Ethiop. J. Biol. Sci., 3(2): 153-161, 2004

EFFECT OF PLANT POPULATION AND HARVESTING TIME ON TUBER YIELD OF POTATO (*SOLANUM TUBEROSUM* L.)

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ABSTRACT: A field study conducted at Alemaya involving potato varieties Al-111 and Al-624 with four population densities and three harvesting times revealed that the highest plant population (88,888 plants/ha) recorded 24.7% higher total yield per unit area than the lowest one (33,333 plants/ha). Yield of large size grades, mean tuber weight and tuber yield per plant were inversely related to plant population. This study suggested that high plant population promoted production of maximum total and marketable tuber yield per unit area irrespective of varieties studied. Early harvesting resulted in loss of marketable and total yield and stabilized around 90 days after planting (DAP). No significant incremental benefits appeared possible by prolonging the harvesting to 110 DAP.

Key words/phrases: Bulking rate and duration; Graded tubers; Tuber number and yield.

INTRODUCTION

Plant population has been shown to affect tuber yield and quality by influencing size distribution, total and per stem yield and number of tubers (Nelson, 1967; Proctor and Smartt, 1976). Higher plant population generally results in higher total yields and a greater number of small tubers (Nelson, 1967). The same work also pointed out that total yield was linearly related to stem density during early tuber growth. This relationship became more pronounced as lifting was delayed; and although plant population increased yield, it significantly influenced tuber size. Iritani *et al.* (1983) and Beukema and Zaag (1990) reported that plant density affected both yield and tuber size.

Studies generally showed small-sized (and decreasing marketable) tuber yields with wider spacing between seed pieces within a row; conversely, the yield of over-sized tubers increased (Rex *et al.*, 1987). Contrary to this, the work of White (1974) and Lynch and Rowberry (1977) indicated that increased spacing did not affect total yield but significantly increased the yield of ware size tubers. Increase in tuber fresh weight was dominated by a long period during which tuber growth was more or less linear. This

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indicated yield to be a function of bulking rate which remained almost constant for few weeks after tuber initiation (Bremner and Taha, 1966).

Generally, there appears to be little consistency among research reports on the influence of population density and/or harvesting time on yield of potatoes. Thus, this paper highlights data on the effect of varying population densities and harvesting times on the number, total and graded tuber yields of potato varieties, Al-111 and Al-624 under semi-arid highland conditions of eastern Ethiopia.

MATERIALS AND METHOD

The study was conducted in the research field of Alemaya University during the main crop season (2000/01). The experimental site is located at 42° 3'E longitude, 9° 26'N latitude and at an altitude of 1980 m a.s.l. in M_2 (tepid to cool moist mid highland) zone of eastern Ethiopia (EARO, 1999). The soil of the experimental site is a well-drained deep alluvial, with sub-soil stratified with loam and sandy loam that contains 3% organic matter and pH of 7.7 (Tamire Hawando, 1973). The region receives a mean annual rainfall of 780 mm and the mean annual maximum and minimum temperatures recorded were 23.4 and 8.25°C, respectively.

The experiment was laid out in a Split Plot design to fit into randomized complete blocks with three replications. The whole seed tubers of medium size, ranging from 40-70g of the respective varieties viz., Al-111 (V_1) and Al-624 (V_2), stored for six months under diffuse light storage having green, firm and strong sprouts were used for planting.

Uniform row spacing of 75 cm was used with varying intra-row spacing of 40 cm (P_1), 30 cm (P_2), 20 cm (P_3) and 15 cm (P_4), resulting in population densities of 33333, 44444, 66666 and 88888, plants/ha, respectively. Each experimental plot contained three rows of 3.6 m length corresponding to a gross plot size of 8.1 m^2 (4 rows with 5.4 m length) and net plot size ranging from 6.3 - 7.425 m^2. The crop was harvested three times at intervals of 20 days starting from the 70th day after planting (DAP) (= H_1), 90 DAP (= H_2) and 110 DAP (= H_3). The crop was raised under standard cultural practices applicable to the region with necessary crop protection measures when required.

