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Plant Population Density and N Rate Influence the Growth and Seed Producibility of Intermediate Maturing Maize Parental Line at Sub-humid Agro-Ecology of Western Oromia, Ethiopia

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Abstract. At the study location of Bako National Maize Research Center, the experiment was carried out on BKL004 maize inbred line in 2019 to 2021 cropping season. The goal of this experiment was to determine an optimum plant population density and N rate on the BKL004 maize parental line. The experiment had two factors: five levels of plant population densities (44,444, 53,333, 66,666, 88,888 and 133,333 plants ha^{-1}) and four levels of nitrogen (111, 157, 203, and 249 kg ha^{-1}). The experiment included a total of twenty treatments (4*5) that were distributed in a factorial arrangement using an RCBD design. Each treatment was repeated three times. Different BKL004 maize parental line growth, phonological, and yield characteristics were gathered. Also, partial budget analysis were done to identify the most profitability treatment. Plant population density exerted a significant ($p<0.05$) effect on plant height, ear height, girth, days to 50% female flowering and seed yield. The tallest plant and ear height were recorded at plant population density of 133,333 plants ha^{-1} with average plant and ear height of 146.50 cm and 61.32 cm respectively. The maximum girth (17.47) was obtained at 53, 333 plant population ha^{-1}. The highest plant population density extends the appearance of 50% days to silking by 91.72 days. The highest seed yield (3307 kg ha^{-1}) was recoded at plant population of 133,333 plants ha^{-1}, followed by seed yield recorded at plant population of 88,888 plants ha^{-1}. N at the rate of 249 kg ha^{-1} with 133,333 plants ha^{-1} was the most economically profitable than all the other treatments, followed by economic return obtained at 88,888 plants ha^{-1} with 157 kg ha^{-1} of N rate. However, as plant population affect the size of seed it may affect the seed germination and seedling vigor. Thus, 88.888 plants ha^{-1} with 157 kg ha^{-1} N rate was recommended for seed producer.

Keywords. Ear, Kernels, Plant and ear height, Plant ha^{-1}, Seed yield.

1. Introduction

The grain crop maize (Zea mays) is originated in Mexico, and Native Americans advanced maize into a good source of food [1]. It was brought to West Africa in the early 1500s by the Portuguese traders [2]. Maize was introduced to Ethiopia meanwhile 1600s to 1700s (Haffangel, 1961). Currently, maize is grown throughout the world, United States, China, and Brazil are being the leading three maize-producing countries in the world [1]. Directly, more than 30 % of the total world production is used for human consumption and input for industry, while 70 % is used as feed for animals [3].

Maize is the third most important grain crop in the world following wheat and rice [4]. In sub-Saharan African countries, maize is a basic food for more than 50% of the population and provides 50% calories [4]. In case of Ethiopia, it constitutes about 60% of the caloric intake of household [5]. Ethiopia is the second highest maize producer in Sub-Saharan Africa next to Nigeria [6]. In case of Ethiopia, it is the second most widely produced grain cops under diverse agro-ecologies and socioeconomic conditions [7]. Predominantly, it is grown during the main season known as meher from May-September rainfall [5], mostly between 50° latitude north and south of the equator and from sea level to 3000 m.a.s.l [2].

In Ethiopia, Maize production was increased from 939 thousand tonnes in 1970 to 8500 thousand tonnes in 2019, growing at annual rate 7.64% [8]. Correspondingly, Maize production increased from 8350 thousand tonnes in 2018 to 8500 thousand tonnes in 2019 with growing annual rate 1.8% [8], Indubitably, it has great importance in the livelihood of most Ethiopians population. Of cereals, maize holds the lion shares (30.88%) with 10.56 million tonnes annual production [9]. Maize is cultivated on an area of about 2.52 million ha with average production of 10.56 million tonnes and national average yield of 4.18 t ha^{-1} [9]. Despite of an increment in land coverage area, annual production and world's average yield which is 5 .83 t ha^{-1} [10], maize productivity in Ethiopia is low.

