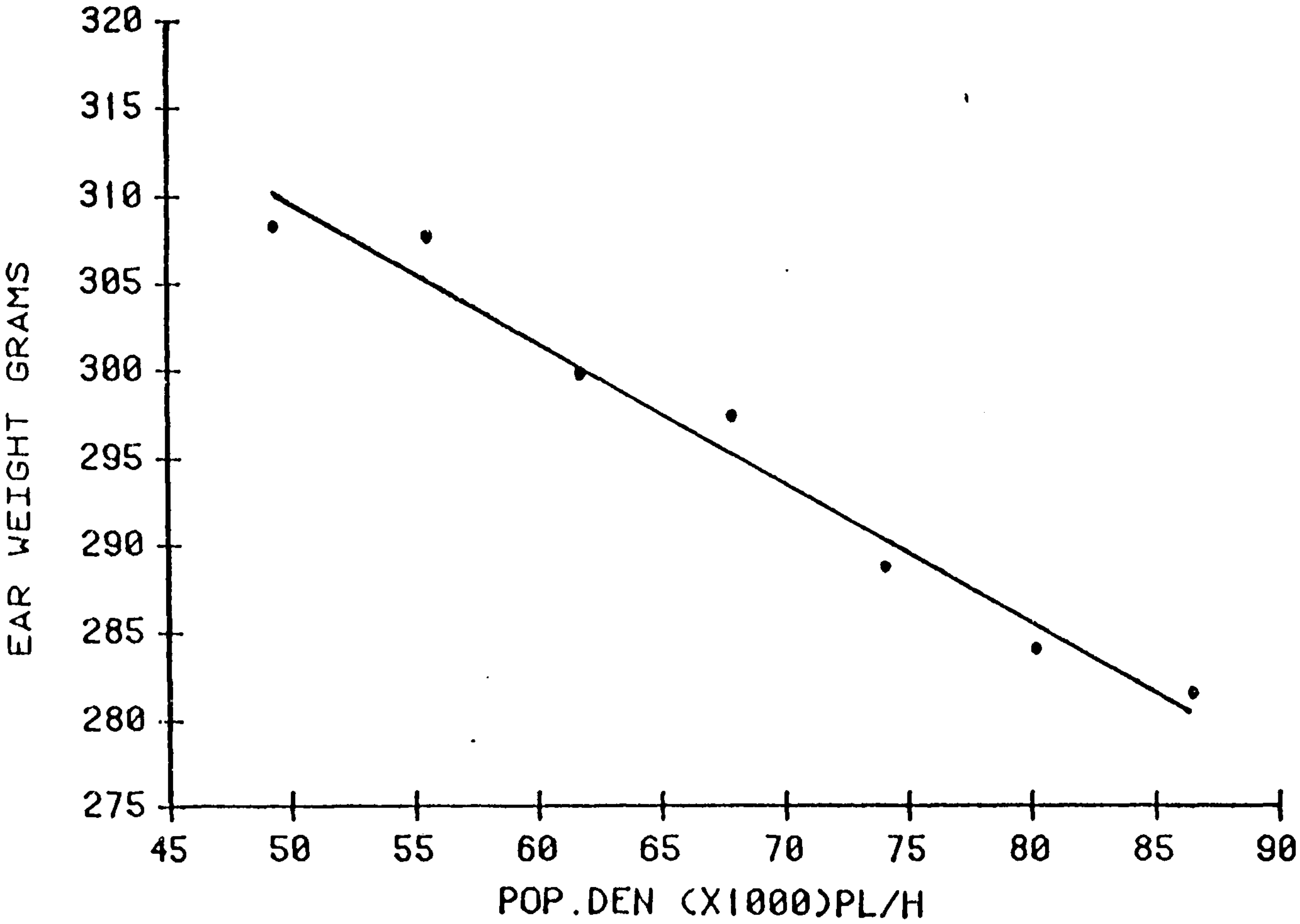
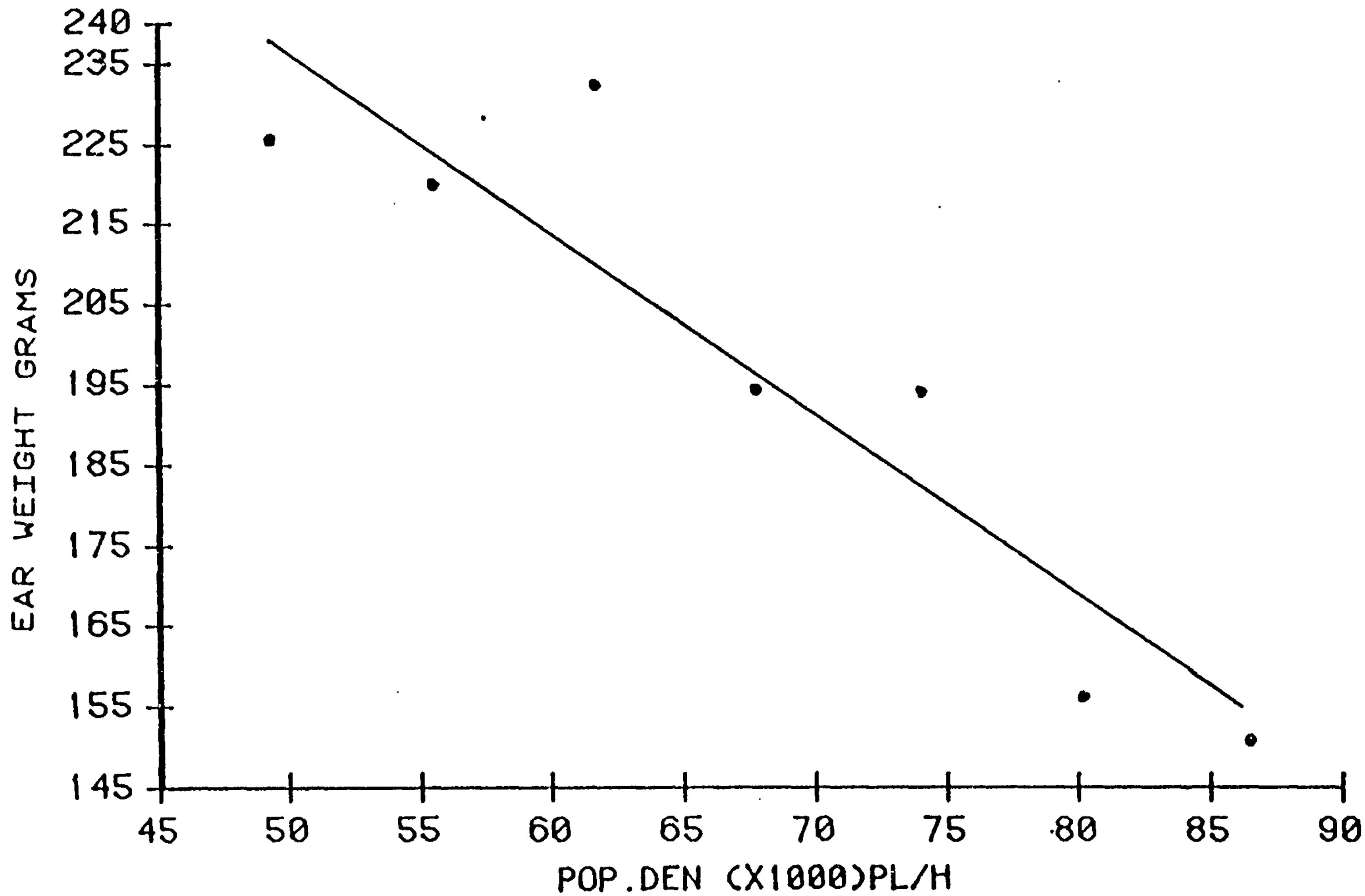


Figure 10. Effect of population density on ear weight first ear (E_1) and second ear (E_2) in the early (D_1) and late (D_2) planting dates.