Total tuber number at each harvest was recorded and expressed as tuber number per plant and thousands per hectare. Total weight of tubers as mean tuber weight, tuber yield per plant and tuber yield per hectare were also determined. Tubers of the respective harvests were cleaned and graded

according to their weights as undersized (less than 40 g), marketable (40-250 g) and oversized tubers (above 250 g) with their respective number and weights recorded. Undersized tubers were categorized as unmarketable.

RESULTS AND DISCUSSION

Total Number of Tubers

Higher total tuber numbers were recorded at higher plant populations (Table 1). This was likely perhaps due to initiation of large number of developing tubers within unit area earlier than that at low plant population leading to high bulking rate over long period (Ifenkwe and Allen, 1978). Iritania *et al.* (1983) also reported higher tuber number under closer spacing. This is possibly due to larger amounts of assimilates being made available resulting from higher amount of foliage (haulm) per unit area at the time of initiation (Thompson and Taylor, 1974).

Table 1 The effect of plant population and harvesting time on tuber number (in 000's/ha and per plant).

Harvesting Date (H)	Tuber number, 000's/ha (per plant) by plant population (P)				Mean of H's
	P_1	P_2	P_3	P_4	
H_1	283.3 (8.7)	369.8 (8.8)	445.6 (6.4)	554.6 (6.5)	413.36 (7.65^b)
H_2	338.5 (10.1)	350.0 (8.3)	497.8 (8.3)	537.1 (7.0)	432.15 (8.46^a)
H_3	316.1 (10.1)	387.4 (9.0)	450.9 (7.6)	472.7 (6.4)	407.60 (8.32^{ab})
Mean of P's	312.6^d (9.66^a)	369.1^c (8.72^b)	464.8^b (7.5^c)	521.5^a (6.68^c)	
		P	H		
$LSD_{0.01}$		41.23(0.846)			
$_{0.05}$			(0.733)		

Means within row and column superscripted by the same letter are non-significant at 1% and 5% levels, respectively.

When tuber number per hill was considered, Al-624 produced a higher number of tubers (8.87) than Al-111 (7.41). Generally, tuber number per hill was inversely related to plant population (Table 1) probably arising from inter and intra-hill competition under high plant population. This might lead to loss of vigor with consequential reduction in photosynthate production per plant. Harvesting time also affected tuber number per hill (Table 1). This is in agreement with the findings of Bremner and Taha (1966) and Ifenkwe and Allen (1978).

Graded Tubers

Marketable tubers (40-250 g)

The term "marketable tubers" in the present study refers to those tubers weighing between 40-250 g. In accordance with this range, the tubers were graded for recording both number as well as weight of tubers of the respective categories. Plant population influenced significantly the number

of marketable tubers produced per hectare (Table 2). The difference between the highest and lowest population might be attributed to higher net assimilate rates at higher population density per unit area. The data indicate that number of marketable tubers is directly proportional to plant population (Ifenkwe and Allen, 1978). On the other hand, Lynch and Rowberry (1977) suggested no effect of plant population on the number of tubers reaching marketable size. This may be perhaps due to varied norms of grading adopted by different workers.

Table 2 Effect of plant population and harvesting time on yield (in t/ha and 000's/ha) of marketable tubers.

Harvesting Date (H)	Tuber yield, t/ha (000's/ha), by plant population (P)				Mean of Hs
	P_1	P_2	P_3	P_4	
H_1	14.4	17.4	17.2	18.7	16.94^b
H_2	21.2	23.9	25.3	25.4	24.00^a
H_3	22.1	24.4	22.9	26.5	23.92^a
Mean of Ps	19.2^b (203.8^c)	21.7^a (252.3^b)	21.8^a (252.3^b)	23.5^a (280.5^a)	
	P	H			
$LSD_{0.01}$	2.417(25.49)	2.093			

Means within row and column superscripted by the same letter are non-significant at 1% level.

Marketable tuber yield increased at high plant population (Table 2), probably resulting from efficient utilization of resources (Bremner and Taha, 1966). This, however, contradicted the findings of Thompson and Taylor (1974), Lynch and Rowberry (1977) and Rex *et al.* (1987) which may be ascribed to the differential grading norms adopted by these workers. Marketable tuber yield was also significantly affected by harvesting time (Fig. 1).

