INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
11–579/AWB/2012/14–4–545–549
http://www.fspublishers.org

Full Length Article

Influence of Plant Population and Seed Tuber Size on Growth and Yield Components of Potato (*Solanum tuberosum*)

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ABSTRACT

A field study was carried out with the potato (*Solanum tuberosum* L.) variety BP1 to determine the influence of plant population density and seed tuber size on the crop's physiological growth components and yield performance under optimal field conditions. Two factors considered were seed tuber size and population density. The first factor involved four seed sizes; S1 (small), 200-350 mm in diameter; S2 (medium), 350-450 mm in diameter; S3 (large), 450-550 mm in diameter and S4 (very large), greater than 550 mm in diameter. The second factor was population density (E) and it was at three levels; level 1 (E1) at 90 by 15 cm, level 2 (E2) at 90 by 30 cm, level 3 (E3) at 90 by 45 cm spacing. Parameters measured included shoot emergence (germination), haulm growth and yield. There were significant differences in mean percentage germination at 9, 10, 11 and 12 days after planting across the four seed sizes. Plants from larger seed potato tubers exhibited greater physiological growth and yield (kg/ha) compared to smaller seed tubers when the experiment was terminated at 95 days after emergence. Large and very large seed potato tubers exhibited greater overall resource use efficiency of allocation of metabolites as measured by growth components and yield at all plant density levels compared to small and medium sized seed tubers. This had implications on the duration of the bulking, physiological growth and consequently on yields obtained at harvest. At the same time, plant population density had no significant ($p>0.05$) effect on the number of days to emergence. From the results obtained in this study, it can be concluded that the optimum plant population density for good yield was 90 by 30 cm and that large and very large seed sets gave the best yield.

Key Words: Potato; Seed size; Plant population; Growth components; Yield

INTRODUCTION

The Irish potato (*Solanum tuberosum* L.) is one of the most widely grown tuber crops in the world and contributes immensely to human nutrition and food security (Miguel, 1985; Steven, 1999; Karim *et al*., 2010). It is characterized by a shallow and superficial root system but has been shown to be a heavy nutrient feeder, requiring nutrient uptake until maturation. It is a vegetable crop with a relatively high growth rate. This results in it having a relatively short growing period (Durr & Lorenzl, 1981).

The yield of potato is influenced by a number of factors, which include nitrogen, cultivar, seed piece spacing, climatic conditions and geographic location (Barry *et al*., 1990; Arsenault *et al*., 2001). As plant density increases, there is a marked decrease in plant size and yield per plant. This effect is due to increased inter-plant competition for water, light and nutrients. It is therefore, essential to understand how individual plants interact with each other and the environment and to possibly come up with the ideal crop density levels to optimize yields.

Potatoes contain high quality proteins and a substantial amount of essential vitamins, minerals and trace elements. They produce more edible energy and protein per unit area of land than any other crop (Paul, 1985). With the increasing population levels and starvation in developing countries, improving yield performance of the crop could help alleviate starvation as well as increase the disposable income of farmers. The crop has a high consumer demand by all socio-economic classes. Demand for potatoes is expected to rise with the expected rise in the standard of living in developing countries. Irish potatoes are mainly grown by commercial farmers who can afford the high inputs required in their production. The cost of seed represents the greatest proportion of the total production costs (Potatoes South Africa, 1979; Kabir *et al*., 2004; Karim *et al*., 2010). Accatino and Malagamba (1982) estimated that in developing countries, seed potato tubers represent 40 to 70% of the crop's production costs. In

To cite this paper: Masarirambi, M.T., F.C. Mandisodza, A.B. Mashingaidze and E. Bhebhe, 2012. Influence of plant population and seed tuber size on growth and yield components of potato (*Solanum tuberosum*). *Int. J. Agric. Biol*., 14: 545–549

Egypt, the cost of seed tubers was reported to be over 50% of the total cost of production (El Bedewy *et al*., 1991-1994). It becomes imperative that optimum seed size and spacing levels need be established to ensure optimum yield performance and better monetary returns of potato production to farmers (Kabir *et al*., 2004) in a given geographic area.