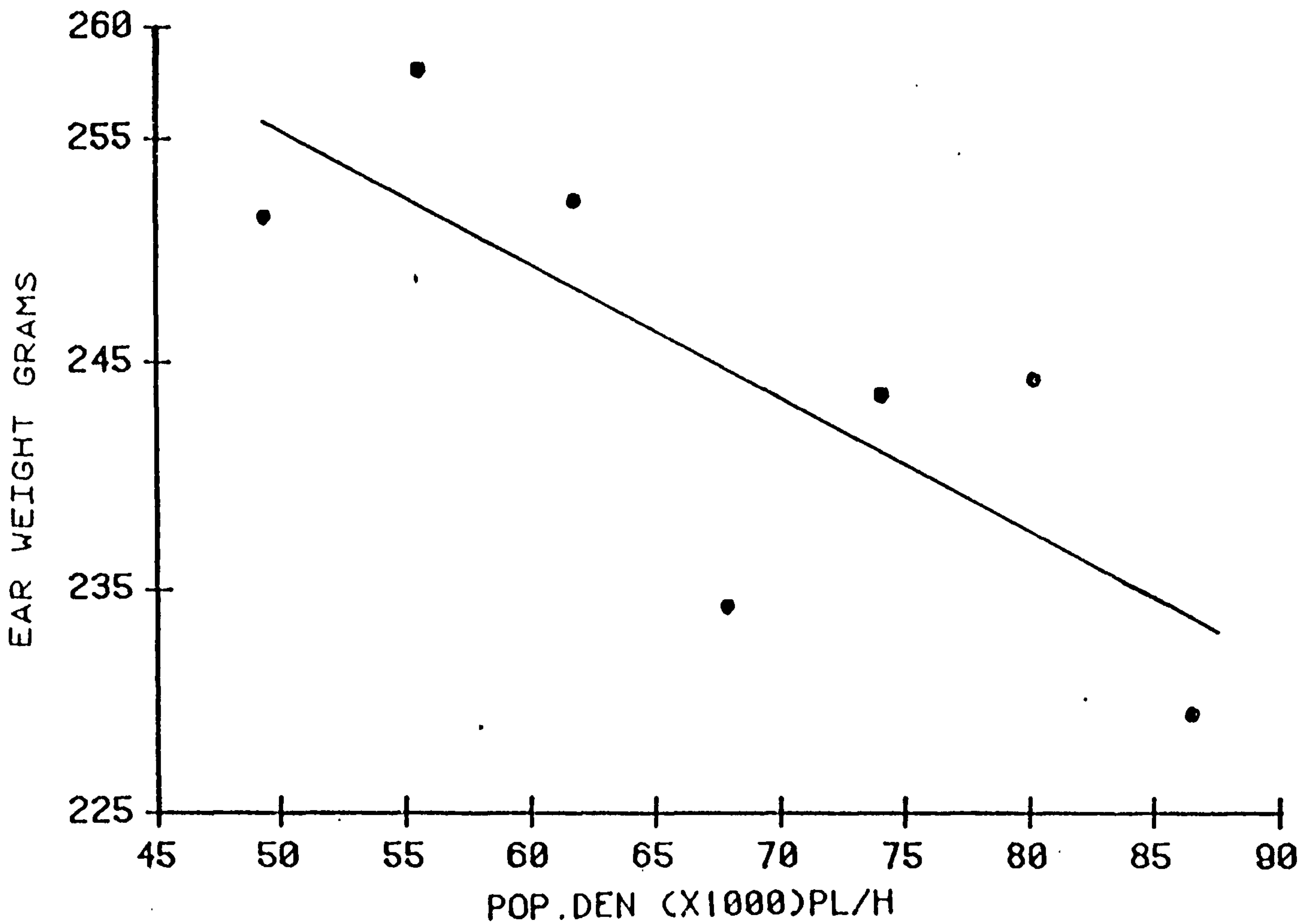
$Y = 349.83 - .802X$
$R^2 = 0.97$

Figure 11. Effect of population density on ear weight of the first ear in the early planting.



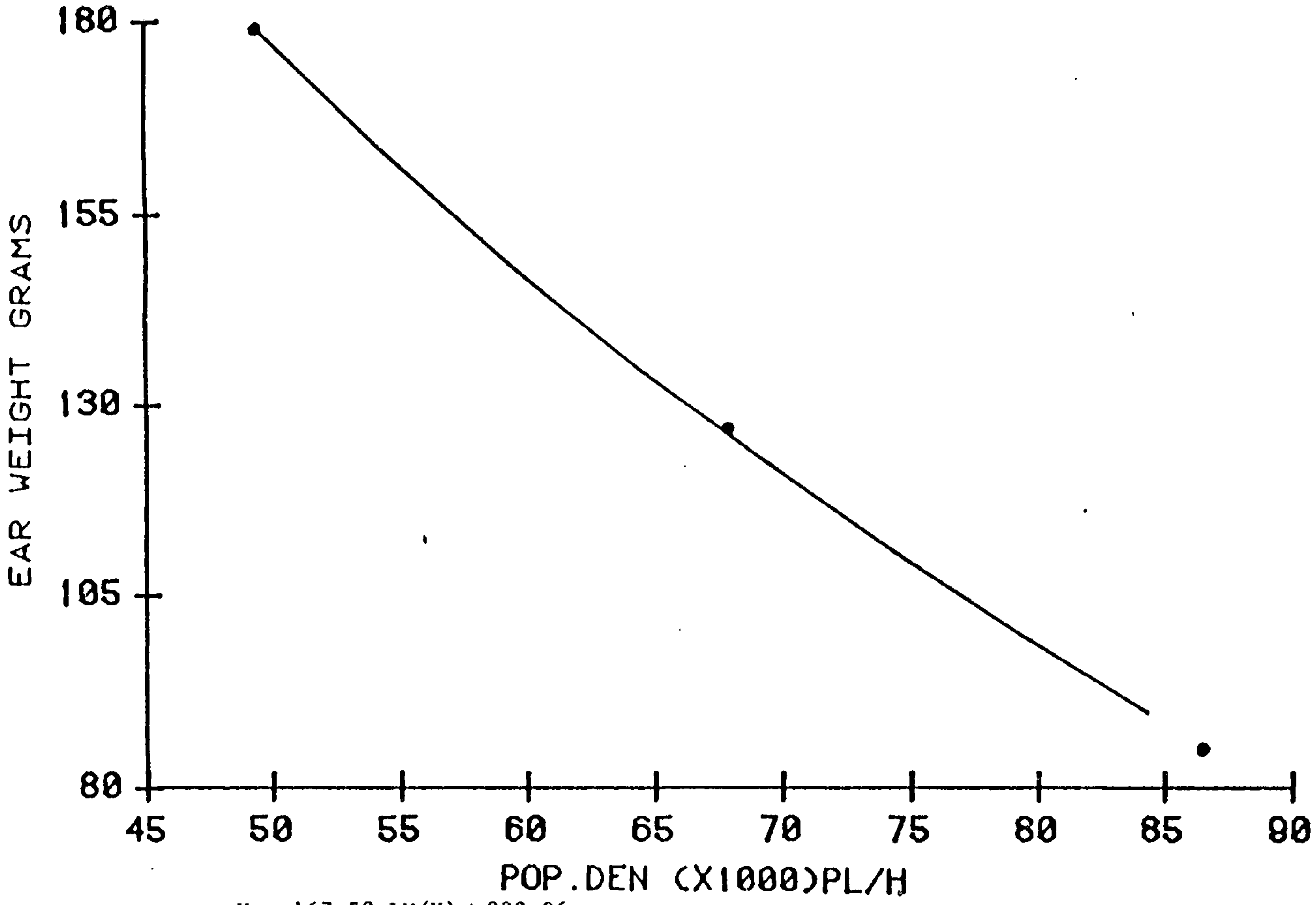
$Y = 348.93 - 2.49X$
$R^2 = 0.85$

Figure 12. Effect of population density on ear weight of the second ear in the early planting.



$Y = 284.96 - 5.92X$
$R^2 = 0.60$

Figure 13. Effect of population density on ear weight of the first ear in the late planting.



$Y = -167.58 \ LN(X) + 832.96$
$R^2 = 0.999$

Figure 14. Effect of population density on ear weight of the second ear in the late planting.

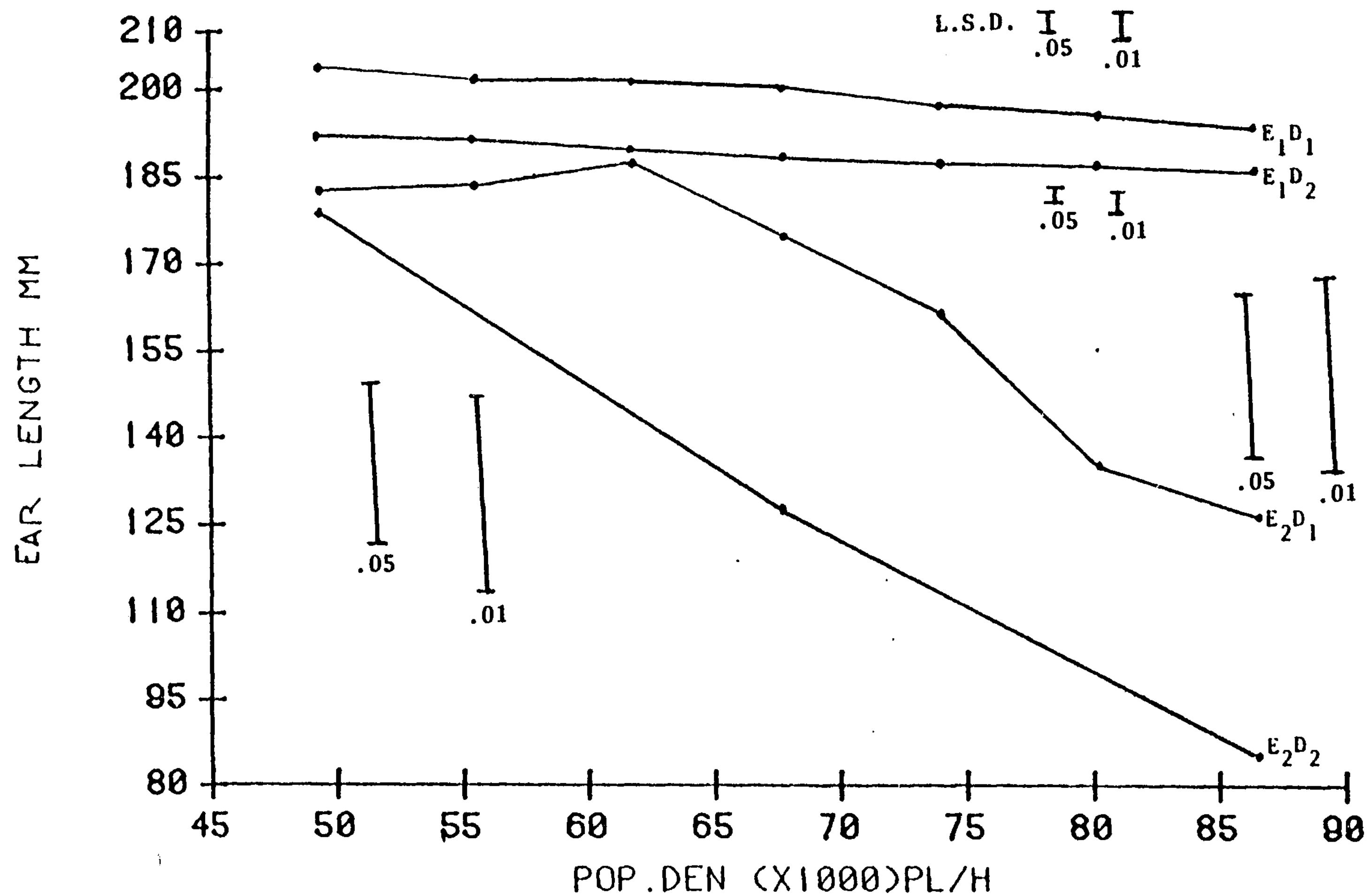


Figure 15. Effect of plant population density on ear length of the first (E_1) and second (E_2) ear in the early (D_1) and late (D_2) planting.