Undersized Tubers (<40 g)

The tubers in this category were unmarketable. Al-624 produced higher number than Al-111 at all plant populations with differences being greater at higher plant populations than at lower. Al-624 produced 71% higher number of undersized tubers than Al-111 (Table 3). The higher number recorded at higher population densities was due to intense competition prevailing at higher population densities perhaps leading to reduced amount of assimilates transferred to tubers (Thompson and Taylor, 1974). Harvesting times however had no significant effect on number of undersized tubers.

Plant population also influenced yield of undersized tubers (Table 3) arising due to intense inter-hill competition as observed under high planting densities (Thompson and Taylor, 1974; Svenson and Negalica 1977).

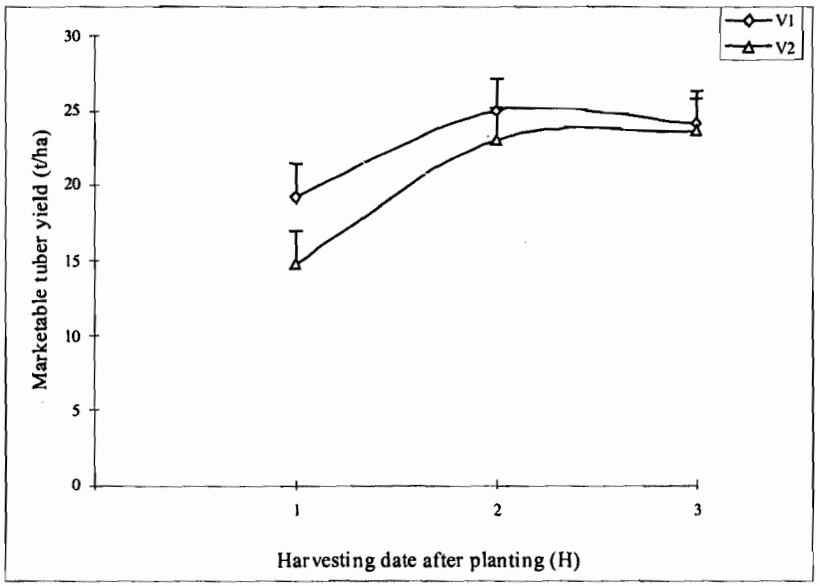

Fig. 1. Effect of variety and harvesting time on marketable tuber yield (t/ha). Vertical bars represent LSD at 5% level.

Table 3 Effect of variety and plant population on yield (in t/ha and 000's/ha) of undersized tubers.

Variety	Tuber yield, t/ha (000's/ha), by plant population (P)				Mean of varieties
	P_1	P_2	P_3	P_4	
Al-111	1.4 (84.3)	1.9 (103.5)	2.7 (143.7)	3.2 (180.2)	2.3 (127.9)
Al-624	3.0 (134.7)	3.3 (158.6)	5.4 (278.7)	5.8 (301.4)	4.4 (218.4)
Mean of Ps	2.2^b (109.5^b)	2.6^b (131.1^b)	4.0^a (211.2^a)	4.5^a (240.8^a)	
	P				
$LSD_{0.01}$	0.94 (41.44)				

Means within row superscripted by the same letter are non-significant at 1% level.

Oversized Tubers (>250 g)

The production of oversized tubers is not desirable as they developed 'hollow heart', misshapen tubers and manifested growth cracks. At first harvest (70 DAP), none of the varieties produced oversized tubers. The rate of increase, however, was progressive over time with Al-111 recording higher number than Al-624. At first harvest, all the plant populations recorded no oversized tubers. However, number of oversized tubers increased with harvesting times and decreased with plant population, with 33,333 plants/ha recording significantly higher number at 110 DAP (Table 4). This indicated a combination effect of reduced competition and extended bulking period (Bremner and Taha, 1966; Ifenkwe and Allen, 1978; Beukema and Zaag 1990).

Effect of variety and harvesting time and plant population and harvesting

time on yield presented trends similar to that of number (Table 4). There was no significant difference between the varieties while plant population and harvesting times ($P < 0.01$) influenced the yield of over sized tubers.