The low yield from farming could be ascribed to disappointment of the farmers to implement good agricultural practice which boosts the productivity from the farm. Indubitably, crop production is encountered with various controllable dares like untimely planting, inappropriate plant spacing, wrong planting method, inappropriate sowing depth, weed infestation, insect pests and diseases problems, drought and untimely harvesting [11,12]. Also, low soil fertility, nutrient management and low yielding cultivars are another factors restraining maize productivity in Ethiopia [5,13,14].

Having recommended agronomic practices which help to boost production and productivity for released/cultivated varieties are very important. Optimal agronomic practices are varies with location, season and cultivars. So, to maximize maize productivity per unit area of land, location, season and cultivar based optimal crop management practices are too important. So far, [15], recommended 100 kg ha^{-1} of NPS as an optimum rate and economically feasible in relatively uniform rainy seasons for BH661 maize hybrid which is classified under late maturing maize group. Moreover, Begizew et *al.* (2019) found BH-661 maize hybrid gave the highest yield at plant population of 53333 plants ha^{-1} with 115 kg N ha^{-1}. Also, [16], recommended application of 92 N kg ha^{-1} at 10–15 days after planting and 35–40 days after planting for BH661 maize hybrid. While, in the case of erratic and heavy rainy areas, application of 92N kg ha^{-1} at three application times 1/3 N at 10–15, 1/3 N at 35–40 and 55–60 days after planting were suggested to get maximum profit and acceptable marginal rate of return.

However, for all agricultural crops, optimal agronomic practices are varies with species (even varieties), soil and atmospheric factors and production season. This truly stands for maize, as the productivity of maize varies with location, year, soil types, rainfall (distribution and amount), fertilizer rates, plant population density and the others. Even within the maize hybrid and inbred lines, the optimal package (fertilizer rate, plant population density, seed rate, N application time and cycle) varies with late maturing and intermediate maturing maize groups. Based on these researchable gaps, this study was focused on studying BKL004 maize inbred lines against different N rates and plant population densities. Thus, the objective of this research was to identify an optimum plant population density and N rate on BKL004 maize inbred lines which may gave the highest grain yield and maximum net benefit (acceptable marginal rate of return).

2. Materials and Methods

2.1. Description of Experimental Site

The experiment was conducted at Bako National Maize Research Center study site for the last three years (2019-2021 year). The study area has the following weather and geographic characters (Table 1).

Table 1. Study area's geographic and Weather description.

Zone	Wereda	Annual Rainfall (mm)	Temp. (^{0}C)	Altitude (masl)	Latitude (N)	Longitude (E)
East Wellega	Gobu seyo at BNMRC study site	830-1658	13 - 27	1556-2580	9°01'01"-9°20'33"	36°53'11"-37°03'06"

Source: (Eshetu *et al*., 2020, Urgessa and Fekadu, 2021).
BNMRC = Bako national maize research center.

2.2. Soil Sampling and Physicochemical Properties Analyzed

Soil sample of experimental area was taken in a diagonal pattern at 5m interval. From each sampling spot, soil sample were taken at a depth of 20cm using soil sampling auger. After collection, the collected samples were mixed thoroughly, then nearly 1 kg soil was taken from the composite sample for physicochemical study at laboratory. The composite sample was air dried, ground to pass through 2 mm sieve and analyzed for texture class, available Cation exchange capacity (CEC cmol/100g soil), Phosphorus (ppm), Organic carbon (OC %), Total Nitrogen (N %), and potential of hydrogen (pH). However, for the rest soil chemical properties, the chemicals were not available. The result of soil physiochemical properties tested at BARC was illustrated in (Table 2).

Textural class of the soil was analyzed using hydrometer method. The result indicated that the soil textural class is sandy clay. The total nitrogen was analyzed using Kjeldahl method by digestion of soil (copper sulphate-potassium sulphate catalyst). The pH was measured by Potentiometer in the ratio of 1:2.5 soil to water suspension. Available P was examined using Bray-II process and calorimetrically used vanadomolybedate acid as an indicator. CEC was determined by using NH_4 AC extraction ammonia distillation method. OC was measured by Walkley-Black wet oxidation method of (Hazeltonand Murphy) and converted to organic Matter (OM) by multiplying the value of OC by 1.724 (Nelson and Sommers).

Table 1. Soil Physiochemical Properties of experimental area.