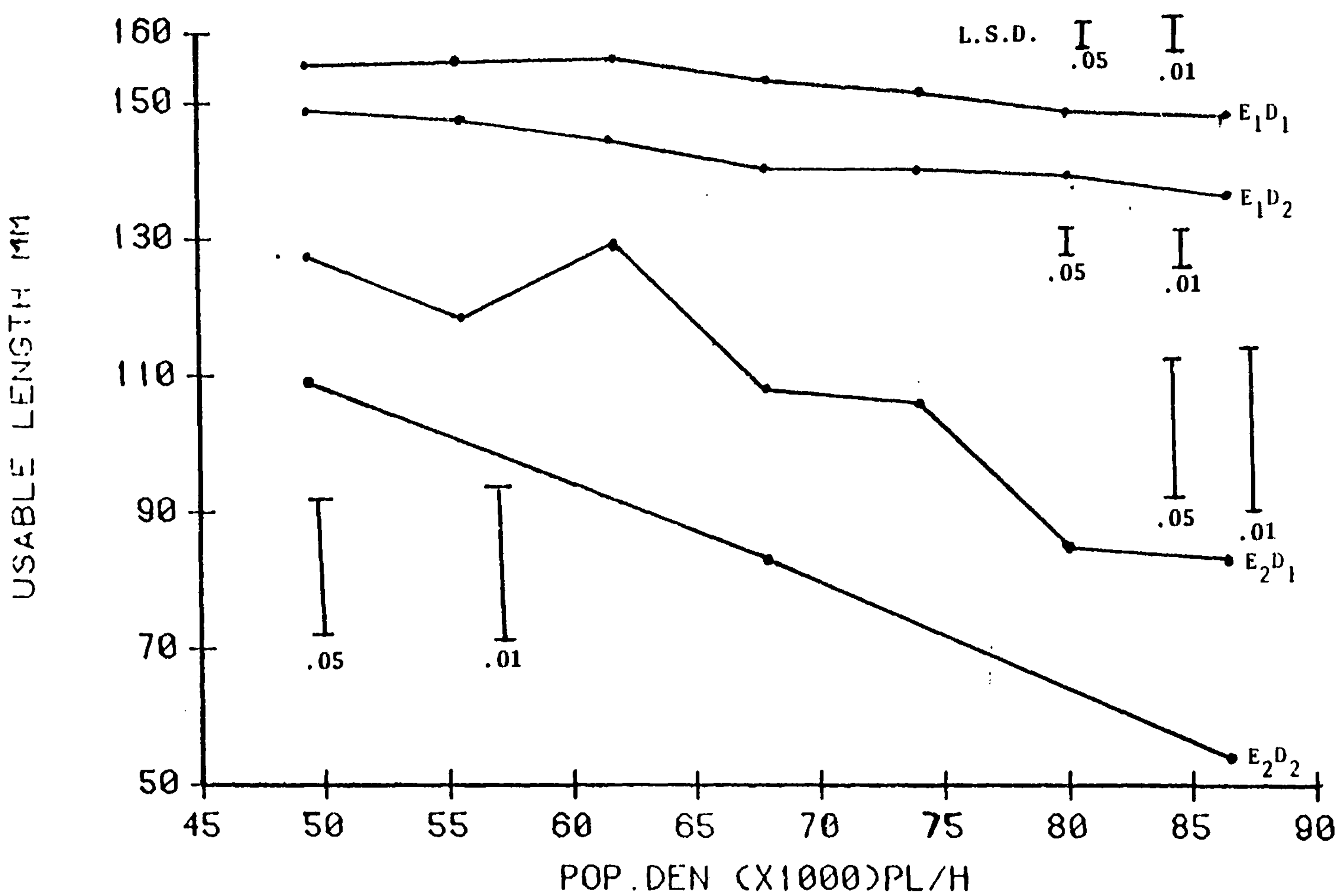
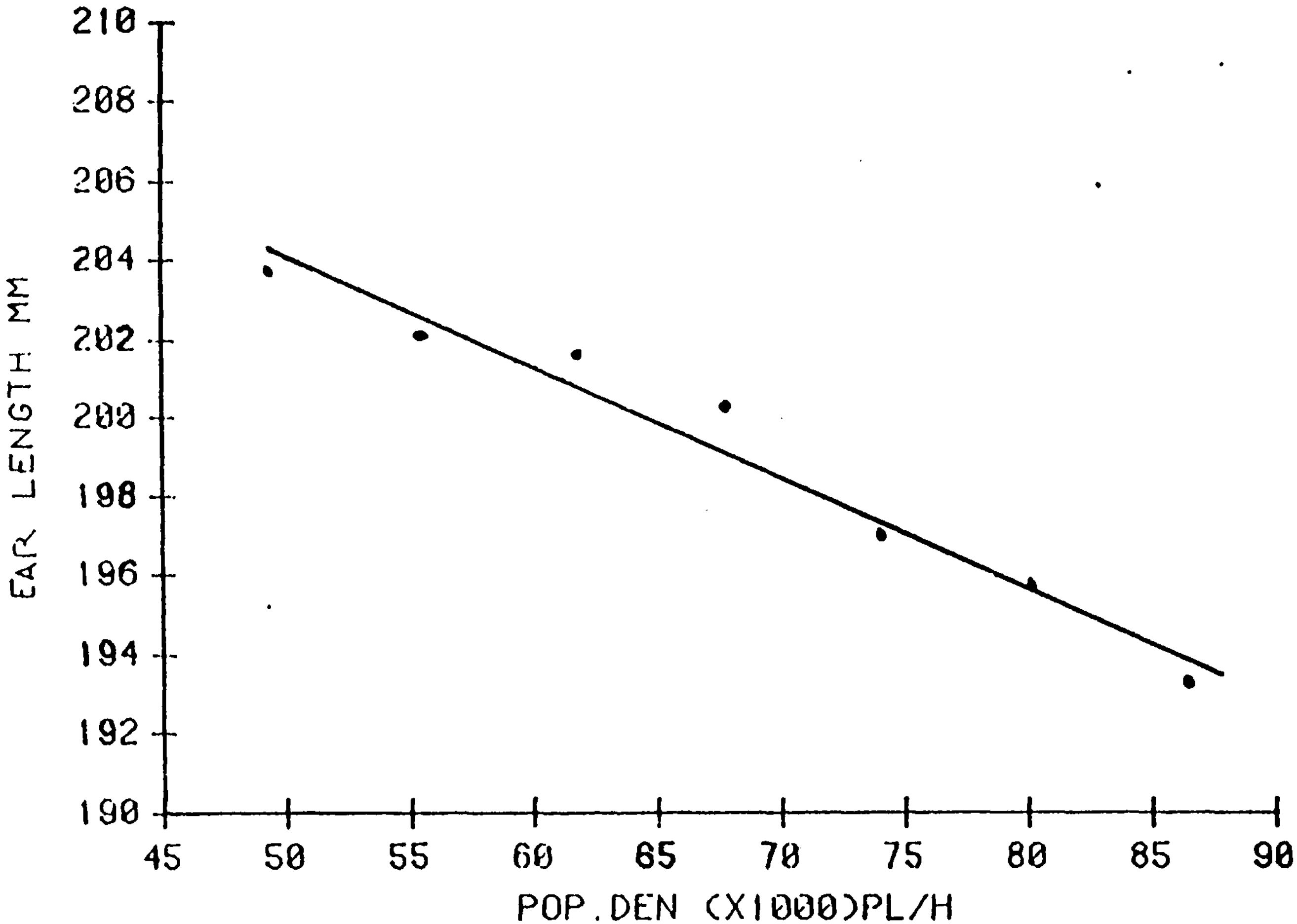
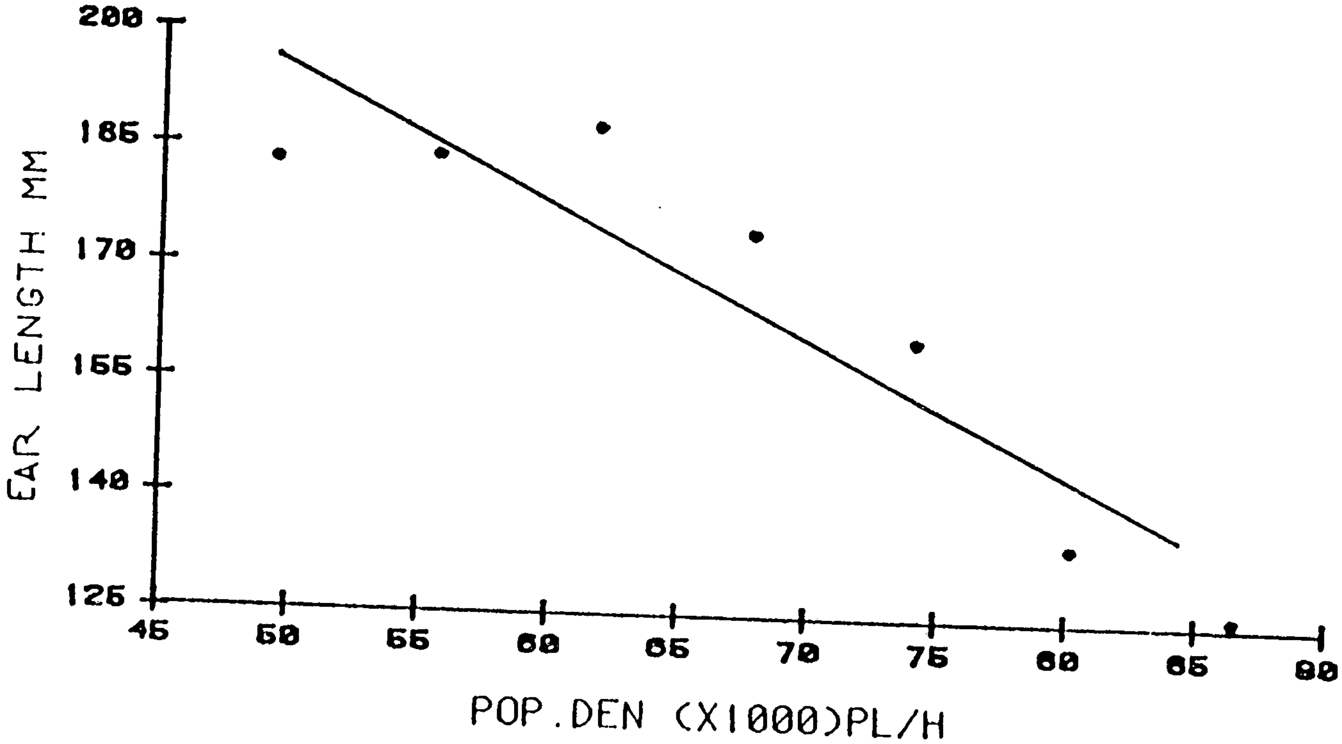


Figure 16. Effect of population density on usable length of the first (E_1) and second (E_2) ears in the early (D_1) and late (D_2) plantings.