Table 4 Effect of plant population and harvesting time on yield (in t/ha and 000's/ha) of oversized tubers.

Harvesting date (H)	Tuber yield, t/ha (000's/ha), by plant population (P)				Mean of Hs
	P_1	P_2	P_3	P_4	
H_1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.00^c (0.00^c)
H_2	1.2 (4.0)	0.7 (2.4)	0.2 (0.9)	0.2 (0.4)	0.61^b (1.95^b)
H_3	3.6 (6.8)	1.1 (3.7)	0.9 (2.9)	0.6 (1.4)	1.45^a (3.73^a)
Mean of Ps	1.45^a (3.62^a)	0.63^b (2.06^b)	0.40^b (1.28^c)	0.27^b (0.62^c)	
	P	H			
$LSD_{0.01}$	0.596 (0.663)	0.516 (0.574)			

Means within row and column superscripted by the same letter are non-significant at 1% level.

Generally, tuber number and yield increased with increase in plant population. As the grade size increased, however, the number and yield of tubers per unit area decreased, especially in those treatments recording higher total number of tubers at early harvest. This could be attributed to intense inter-hill competition and reduced bulking rate per plant (Thompson and Taylor, 1974).

Mean Tuber Weight

Al-111 recorded significantly higher (70.8 g) mean tuber weight than Al-624 (56.7 g). Mean tuber weight was inversely related with plant population (Table 5), attributable to increased bulking rate per plant with decreasing plant population (Thompson and Taylor, 1974). Harvesting time also influenced ($P < 0.01$) the mean tuber weight. The increase in tuber fresh weight (Table 5) with delayed harvesting (H_3) tallied broadly to the pattern outlined by Bremner and Taha (1966) that the tuber fresh weight increase was dominated by a long period, during which tuber growth was more or less linear.

Table 5 Effect of plant population and harvesting time on mean tuber weight (g).

Harvesting date (H)	Mean tuber weight (g) by plant population (P)				Mean of Hs
	P_1	P_2	P_3	P_4	
H_1	56.9	55.1	48.7	43.9	51.19^b
H_2	74.5	75.8	61.1	57.5	67.26^a
H_3	86.1	73.2	63.9	65.6	72.21^a
Mean of Ps	72.52^a	68.06^a	57.95^b	55.69^b	
	P	H			
$LSD_{0.01}$	6.716	5.816			

Means within row and column superscripted by the same letter are non-significant at 1% level.

Total Yield

Varieties indicated no yield differences when averaged across different plant populations and harvesting times. Significant differences, however, were

observed among plant populations and harvesting times. Under high plant population, large number of developing tubers was initiated with higher foliage produced within unit area than at low population resulting in high bulking rate (Ifenkwe and Allen 1978). As yield of potato is dependent both on number and the weight of tubers, high plant population gave more yield than low population density. Both number (Table 1) and weight (Table 6) of tubers increased with increasing plant population, corroborating earlier results (Bremner and Taha, 1966; Thompson and Taylor, 1974 and Ifenkwe and Allen, 1978). On the contrary, Lynch and Rowberry (1977) indicated no response of total yield to increased plant population in 'Russet Burbank' where net assimilation rate decreased with increase in leaf area index and reduced bulking rate occurred at high plant populations resulting from intra-hill competition among developing tubers.

Tuber yield in potato has been reported to be a function of bulking rate and duration (Ifenkwe and Allen, 1978). The longer the time left after tuber initiation, the higher will be the bulking period, irrespective of bulking rate which remained almost constant for few weeks after tuber initiation (Beukema and Zaag, 1990), resulting in higher yield. Therefore total tuber yield in potato is linearly related with delay in harvesting except for delay which is prolonged after the haulm death, as in the case of harvesting at 110 DAP which is in conformity with the investigations of Bremner and Taha (1966) and Thompson and Taylor (1974). In contrast to this, the increase in tuber yield per plant with decreased plant population, particularly at delayed harvesting (Fig. 2), is due to increased bulking rate and duration (Thompson and Taylor, 1974).