SN	Result	Status
TN (%)	0.10	Very Low
Available P (%)	6.01	Very Low
CEC (cmol)	17	Low
OC (%)	1.11	Very Low
OM (%)	1.92	Very high
pH	4.78	Moderately acidic
Clay (%)	44	
Sand (%)	9	
Silt (%)		
Soil textural class: Sandy Clay		

TN = total nitrogen, Av. P. ppm = available phosphorus in parts per million, CEC (Cmolkg^{-1}) = cation exchange capacity in cent mole per hundred gram of soil, pH= hydrogen power, OC = organic carbon, OM = organic matter.
Source: [12].

2.3. Description of Experimental Materials

Maize inbred line BKL004, was used for the study. As primary source of Nitrogen, urea (46% N) was used. Also, NPS (19 %N, 38% P2O5, and 7 % S) fertilizer were used as a source of nitrogen, Phosphorus and sulfur respectively.

2.4. Treatments and Experimental Design

Two factors: Four N rate: 111, 157, 203 and 249 kg ha^{-1} in the form of urea and five plant population levels 44,444, 53,333, 66,666, 88,888 and 133,333 plant ha^{-1} planted at intra row spacing of 75*30,

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75*25, 75*20, 75*15 and 75*10 cm respectively. BKL004 was planted at inter row spacing of 75cm. 38 P_2O_5 kg ha^{-1} in the form of NPS was applied evenly at the time of planting.
The experiment was laid out in RCBD design in factorial arrangement (4*5) and each treatment was replicated three times. An experimental unit (a plot) has a length of 3m and width of 4.5 m (13.5 m^2 plot area). Treatments were assigned to the experimental units within a block at randomly. The blocks and plots were separated by 2 m and 0.5 m wide space respectively.

2.5. Experimental Procedures
Experimental site was ploughed till good conducive condition is met from March to May by using tractor plough. Inter row spacing (distance between one furrow to another farrow) was manipulated at 75 cm distance. Maize sowing was done in the first week of June by placing two seeds per hole in furrows at a specified intra row spacing. During seeding, NPS was applied uniformly to all plots at the depth of 2.5-5 cm around the seed with side-banding method (McKenzie). Before emergency, Primagram gold herbicide was applied to suppress weed emergency at the rate of 3l/ha. After complete germination, seedlings were thinned to one plant per hole by keeping a vigor seedling. Half dose of N fertilizer was applied at 21-25 days after planting and the remaining half dose was applied at 35-40 days after planting in the same method of application, side-banding. Once applied, Urea releases ammonia within a few hours which can be toxic to seedlings, thus, it must be placed approximately 5-7 cm distance from the plant and covered with soil (www.extension.umn.edu).
All agronomic cultural practices were applied at the standard time. Finally, maize in the central net plot area was harvested at harvesting maturity stage for the next work and analysis.

2.6. Data Collected
In this experiment data were taken from five representative randomly selected plants for some parameters and from net plot areas for the rest parameters. Generally, growth, phonological and yield parameters data were collected

Physiological maturity days	Days to 50% tasseling
Number of kernels per ear	Days to 50% silking
Thousand kernels weight (g)	Plant height (cm)
Grain yield (kg ha^{-1})	Ear height
Harvest index:	Girth
Lodging	

2.7. Data Analysis
Data were analyzed using SAS software version 9.3 following a procedure appropriate to a randomized complete block design. Comparison of treatment means was done using the Fisher's least significant difference (LSD) test at 5% probability.

3. Results and Discussion

3.1. Growth Parameters

3.1.1. Plant and Ear Height (cm)
Plant and ear height were significantly ($p<0.05$) influenced by the main effect of plant population density. However, it was not statistically significantly ($p \geq 0.05$) influenced by the main effect of N rates and the interaction of N rates and plant population density (Table 3). Plant and ear height of BKL004 maize inbred line were ranged from 136.60 cm to 146.5cm and 55.92cm to 61.32 cm respectively. The tallest plant (146.50 cm) and ear height (61.32 cm) were recorded at the highest plant population density 133,333 plants ha 1, followed by the plant and ear height recorded at the plant population of 88,888 plants ha 1. At the lowest plant population density, the shortest plant and ear height were recorded (Table 3).
Higher plant population density results thinner plants of elongated height [17]. Similarly, Zhang [18] report indicated as the taller plant resulted under the highest planting density. The greater plant density escalates the rate of internode elongation and decreases the duration of rapid internode thickening,