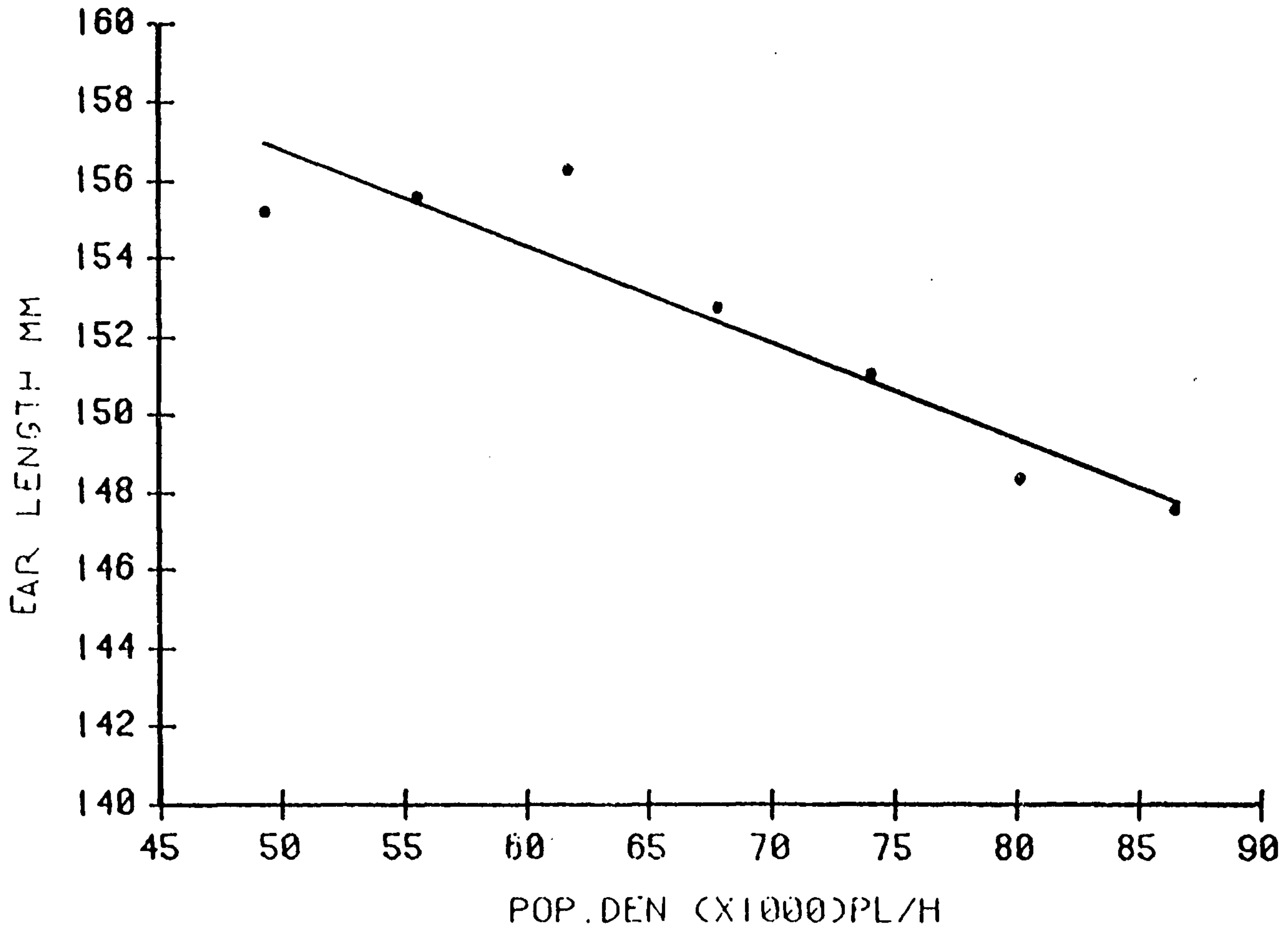
$Y = 218.312 - .283X$
$R^2 = 0.965$

Figure 17. Effect of population density on ear length of the first ear in the early planting.



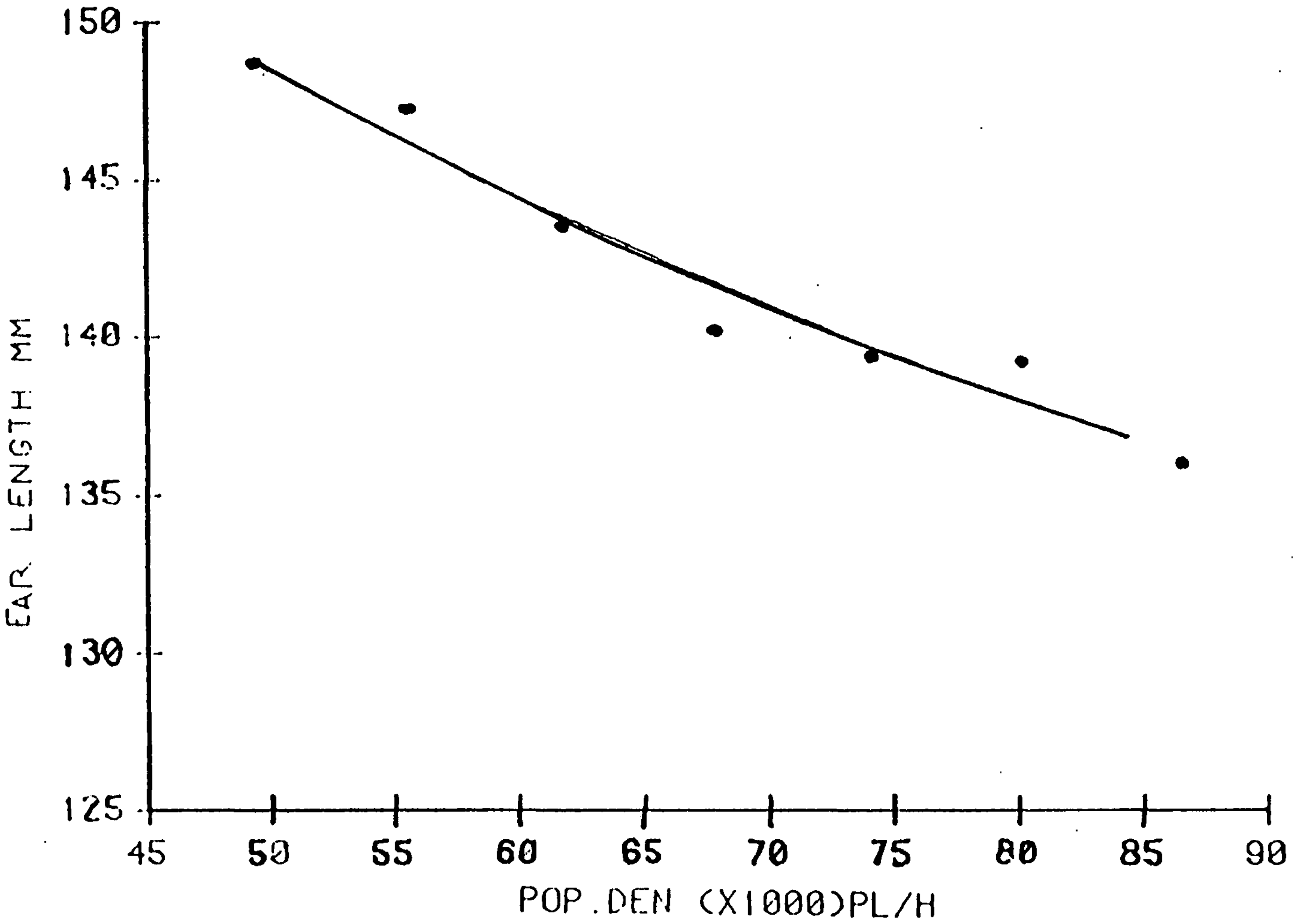
$Y = 280.73 - 1.7103X$
$R^2 = 0.84$

Figure 18. Effect of plant population density on ear length of the second ear in the early planting.