Haulm growth and tuber expansion are closely inter-related. It is therefore essential to determine the ideal potato tuber size, which when grown at the correct density is able to exhibit high yield performance. These factors considered depends on whether one is aiming to produce table or ware potatoes. Four seed sizes; S1 (Small) to S4 (Very large) are currently in use in the potato seed industry in Zimbabwe but the seeding rate is based on a weight of approximately 2 tons/ha of seed potato tubers. Thus, there is need therefore to establish standard-seeding rates or spacing for all the four seed sizes to ensure optimum yield performance. Seed spacing have been reported to influence yield, tuber size distribution, tuber, stem density and net returns of potato cultivars (Van der Zaag *et al*., 1990; Love & Thompson-Johns, 1999; Zamil *et al*., 2010).

Despite many investigations over many years on this important crop, more information is required on interrelationships of plant populations and tuber sizes in relation to its growth and subsequent yield. Some important studies were done few decades ago (Bremner & Taha, 1966), while others are recent (Das & Deka, 2002; Khan *et al*., 2010). Plant population studies with the potato are never outdated because of unique tuber characteristics of new cultivars and the changing tuber requirements of evolving industries (Wurr, 1974; Wurr *et al*., 1993). There is still much to learn about even the simple interrelationships of haulm and tuber growth and the interference between branches. An understanding of these inter-relationships should allow the crop to be managed so as to provide a wide range of responses, such as radiation interception and influence of climate variation in maturity, earlier tuber formation and control of the number and sizes of tubers at maturity (Kooman *et al*., 1996). More research will even be necessary in Southern Africa when we factor in the impact of climate change in production of crops.

This investigation was aimed at finding out how potato seed tubers of different sizes interact at varying spacing levels to influence pre-emergence rate, haulm growth at various tuber growth stages. The agronomic aim of the study was to manipulate these two factors and come up with seeding rates that will optimize yield performance.

The specific objectives of this study were to: 1) to compare the physiological growth components of Irish potato (*S. tuberosum*) variety B.P. (1). As influenced by seed potato tuber size and plant population density using growth analysis techniques and (2). To determine the effect of seed potato tuber size and plant population density on yield performance of field grown potatoes.

MATERIALS AND METHODS

Experimental site: The experiment was carried out at the University of Zimbabwe (UZ) farm during the summer period of the 2003/2004 season. The UZ farm is located at latitude 17^{o}50’S and longitude 30^{o}01’E with an altitude of 1, 460 m above sea level. The place has a long term annual rainfall of about 750-1 000 mm and has a semiarid subtropical climate. The average temperature in June ranges from 7^{o}C to 21^{o}C, while in November it ranges from 16^{o}C to 27^{o}C. Since potatoes are of Andean highlands origin (Bolivia), it makes the site suitable for potato production. The climatic conditions allow for summer production of potatoes.

Plant material: The superior quality, disease resistant, commercial potato variety, BP1 was used in the experiment and was treated with an insecticide, malathion. It was sourced from Seed Potato Association in Harare, Zimbabwe. Origin of the seed was Nyanga, Manicaland Province whose coordinates are 18^{o}13’S and 32^{o}45’E, were it was screened against viral infection grown under virus-free conditions at 1250 m above sea level. The variety is a medium maturing one and takes 95 days to reach physiological maturity. Seed potato tubers were adequately sprouted at planting. The land planted to potatoes was winter ploughed, ridged and was irrigated to field capacity a day before planting, just after planting and three days after planting (DAP).

Experimental design: Two factors were considered. These were seed tuber size and population density. The first factor involved four seed sizes; S1 (small-S), 200-350 mm in diameter; S2 (medium-M), 350-450 mm in diameter; S3 (large-L), 450-550 mm in diameter and S4 (very large), greater than 550 mm in diameter. The second factor was population density (E) and it was at three levels; level 1(E1) at 90 by 15 cm, level 2(E2) at 90 by 30 cm, level 3 (E3) at 90 by 45 cm. The experiment was set up as a 4 x 3 factorial arranged in a randomized complete block design (RCBD) with four replications in each treatment. Thus, there were 12 treatment combinations. Plot sizes were kept constant at 3.6 × 3.6 m. Each plot comprised four lines with plants grown at a density of 90 by 15 cm and had 24 plants per line. Those planted at 90 by 30 cm had 9 plants per line and those planted at a density of 90 by 45 cm had 8 plants per line. Two outer rows of plants were treated as border rows, while the two middle rows in each plot were regarded as experimental row plants. Potato variety BP1 was planted at three intra-row spacing of 15, 30 and 45 cm, while the inter row spacing was kept constant at 90 cm.