results internodes to increase in length and decrease in diameter [19-21]. The length of internodes below the ear increases as plant density increased, causing ear and plant height to increase. These are mainly and highly related with physiological function of plants in general. Rationally, light intensity reaching the maize canopy reduced as plant population increased, which results in inhibition auxin photo destruction. Also, Auxin contribute for internode elongation and causes extended internodes length which result highest plant height [22]. Furthermore, plant density influences the light quality (ratio of red to far-red) during the early growing period and affects internode length in the lower canopy [23].

3.1.2. Girth

Plant population density exerted a significant ($p<0.05$) effect on girth of BKL004 maize inbred line. The main effect of N levels and the interaction of plant population density and N rates were not significantly ($p\geq0.05$) affect girth of BKL004 maize parental line (Table 3). The maximum girth (17.47) was obtained at 53, 333 plant population ha^{-1} which is significantly the same with all the planting density except girth recorded at 133, 333 plants ha^{-1} which is plant population density at which the lowest girth diameter was recorded.

High plant population reduces above ground biomass and HI, increased barrenness, delayed reproductive processes, reduced kernel weight and number and affect grain yield [24]. The main causes of increased barrenness and decreased girth at high plant densities is high interplant competition for space, light, water and nutrients. At high plant population density, maize is characterized as elongated plant height, thinnest girth, long anthesis to silking interval, and smaller ear size, producing relatively more ear less plants and low yield per plant. Gradual decreased yield rate relative to density increase, and lastly a yield plateau at some relatively high plant population density [20,25].

3.2. Phenological Characters

3.2.1. Days to 50% Male and Female Flowering

Days to 50% female flowering was significantly ($p<0.05$) influenced by plant population density. Both days to 50% male and female flowering of BKL004 maize inbred line were non-significantly ($p\geq0.05$) affected by the main factor of N rates. Days to 50% male flowering was also not significantly ($p \geq0.05$) affected by plant population density (Table 3). Days to 50% female flowering ranges from 89.69 to 91.72 days. The highest plant population density extends the appearance of 50% days to silking by 91.72 days. As plant population increased, days to 50% female flowering was increased (Table 3).

In line with current finding, [6,26] reported that maize reproductive phase (tasseling and silking), were significantly affected by plant population density. Similarly, [27] reported that days to tasseling under 55555 plants ha^{-1} was significantly lower than that obtained under 83333 plants ha^{-1}. High plant population increased barrenness and delayed reproductive processes. Even, at high plant population, many kernels may not develop due to poor pollination resulting from a silking period that is delayed relative to tassel emergence [24,28]. Light is critical to measure day length and phenology of plants. Competition for light and water delayed silk emergence and results in anthesis silking interval problem [29,30]. This indicate that in case of high plant density, there is extreme competition for light which result elongated plant height and delay the appearance of male and female flowering.

Table 2. Main effect of nitrogen rate and plant density on different growth and phonological characters of BKL004 maize inbred line (from 2019 to 2021 cropping season).

NR Kg/ha	Mean of growth and phonological characters				
	MF	**FF**	**Girth**	**PH**	**EH**
111	87.58	90.69	16.55	142.4	59.24
157	88.04	90.98	16.67	140.6	56.57
203	87.91	89.82	16.84	141.6	58.25
249	87.91	90.24	16.59	140.5	57.51
LSD (5 %) F-test	ns	ns	ns	ns	ns

NR	Mean of growth and phonological characters				
Kg/ha	MF	FF	Girth	PH	EH
PD/ha					
44444	87.47	89.78[b]	17.28[a]	136.6[c]	55.92[b]
53333	87.64	89.69[b]	17.47[a]	139.0[bc]	55.99[b]
66666	87.86	90.08[b]	16.70[a]	140.6[bc]	56.48[b]
88888	88.14	90.89[ab]	16.98[a]	143.7[ab]	59.76[ab]
133333	88.19	91.72[a]	14.87[b]	146.5[a]	61.32[a]
LSD (5 %)	ns	3.03	1.75	11.60	8.65
F-test		*	*	**	*
CV (%)	2.9	3.6	12.7	8.8	16.0