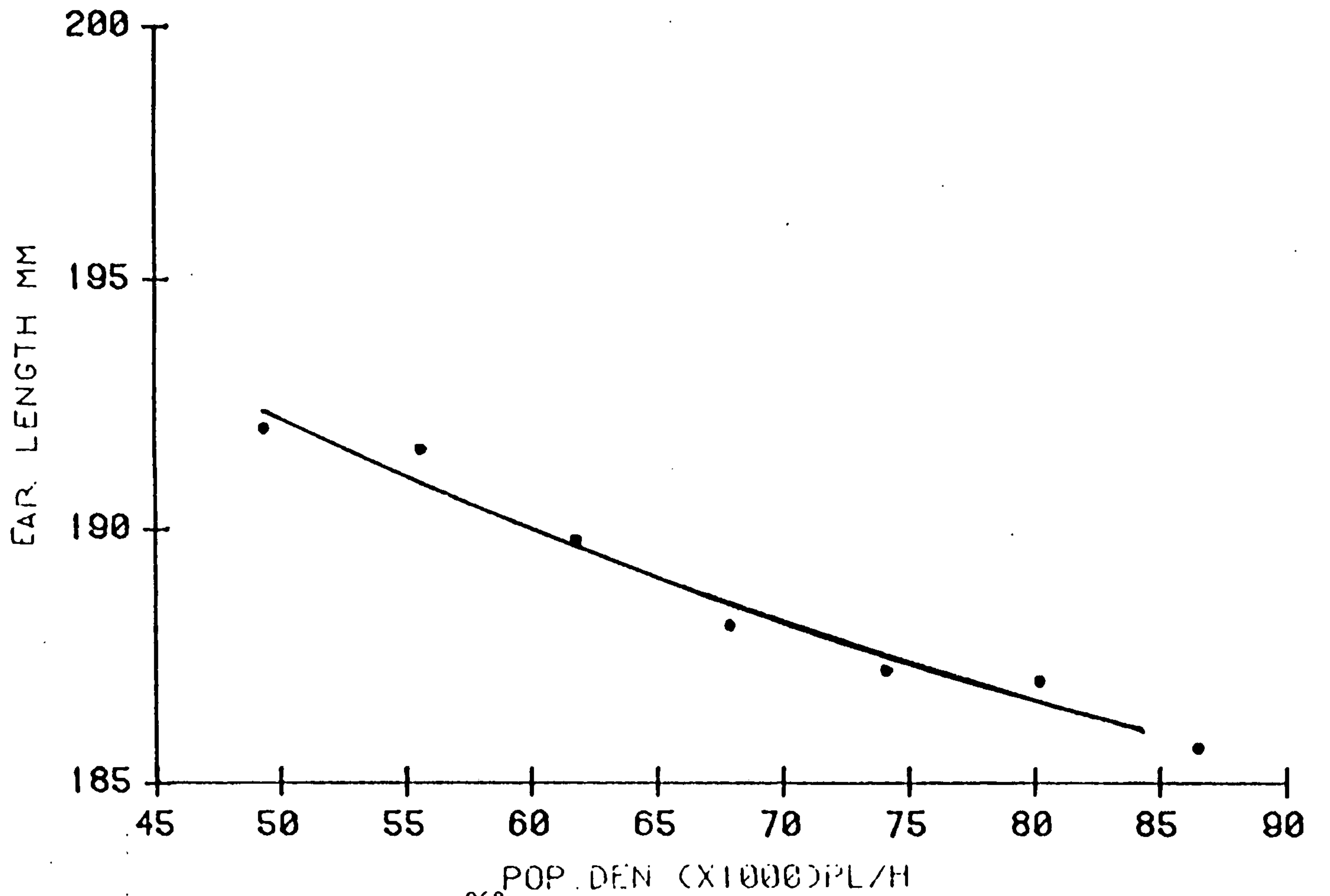
$Y = 169.085 - .245X$
$R^2 = 0.865$

Figure 19. Effect of population density on usable length of the first ear in the early planting.



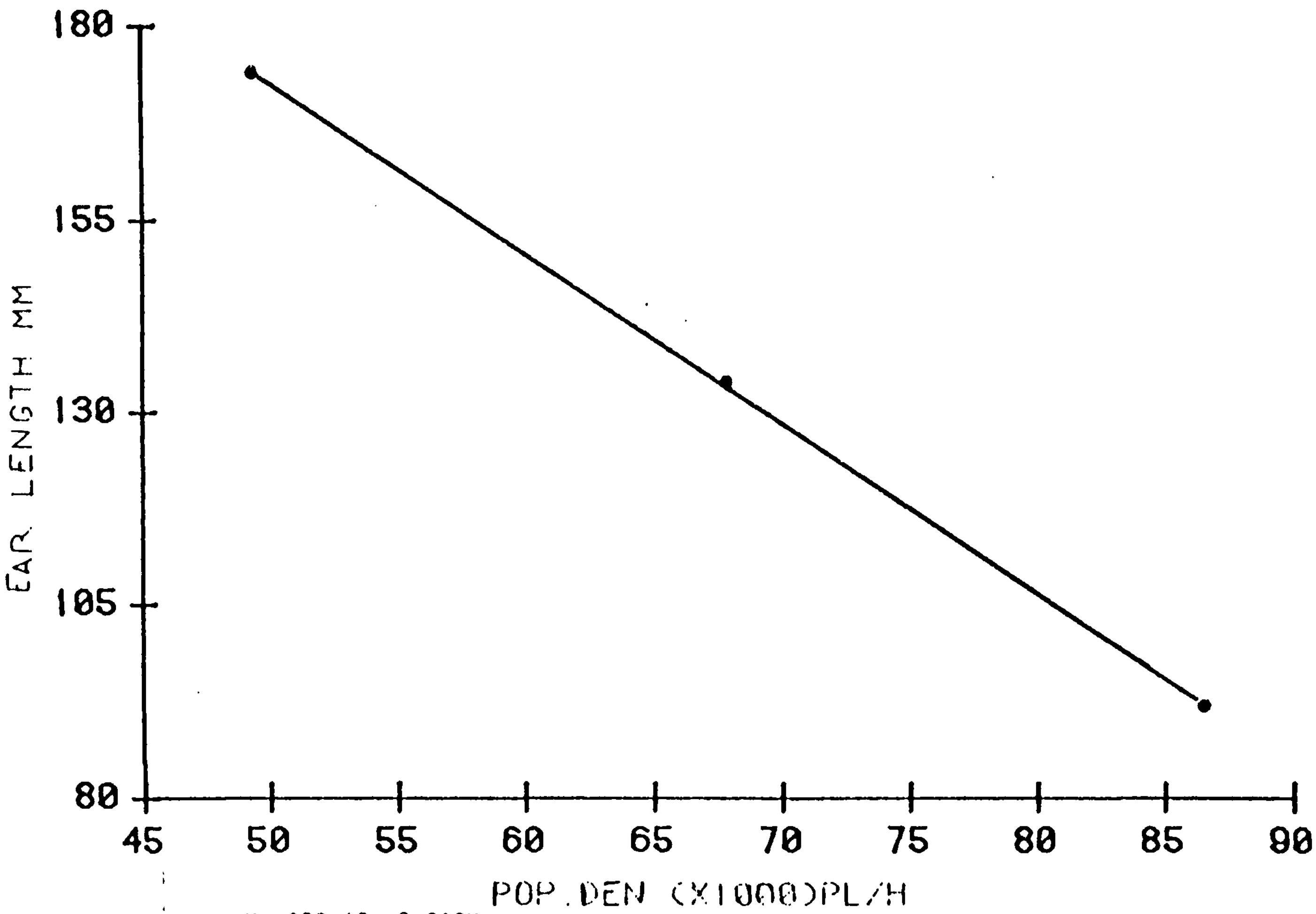
$Y = 236.663 - 22.5226\ LN(X)$
$R^2 = 0.958$

Figure 20. Effect of population density on usable length of the first ear in the late planting.



$Y = 245.647 * X^{-.069}$
$R^2 = 0.98$

Figure 21. Effect of population density on ear length of the first ear in the late planting.



$Y = 283.48 - 2.210X$
$R^2 = 0.999$

Figure 22. Effect of population density on ear length of the second ear in the late planting.