Management practices and fertilizer schedule: Soil analysis was carried out before the trial was undertaken. The soil of the trial site had a pH ($CaCl_2$) of 5.3, total N 30 mgkg^{-1}, available P 5.82 mgkg^{-1} and exchangeable K 0.19 cmolkg^{-1}, Ca 6.12 cmolkg^{-1}, Mg 2.56 cmolkg^{-1} and cation exchange capacity (CEC) of 13.1 meq/100g. A basal dressing of Compound S (N=7%, P=21%, K=7%) was

Table I: Effect of seed tuber size (S) on leaf area development (LA-cm^2) at 10, 20, 30, 60 and 90 days after emergence (DAE)

Seed tuber size category (S)[1]	LA at 10 DAE	LA at 20 DAE	LA at 30 DAE	LA at 60 DAE	LA at 90 DAE
S1	687.4^a	1188.6^a	2629.4^a	18908.4^a	86565.0^a
S2	949.9^b	1306.0^a	3263.7^a	24891.8^b	18366.6^b
S3	1191.1^c	3319.2^b	7944.0^a	30629.5^c	27145.0^c
S4	1606.1^d	12586.0^c	18610.1^b	40873.9^d	34630.0^d
LSD	100.1	789.0	5085.0	4847.0	2010.2
CV (%)	25.3	31.2	23.3	21.4	15.9
P value	0.001	0.001	0.05	0.001	0.001

[1]Tuber size classification (Diameter in millimeters): 200≤S1≤350; 350<S2≤450; 450<S3≤550 and S4>550

Means within a column are significantly different if they do not share a common superscript (P<0.05)

Table II: Effect of plant population (E) on leaf area development (LA-cm^2) at 10, 20, 30, 60 and 90 days after emergence (DAE)

Plant population (E)[2]	LA at 10 DAE	LA at 20 DAE	LA at 30 DAE	LA at 60 DAE	LA at 90 DAE
E1	1097.1^a	4854.5^a	5614.9^a	24745.0^a	17790.9^a
E2	1118.9^a	5208.1^a	7955.2^a	30576.5b	23207.0^b
E3	1104.1^a	4104.5^a	10765.2^b	33472.0^c	25601.4^b
LSD	122.67	1234.0	33472.0	4197.7	4197.65
CV (%)	18.6	33.2	16.1	28.1	22.6
P value	>0.05	>0.05	0.05	0.001	0.001

[2]Plant population classification (Plants per hectare):E1=24,600; E2=37,000; E3=74,000

Means within a column are significantly different if they do not share a common superscript (P<0.05)

Table III: Effect of seed tuber size (S) and population density on potato tuber yield (kg/hectare)

	Plant population (E)[2]		
Seed tuber size category (S)[1]	E1	E2	E3
S1	11683.0^a	17684.8^{ab}	15175.3^a
S2	20767.5^b	24800.2^b	24696.8^b
S3	28627.7^c	32988.4^{cd}	31077.9^c
S4	32955.6^{cd}	35298.1^d	32885.9^{cd}
LSD (5%)	4893.0	4893.0	4893.0
CV (%)	12.0	12.0	12.0
P value	0.001	0.001	0.001

[1]Tuber size classification (Diameter in millimeters): 200≤S1≤350; 350<S2≤450; 450<S3≤550 and S4>550

[2]Plant population classification (Plants per hectare):E1=24,600; E2=37,000; E3=74,000

Means within a column and within a row are significantly different if they do not share a common superscript (P<0.05)

applied at a rate of 200 kg/ha at planting. A top dressing of ammonium nitrate was applied at 4 and 8 weeks after emergence at a rate of 20 kg ha^{-1}.