N Kg ha^{-1} = Nitrogen level in kg ha^{-1}, PD ha^{-1} = plant density per hectare, MF = days to 50% male flowering, FF= days to 50% female flowering, PH=Plant height, EH = ear height, L =Stalk lodging percentage. * = significant at P≤0.05, ** = significant at p≤0.01, ns= not significant
Means within columns followed by different letter (s) for each variable are significantly different at *(p<0.05)*

3.3. Yield Attributor Characters

3.3.1. Thousand Kernels Weight (g) and Harvest Index

Harvest Index was not significantly affected by the main effect of N rates and plant population density. Thousand seed weight was not significantly affected by the main effect of N rates and plant population density.

3.3.2. Seed Yield (kg ha^{-1})

Seed (grain) yield of BKL004 maize inbred line was significantly (p<0.05) influenced by the main effect plant population density. However, the main factor of N rate and interaction of plant population density and N rate were not exerted significant effect on seed yield of BKL004 maize inbred line (Table 4). Accordingly, the maximum seed yield (3307 kg ha^{-1}) was recoded at plant population of 133,333 plants ha^{-1}, followed by seed yield recorded at plant population of 88,888 plants ha^{-1}. However, the lowest seed yield was recorded at plant population of 44,444 plants ha^{-1}, followed by grain yield observed at plant population of 53,333 and 66,666 plants ha^{-1} (Table 4).
Significant differences on seed yields and biomass were observed as the plant population/plant spacing of both male and female inbred lines varies. The maximum seed yield was obtained at 83,333 plants ha^{-1} with 60 cm inter and 20 cm intra row spacing. Also, the lowest biomass and seed yield were recorded at 61,535 plants ha^{-1} [31]. This result is in line with the finding of [32,33], reported that intra row spacing play a great role in determining the productivity of the crop.
Since it is naturally less vigor and low leaf canopy, the seeds of inbred lines need less inta and inter row spacing compared to certified seeds of maize hybrid [32,33]. Akbar *et al.* reported that optimum plant population density gave greater yield due to soil nutrients utilization more powerfully. The author also found lower grain yield with highest plant population density as of smaller ear size, less number of ear $plant^{-1}$ due to more competition for factors regarding growth. Moreover, some scholars have an opinion that maize grain yield normally revealed a quadratic response to plant density, while a gradual decreased yield rate relative to density increase, and lastly a yield plateau at some relatively high plant population density [20,25].

Table 3. Main effect of nitrogen rate and plant density on growth and yield characters of BKL004 maize inbred line (from 2019 to 2021 cropping season).

NR	Mean of Yield and Yield related traits		
Kg/ha	HI	TSW	GY
111	0.36	286.7	2684
157	0.37	296.2	2697
203	0.30	305.7	2542
249	0.38	285.7	2436

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NR Kg/ha	Mean of Yield and Yield related traits		
	HI	TSW	GY
LSD (5 %)	ns	ns	ns
F-test			
PD/ha			
44444	0.39	300.3	1836 [c]
53333	0.34	291.1	2153 [c]
66666	0.41	297.6	2518 [bc]
88888	0.25	292.4	3134 [ab]
133333	0.37	286.2	3307 [a]
LSD (5 %)	ns	ns	1522.0
F-test			*
CV (%)	16.4	17.3	21.3

N Kg ha^{-1} = Nitrogen level in kg ha^{-1}, PD ha^{-1} = planting density per hectare, HI = Harvest index, TSW = thousand seed weight, GY (kg ha^{1}) = grain yield in kilogram hectare, * = significant at P≤0.05, ns= not significant

Means within columns followed by different letter (s) for each variable are significantly different at *(p<0.05).*

3.4. Partial Budget Analysis

3.4.1. Net Benefit and Marginal Rate of Return Analysis

Production of BKL004 at plant population of 133,333 plants ha^{-1} with 249 kg ha^{-1} N rate gave the maximum net benefit (207205.5 ETBr.). Following this, BKL004 planted at plant population of 88.888 plants ha^{-1} with N rate 157 kg ha^{-1} gave 179624.7 ETBr net benefit. In general, the lowest net benefit was recorded at 44,444 plant ha^{-1} (Table 5).