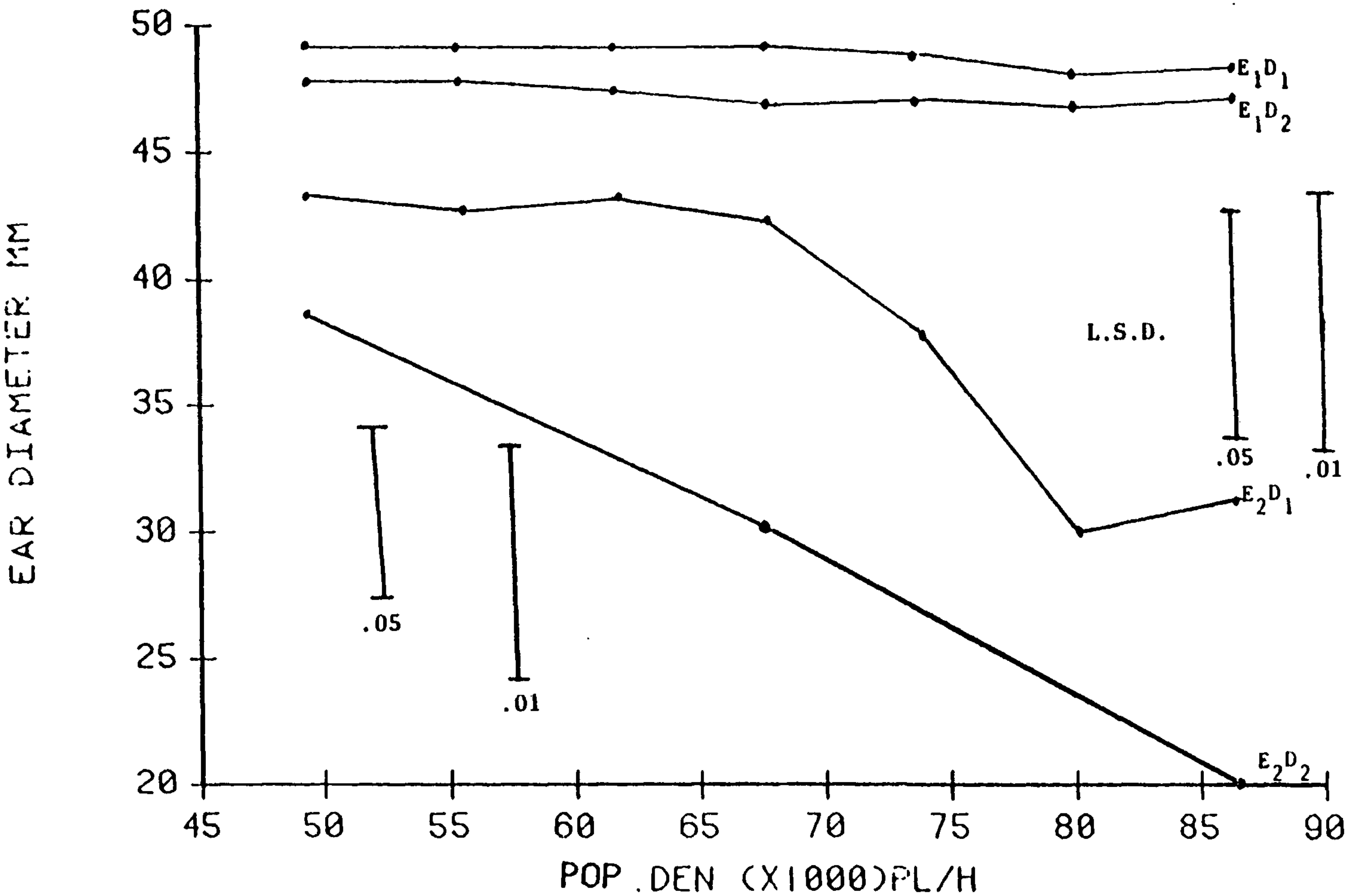
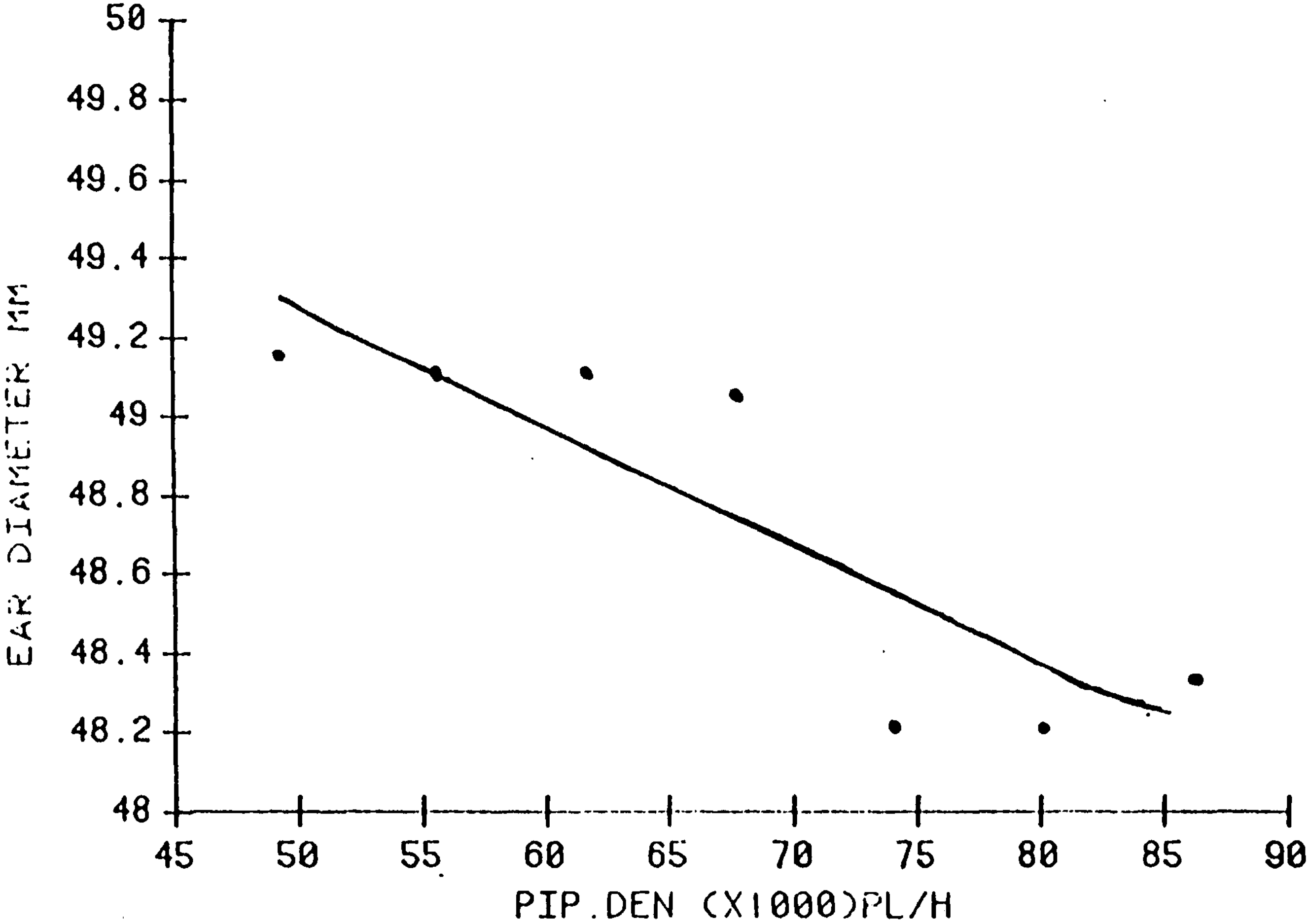


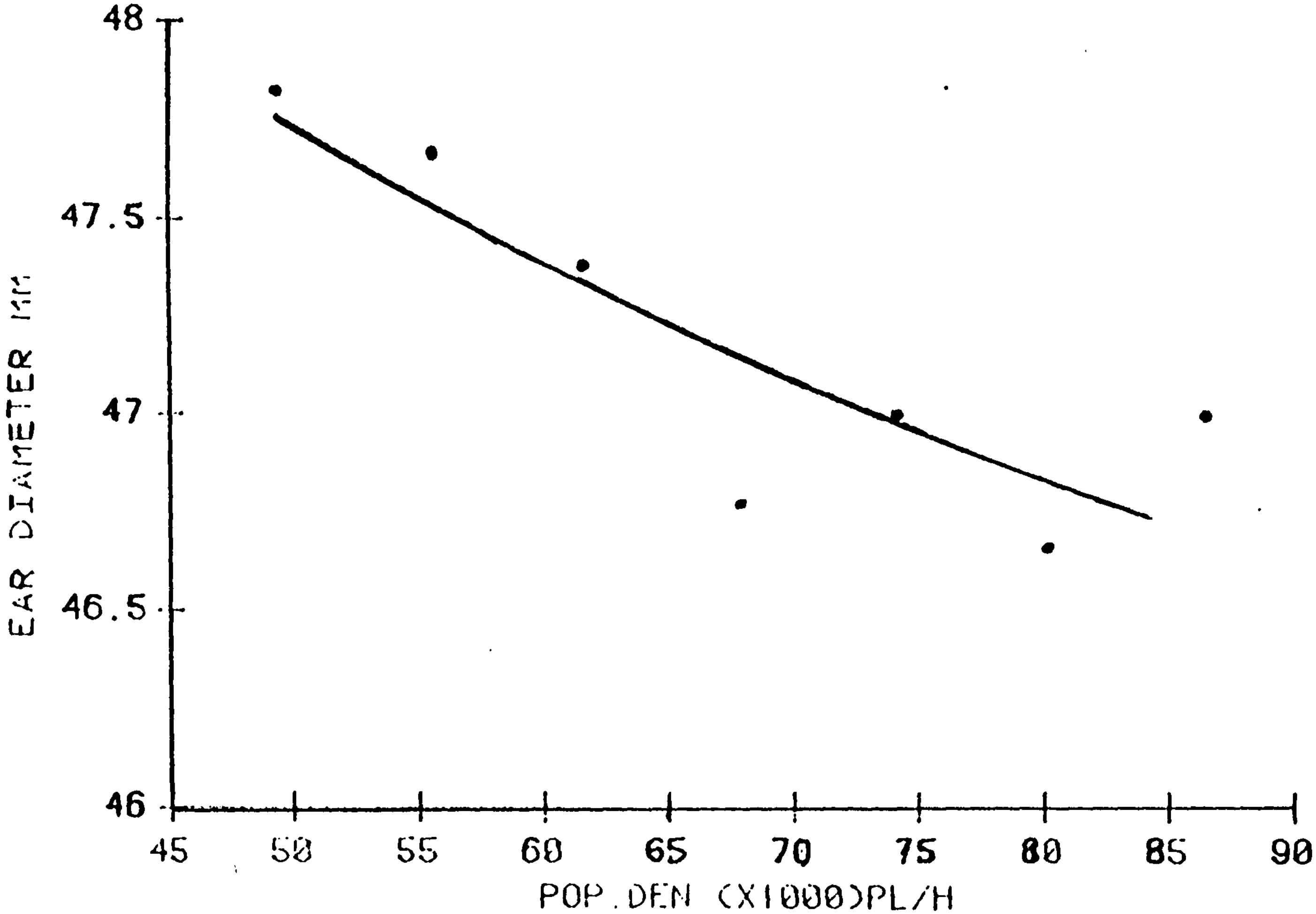
Figure 23. Effect of population density on first (E_1) and second (E_2) ear diameter in the early (D_1) and late (D_2) plantings.



$Y = 56.066 - 1.724\ LN(X)$

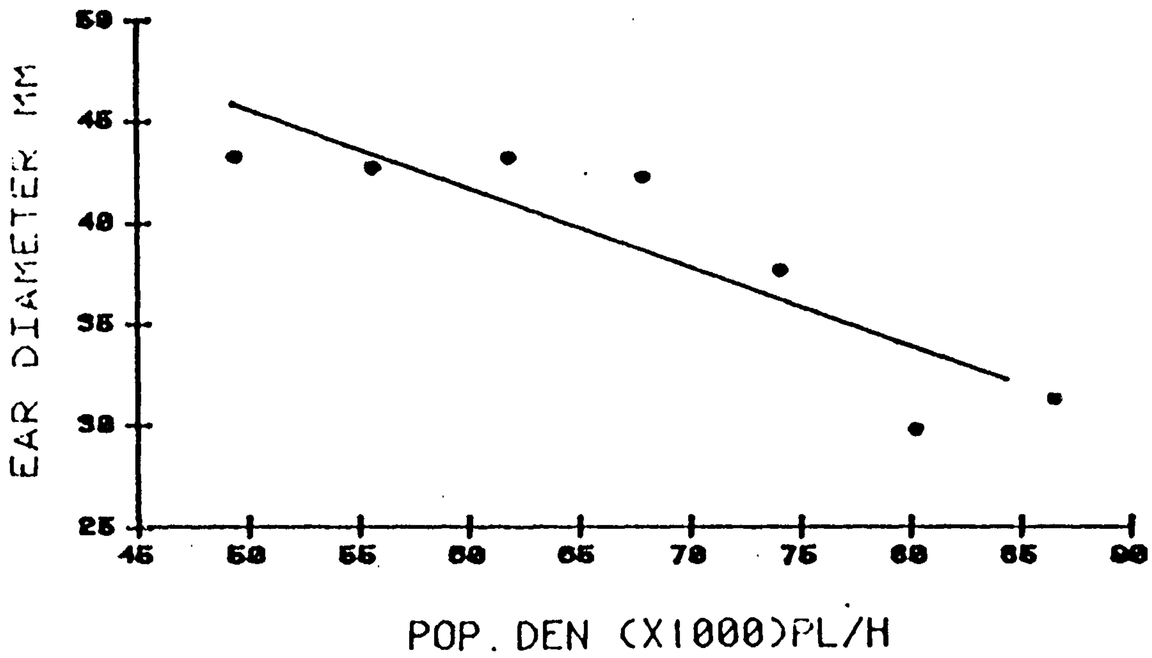
$R^2 = 0.745$

Figure 24. Effect of population density on ear diameter of the first ear in the early planting.