Weeding was carried out by hand and hoed once the young weed plants were visible. The first ridging was done when plants were about 10 cm in height. Second and subsequent ridging were done as and when necessary until desired ridges were built. A fungicide, Dithane M45, was applied in rotation with copper- oxy- chloride as protective foliar spray, soon as the crop was established until the crop reached maturity.

Data collection: Leaf area during the experimental period was recorded using the dimensions method by measuring the leaf length and leaf width, multiplied with the leaf number values. The crop was harvested at 95 days after emergence. The weight and number of tubers per plot were taken. Number of leaves and stems were counted at the end. At 90 days after emergence, all the above ground growth was removed and a sample of three plants per plot was taken. The sample was used to derive number of stems per plant, number of leaves per plant and to calculate leaf area per plant for each treatment. Measurements of the number of leaves and the leaf area per plot were also taken during the crop growth period at 10, 20 30, 60 and 90 days after emergence (DAE).

Data analysis: Collected data was analyzed using Minitab Statistical package licensed to the University of Zimbabwe. Data were subjected to analysis of variance (ANOVA) at p<0.01 and P<0.05 according to Steel and Torrie (1980). Where significant differences were detected mean separation was by least significant differences (LSD).

RESULTS AND DISCUSSION

Seed tuber size x population density interaction: Results suggested that both seed tuber size (S) and plant population density (E) had an influence on many aspects of potato growth. Seed tuber size (S) had a significant (p<0.05) effect on leaf area development at 10, 20, 30, 60 and 90 DAE (Table I). There were significant (P<0.05) differences in the mean leaf area values across the three planting densities. Leaf area increased in plants established from small seed to those arising from very large tubers. Plant population density (E) also had a significant (p<0.05) influence on leaf area development over the same time period (Table II). There was no interaction (p>0.05) between these two factors to influence leaf area development (app. 5, 9, 12, 15, 18) over the same period. The only significant (p<0.05) interaction in the experiment was that observed for weight (g/plot). There was a significant interaction between seed tuber size (S) and plant population density (E). As the seed tuber size increased there was a corresponding increase in yield (Table III).

Days to emergence (DTE): Seed tuber size significantly (P< 0.05) influenced the number of days taken for the crop to emerge. There were significant differences in percentage germination at 9, 10 and 11 DAP across the whole range of seed sizes. At the same time, E had no significant (p> 0.05) effect on the number of days taken for the crop to emerge when it was assessed at 9 to 12 DAP (Table IV & VII).

Seed tuber size (S) significantly (p<0.05) influenced the number of days taken to emergence whereas plant population density (E) had no significant (p> 0.05) influence on DTE (Table VII). Plants from large seed classes significantly (p <0.05) emerged earlier than plants derived from smaller seed classes. There was a gradual increase in the days to emergence as we moved from very large (S4) seed to small (S1) seed tubers. Generally, a greater proportion of very large and large seed potato tubers emerged earlier than small to medium sized tubers. At 12 DAP, germination percentages ranged from 85% to 99%. This represented a uniform gradation where the 85% germination was for small seed and the highest percentage (99%) was for very large seed potato tubers (Table VII). The significant difference between the means for days to emergence (DTE) suggest seed size as the factor causing significant differences in the number of days taken for the crop to establish itself. At the same time, E had no significant ($p>0.05$) effect on the DTE throughout the emergence period. This was because emergence was largely dependent on the utilization of reserve material and metabolites in the mother tuber (Wurr *et al*., 1993; Love & Thompson-Johns, 1999; Kabir *et al*., 2004).

At 9 DAP both S and E had a significant effect on number of days to emergence. The significant difference between the means for seed size in terms of germination percentages was related to the amount of reserve material and meristematic 'capital' in tubers across the four seed sizes, with large (S3) and very large (S4) seed having a greater amount of these attributes than small (S1) to medium sized (S2) tubers. Larger seed tubers have a greater initial meristematic 'capital' and a greater amount of reserve material than smaller seed tubers (Wurr *et al*., 1993; Love & Thompson-Johns, 1999; Kabir *et al*., 2004). This resulted in higher relative growth rates of large seed than small seed in the pre-emergence as well as the post-emergence periods. Very large and large seed tubers significantly ($p< 0.001$) emerged earlier than small and medium sized tubers. This was because large seed is associated with large embryo axis, leaf primordial and cotyledon area. Large and very large seed tubers had slightly longer and thicker sprouts at planting time and this contributed to earlier germination and crop establishment. This enabled tubers to establish faster since the tubers were not yet photosynthesizing but were relying solely on the supply of metabolites from the mother tubers. Spatial arrangement had no effect on days taken for the crop to emerge.