Application of 249 kg ha^{-1} of N in combination of 133,333 plants ha^{-1} gave the highest economic return than all the other treatments, followed by net benefit obtained at 88,888 plants ha^{-1} in combination with 157 kg ha^{-1} of N rate. However, as plant population affect the size of seed hence endosperm, it may affect the seed germination and seedling vigor. Thus, using the second most profitable treatment (88.888 plants ha^{-1} with N rate of 157 kg ha^{-1}) is suggested until the seed germination parameters and seedling vigor of seed obtained at 133,333 plants ha^{-1} studied.

Table 4. Net benefit, Dominance and marginal rate of return analysis for BKL004 maize parental line under different plant population and N rates at Bako National Maize Research Center study site from 2019 – 2021 production year.

N	PP	GY	AGY	TC	GFB	NB	MRR%
111	44444	2309	2078.1	62466.91	170404.2	107937.3	
111	53333	2745	2470.5	63466.91	202581	139114.1	31.1768
111	66666	2891	2601.9	64766.91	213355.8	148588.9	7.288308
111	88888	2630	2367	65966.91	194094	128127.1	
157	44444	1779	1601.1	66466.91	131290.2	64823.29	
157	53333	2235	2011.5	67466.91	164943	97476.09	32.6528
111	133333	2844	2559.6	68166.91	209887.2	141720.3	63.206
157	66666	3012	2710.8	68766.91	222285.6	153518.7	19.664
157	88888	3382	3043.8	69966.91	249591.6	179624.7	21.755
203	44444	2412	2170.8	70666.91	178005.6	107338.7	
203	53333	1665	1498.5	71666.91	122877	51210.09	
157	133333	3075	2767.5	72166.91	226935	154768.1	207.116
203	66666	1934	1740.6	72966.91	142729.2	69762.29	
203	88888	3288	2959.2	74166.91	242654.4	168487.5	82.271
249	44444	845	760.5	74766.91	62361	-12405.9	
249	53333	1966	1769.4	75766.91	145090.8	69323.89	81.7298
203	133333	3412	3070.8	76366.91	251805.6	175438.7	176.858
249	66666	2236	2012.4	77066.91	165016.8	87949.89	
249	88888	3237	2913.3	78266.91	238890.6	160623.7	60.5615

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N	PP	GY	AGY	TC	GFB	NB	MRR%
249	133333	3898	3508.2	80466.91	287672.4	207205.5	21.17355

D = Dominance, N = nitrogen in kg per hectare, pp = plant population hectare^{-1}, GY = Grain yield in kg per hectare, AGY = Adjusted grain yield in kg per hectare, TC = Total cost, NB =Net benefit, GFB =Gross field benefit, MRR = Marginal rate of return in percent.
Cost of urea = 5000 Seed cost = 8200

Conclusions

The result indicated that, most of the growth and developmental and yield characters of BKL004 maize parental line responded to plant population differently, but not to N rates and the interaction of both factors. Plant height, ear height, girth, days to 50% female flowering and seed yield were significantly ($p<0.05$) affected by the main factor of plant population. While, N rates and the interaction of N rates and plant population density did not significantly influence plant height, ear height, girth, days to 50% male and female flowering, kernel number per ear, thousand kernel weight and seed yield. The tallest plant (146.50 cm) and ear height (61.32 cm) were observed at 133,333 plants ha^{-1}.The maximum girth (17.47) was obtained at 53, 333 plant population ha^{-1} which is significantly the same with all the planting density except girth recorded at 133, 333 plants ha^{-1}. The highest plant population density extends the appearance of 50% days to female flowering. The maximum seed yield (3307 kg ha^{-1}) was recoded at plant population of 133,333 plants ha^{-1}, followed by seed yield recorded at plant population of 88,888 plants ha^{-1}. Application of N at the rate of 249 kg ha^{-1} with 133,333 plants ha^{-1} was the most profitable than all the other treatments, followed by net benefit obtained at 88,888 plants ha^{-1} in combination with 157 kg ha^{-1} of N rate. However, Using the second most profitable treatment (88.888 plants ha^{-1} with N rate of 157 kg ha^{-1}) is recommended since it has good seed size and seedling vigor than 133,333 plants ha^{-1} studied.

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