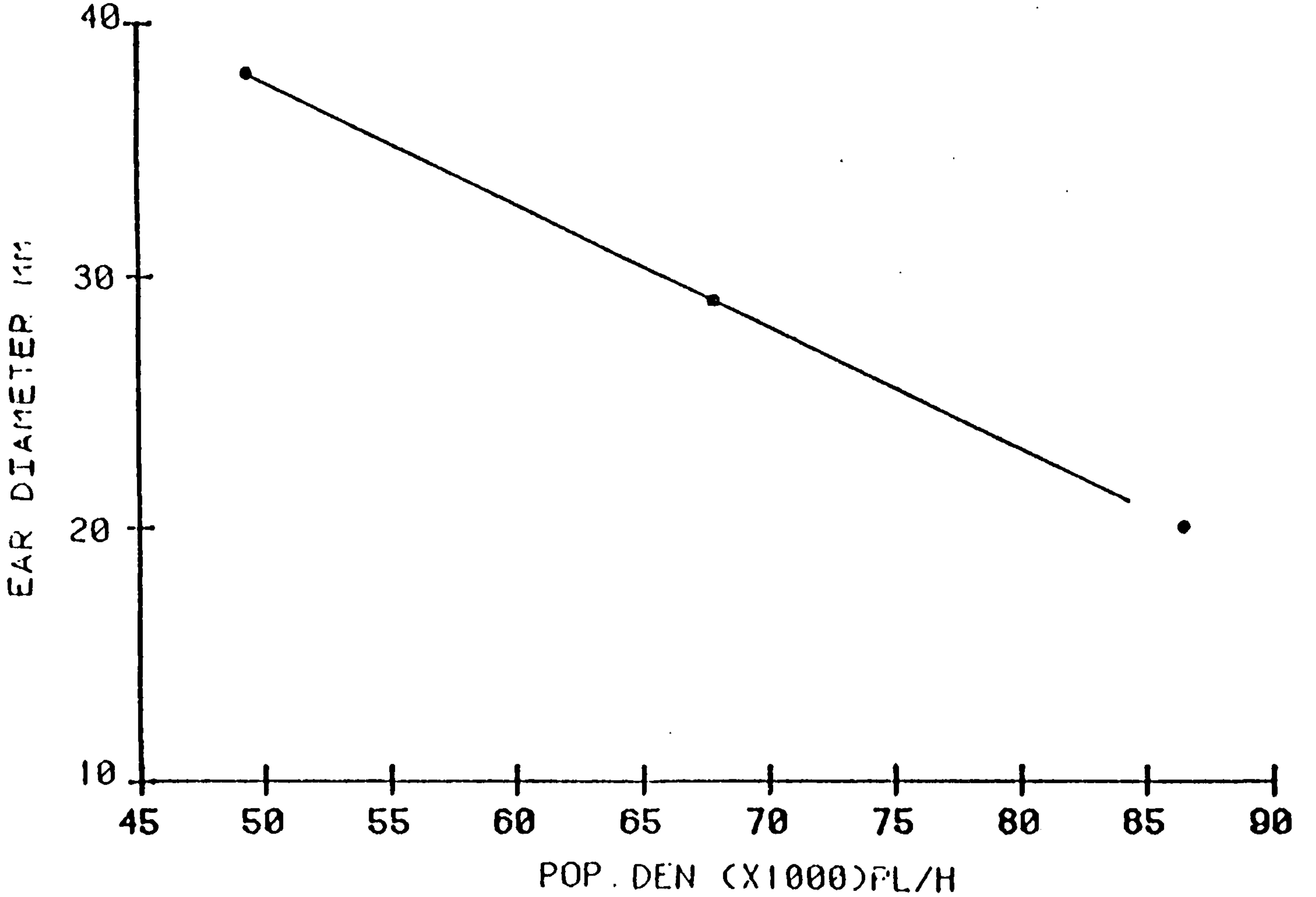
$Y = 55.230 - 1.915\ LN(X)$
$R^2 = 0.75$

Figure 25. Effect of population density on ear diameter of the first ear in the late planting.



$Y = 65.01 - .388X$
$R^2 = 0.79$

Figure 26. Effect of population density on ear diameter of the second ear in the early planting.



$Y = 6.195 - .0485X$
$R^2 = 1.0$

Figure 27. Effect of population density on ear diameter of the second ear in the late planting.