Tuber yield: Yield performance (kg/ha) was greatest at the medium density level (90 by 30 cm), followed by plants established at 90 by 45 cm. It was least for plants established at 90 by 15 cm across all seed sizes. Reducing the intra-row spacing from 45 cm to 30 cm significantly ($p<0.05$) increased plant population and subsequently increased the yield (kg/ha) performance (Table III). Very large to large sized tubers emerged earlier than small and medium sized tubers. Mean tuber yield decreased significantly ($p<0.001$) as seed size decreased from very large tubers to small tubers (Table IV).

Tuber yield was significantly ($p< 0.05$) affected by plant density as plants planted at 90 by 30 cm exhibited highest yield performance compared to those planted at 90 by 15 cm and 90 by 45 cm (Table IV). The 90 by 30 cm spacing treatment gave the highest yield performance values across all seed sizes. There were also significant differences ($p<0.001$) in number of tubers at harvesting time with respect to the size of the tubers used at planting. Plants established from large and very large seed produced smaller but numerous tubers whereas those established from small to medium sized seed produced few but large tubers as previously reported (Bremner & Taha, 1966; Wurr *et al*., 1993; Love & Thompson-Jones, 1999; Khan *et al*., 2010). However, there is also threshold size below and above, which the tuber size becomes non-optimal in terms of maximum obtainable yields, suitability for specific use and other quality attributes depending on industry type. This is why this subject is ongoing, because it also involves an array of factors. The other factors may include environmental and situational in this regard.

There was a significant ($p<0.05$) difference in treatments for the number of tubers formed at the varying

Table IV: Effect of seed tuber size (S) on number of potato tubers/hectare and tuber initiation 30 days after emergence (DAE)

Seed tuber size category (S)[1]	Mean tuber count/hectare	Tuber initiation 30 DAE
S1	150463.0[a]	7716.1[a]
S2	277777.8[b]	19032.9[b]
S3	445987.7[c]	27006.2[c]
S4	535236.7[c]	29063.8[c]
LSD (5%)	91319.5	8225.3
CV (%)	48.75	49.39
P value	0.05	0.05

[1]Seed tuber classification (Diameter in millimeters): 200≤S1≤350; 350<S2≤450; 450<S3≤550 and S4>550

Table V: Effect of tuber seed size and days after emergence on stem numbers per plant

	Number of days post emergence (DAE)				
Seed tuber size category (S)[1]	10	20	30	60	90
S1	1.3[a]	2.0[a]	2.0[a]	5.5[a]	3.6[a]
S2	1.3[a]	1.6[a]	2.7[a]	5.6[a]	6.3[b]
S3	1.6[ab]	1.7[a]	5.0[b]	5.7[a]	7.6[b]
S4	1.7[b]	1.7[a]	5.0[b]	9.0[b]	9.7[c]
LSD (5%)	0.403	0.23	0.95	1.49	1.46
CV (%)	15.7	29.7	16.3	12.8	25.9
P value	0.05	0.05	0.05	0.05	0.05

[1]Seed tuber classification (Diameter in millimeters): 200≤S1≤350; 350<S2≤450; 450<S3≤550 and S4>550

Within a column, means not sharing a common superscript are significantly different (P<0.05)

Table VI: Effect of plant population and days after emergence on stem numbers per plant

	Number of days post emergence (DAE)				
Plant population(E)[1]	10	20	30	60	90
E1	1.5[a]	1.8[a]	2.0[a]	4.8[a]	7.0[a]
E2	1.5[a]	1.8[a]	3.0[b]	6.0[ab]	5.8[a]
E3	2.0[b]	2.0[a]	4.3[c]	8.5[b]	9.3[b]
LSD (5%)	0.21	0.33	0.23	2.98	1.90
CV (%)	35.7	15.0	12.9	13.9	27.9
P value	0.05	0.05	0.05	0.05	0.05