Al-111 (568.8 g/plant) out-yielded Al-624 (531.9 g/plant) with yield per plant inversely related with plant population (Table 6). This is due to high inter- and intra-hill competitions available under high plant population, thereby reducing the vigor of individual stems; this, in turn, reduced the amount of photosynthate production per stem (Bremner and Taha, 1966). The data also suggested that delayed harvesting significantly increased tuber yield per plant (623.67 g/plant) as compared to early harvesting (448.33 g/plant).

At low planting populations where competition for light and other resources is low, yield and number of tubers per plant would be higher or equal to the potential of the genotype. As plant population increased, competition appeared more important. This could lower tuber number and weight below the potential of the genotype, but increased tuber weight and number per

unit area could approach the potential of the environment (Thompson and Taylor, 1974; Rex *et al.*, 1987). These findings are consistent with the present study where, on per plant basis, higher tuber yield was recorded at lower population and on per unit area basis, higher yield was recorded at higher population.

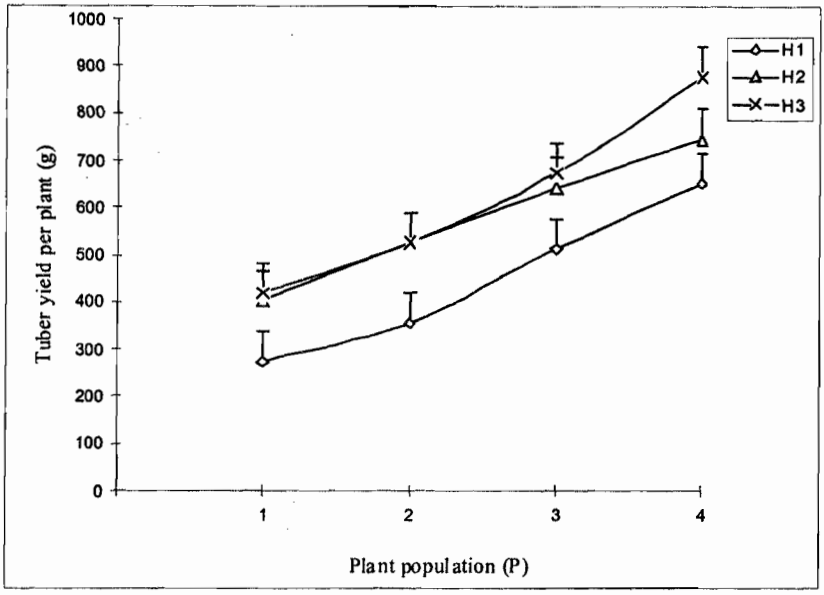

Fig. 2. Effect of plant population and harvesting time on tuber yield per plant (g/plant). Vertical bars represent LSD at 1% level.

Table 6 Effect of plant population and harvesting time on tuber yield (in g/plant and g/ha).

Harvesting date (H)	Tuber yield, g/plant (g/ha), by plant population (P)				Mean of Hs
	P_1	P_2	P_3	P_4	
H_1	651.7 (16.1)	513.3 (19.9)	355.0 (21.0)	273.3 (23.4)	448.3^{c} (20.1^{b})
H_2	745.0 (25.1)	645.0 (26.78)	525.0 (30.1)	401.7 (30.7)	579.1^{b} (28.2^{a})
H_3	877.0 (26.9)	673.8 (28.28)	525.7 (27.7)	418.2 (30.0)	623.6^{a} (28.3^{a})
Mean of Ps	757.8^{a} (22.7^{c})	610.7^{b} (25.0^{b})	468.5^{c} (26.3^{ab})	364.3^{d} (28.3^{a})	
	P	H			
$LSD_{0.01}$	37.44 (2.02)	32.42 (1.75)			

Means within row and column superscripted by the same letter are non-significant at 1% level.

CONCLUSION

The study indicated that high plant population promoted production of maximum total and marketable tuber yield per unit area. Early harvesting resulted in loss of marketable and total yield but was stabilized around 90 days after planting. No significant incremental benefits appeared possible by prolonging the harvesting to 110 days after planting.

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