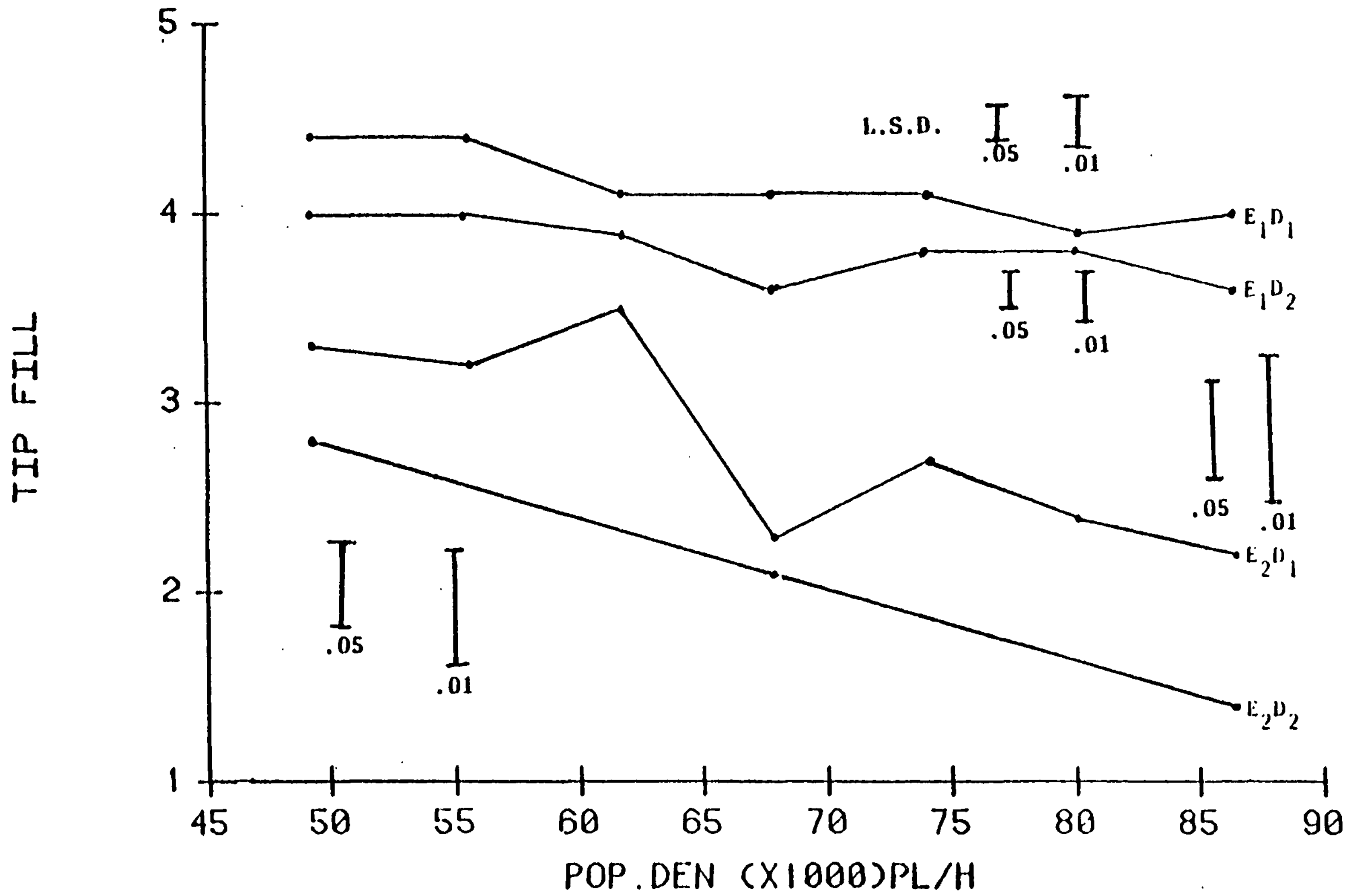
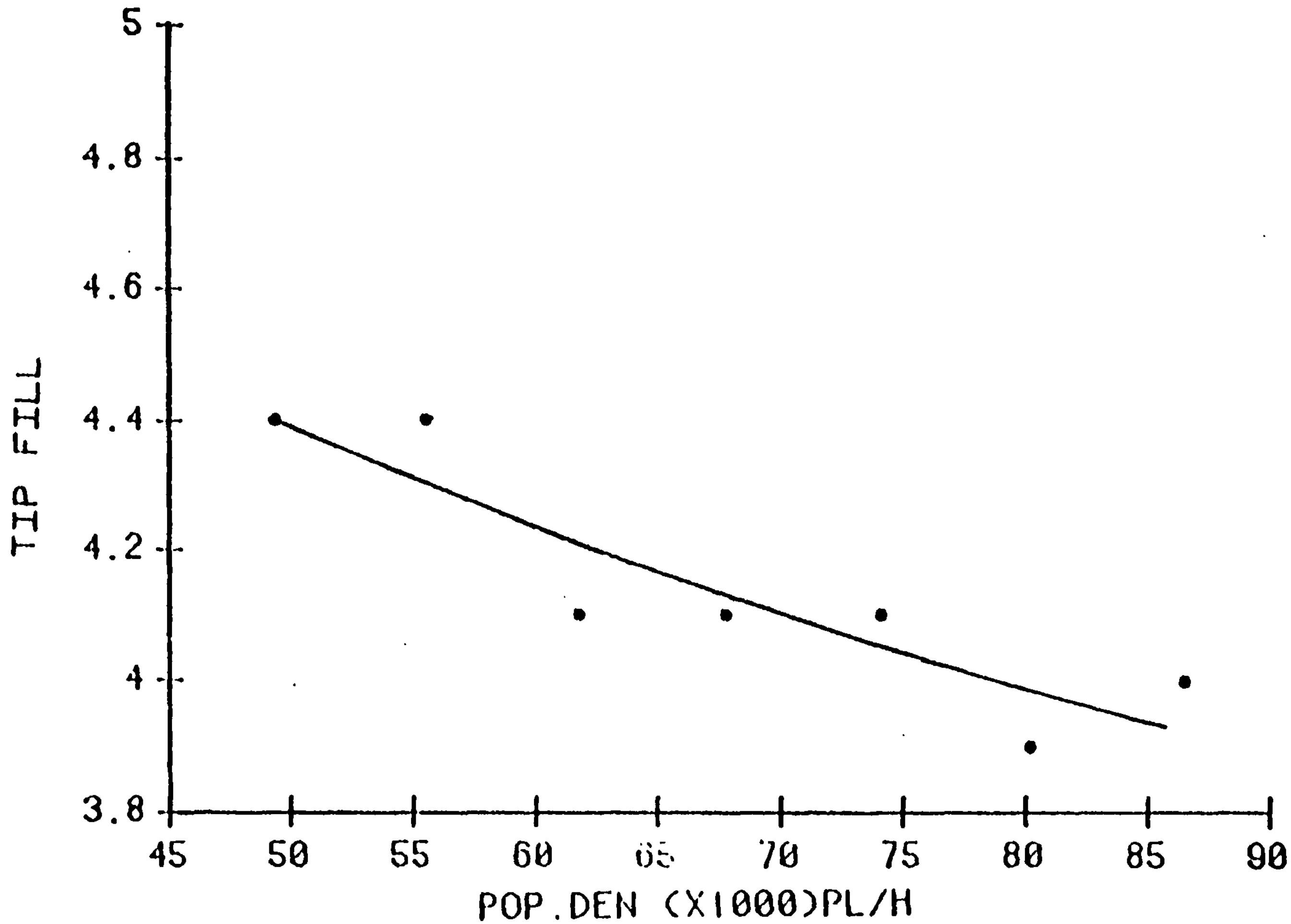
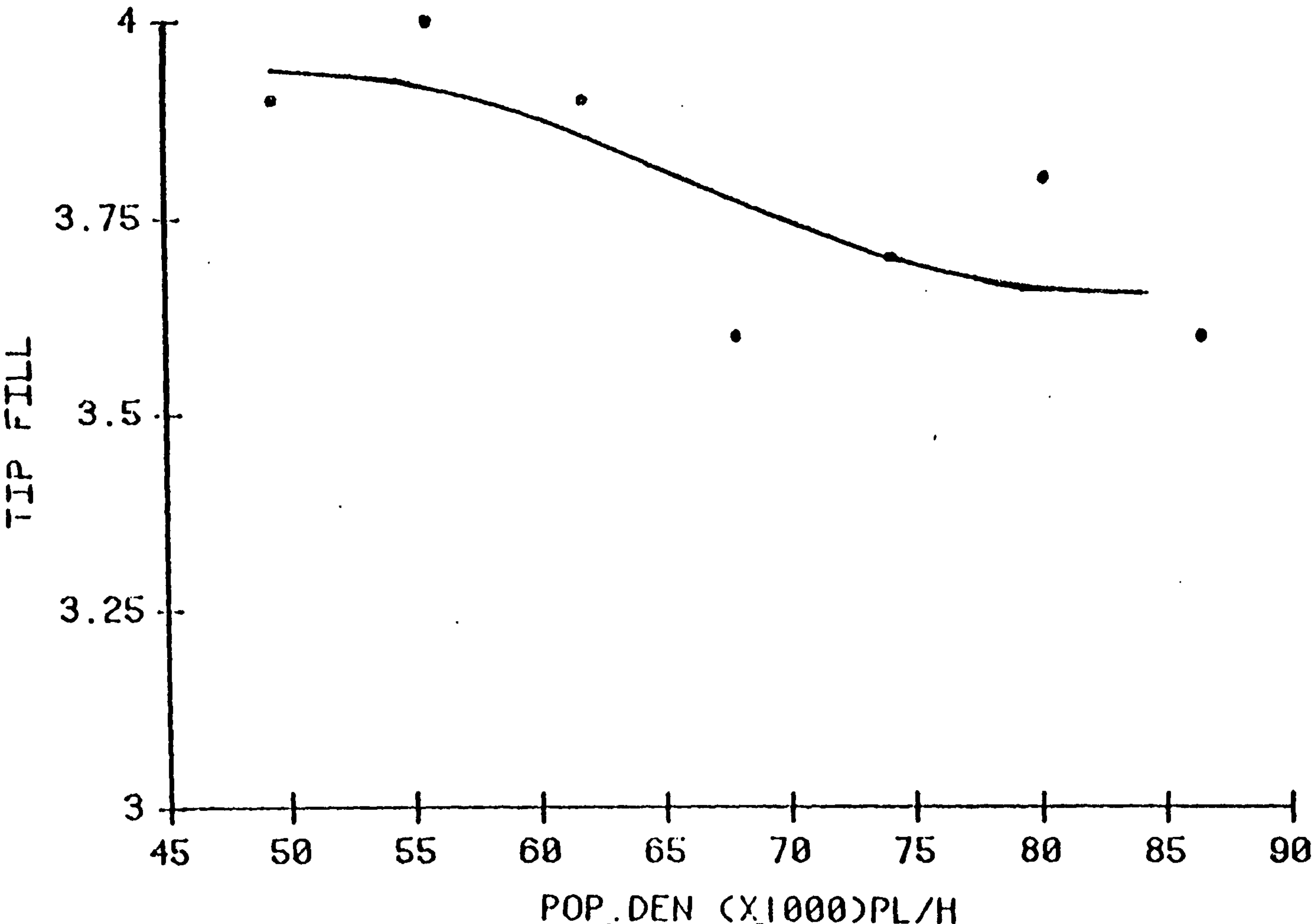


Figure 28. Effect of population density on tip-fill of the first (E_1) and second (E_2) ears in the early (D_1) and late (D_2) plantings.



$Y = 7.75 - .859 \ LN(X)$
$R^2 = 0.822$

Figure 29. Effect of population density on tip-fill of the first ear in the early planting.



$Y = -1.243 + .257X + .00412X^2 + .000020X^3$

Figure 30. Effect of population density on tip-fill of the first ear in the late planting.

Summary and Conclusions

An experiment which included three nitrogen rates (150, 200 and 250 kg/ha), two row spacings (75 and 90 cm), seven population densities (49,400; 55,575; 61,750; 67,925; 74,100; 80,225; and 86,450) was conducted to determine the effect of the above factors on yield and individual ear characteristics of 'Jubilee' sweet corn. Results showed that nitrogen rates over 150 kg/ha did not significantly increase yield. Ear weight of the first ear for the early and late plantings increased about 2% as nitrogen increased from the lowest to the highest rate, while ear weight of the second ear of the late planting increased about 12%. Ear length of first and second ears of the early planting increased 5 and 3.5%, respectively, and 6% for second ear of the late planting. Usable length for the first and second ears of the early planting increased 2.6% and 7.5% for the second ear in the late planting. Tip-fill of the first ear early planting improved 1.6% at the highest nitrogen rate compared to the lowest rate. However, all of the above effects of nitrogen were not statistically significant except for ear weight and usable length of the second ear in the late planting.

Reducing the row spacing from 90 to 75 cm did not significantly increase yield. The yield averaged 3-5% higher at the narrower spacing, but population density per unit area was the same for both row spacings. None of the other plant or ear characteristics were significantly affected by row spacings.

Increasing the plant population density from 49,400 to 86,450 plants/ha increased yield of unhusked total ears 16% for the early planting and 23% for the late planting. Yield of husked good ears was increased 21% and 24% for the early and late planting, respectively. Average number of ears per plant was lower in the highest density compared to the lowest density by 40% for the early and 23% for the late planting. Plants at the highest density were 7 cm taller than those of the lowest. Stalk diameter was reduced 10% as density increased from the lowest to the highest. Weights of the first ear of the early and late planting were reduced 9% on the average. Weights of the second ear were reduced 33% for the early planting and 50% for the late planting at the highest compared to the lowest population density. Ear length of the first ear of the early planting was reduced 5% while total length and usable length of the second ear in the early planting were reduced 30 to 35%. Total length and usable length of the first ear of the late planting were reduced 4 to 8%, respectively. Ear diameter of the second ear in the early and late plantings were reduced 28 and 40%, respectively, as population density was increased from the lowest to the highest. Tip-fill of the first and second ears of the early planting were reduced 9 and 34%, respectively; also first and second ear tip-fill of the late planting were reduced 10 and 50%, respectively at the highest compared to the lowest population density.

Plant population density had the major effect on yield, plant, and ear characteristics of sweet corn in the experiment, compared to the effect of nitrogen rates and row spacings.

Results from this experiment indicate that western Oregon sweet corn growers could increase plant populations from the presently used 55 to 65,000 plants/ha to 80 to 85,000 plants/ha and achieve an increase in yield. But this benefit would need to be evaluated against potential individual ear weight and ear length reductions of the first ear of about 10% and 5 to 8%, respectively.

At a given population density, it does not appear to be important whether or not 75 cm or 90 cm row spacings are used.

Present fertilizer recommendations are for use of 115 to 140 kg N/ha if sweet corn is planted after alfalfa and results of this experiment suggest that these amounts are sufficient. For other crop rotations, the range recommended is from 170 to 250 kg N/ha.

Optimum population and planting arrangements will be determined by several environmental, genetic and economic factors.

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