[1]Plant population classification (Plants per hectare):E1=24,600; E2=37,000; E3=74,000

Within a column, means not sharing a common superscript are significantly different (P<0.05)

Table VII: Effect of seed size on percentage germination

Seed tuber size category (S)[1]	% Germination at 9 DAP[2]	% Germination at 10 DAP	% Germination at 11DAP	% germination at 12 DAP
S1	37.0[a]	51.8[a]	76.2[a]	85.1[a]
S2	40.0[a]	59.4[b]	79.5[a]	91.2[b]
S3	43.5[a]	67.6[c]	86.1[c]	98.1[c]
S4	42.5[a]	77.0[d]	91.4[d]	99.5[c]
LSD (5%)	8.13	2.90	4.85	4.39
CV (%)	7.12	16.94	8.15	7.12
P value	0.05	0.05	0.05	0.05

[1]Seed tuber classification (Diameter in millimeters): 200≤S1≤350; 350<S2≤450; 450<S3≤550 and S4>550
[2]DAP=Days after planting
Within a column, means not sharing a common superscript are significantly different (P<0.05)

Table VIII: Effect of seed tuber size on leaf development

Seed tuber size category (S)[1]	Leaf number/ plant 10 DAE[2]	Leaf number/ plant 20 DAE	Leaf number/ plant 30 DAE	Leaf number/ plant 60 DAE	Leaf number/ plant 90 DAE
S1	13.0[a]	128.6[a]	198.7[a]	283.3[a]	269.0[a]
S2	23.6[a]	143.3[a]	265.3[a]	413.3[b]	382.3[a]
S3	23.6[a]	135.0[a]	220.7[a]	579.7[c]	560.0[b]
S4	32.7[a]	142.6[a]	367.0[b]	747.7[d]	684.0[c]
LSD (5%)	58.85	32.52	98.65	66.30	124.70
CV (%)	34.5	31.28	28.42	39.86	38.90
P value					

[1]Seed tuber classification (Diameter in millimeters): 200≤S1≤350; 350<S2≤450; 450<S3≤550 and S4>550
[2]DAE=Days after emergence
Within a column, means not sharing a common superscript are significantly different (P<0.05)

Table IX: Effect of plant population on leaf development (number of leaves per plant)

Plant population (E)[1]	Leaf number/ plant 10 DAE[2]	Leaf number/plant 20 DAE	Leaf number/ plant 30 DAE	Leaf number/ plant 60 DAE	Leaf number/ plant 90 DAE
E1	23.0[a]	107.3[a]	232.0[a]	455.5[a]	317.8[a]
E2	23.8[a]	136.3[a]	257.8[b]	338.0[b]	477.0[b]
E3	23.0[a]	143.8[a]	254.0[b]	531.5[a]	521.3[b]
LSD (5%)	18.5	16.9	23.62	83.22	120
CV (%)	1.99	14.93	5.62	22.07	24.40
P value	0.05	0.05	0.05	0.05	0.05

[1]Plant population classification (Plants per hectare):E1=24,600; E2=37,000; E3=74,000
[2]DAE=Days after emergence
Within a column, means not sharing a common superscript are significantly different (P<0.05)

plant population density levels. The crop established at 90 by 15 cm produced larger but fewer tubers than that established at 90 by 30 cm or at 90 by 45 cm in decreasing order. Yield performance was greatest at the medium density (90 by 30 cm) level, followed by plants established at 90 by 45 cm density level. This was due to the availability of adequate space for root and tuber expansion and less competition for light, water and nutrients (Wurr *et al*., 1993). Significant differences in yield at 90 by 30 cm and 90 by 45 cm can be attributed to high plant population per plot for plants established at 90 by 30 cm compared to lower plant density at 90 by 45 cm. Lower yields at 90 by 15 cm across the four seed sizes were attributed to greater competition for water and nutrients and generally less room for root or tuber development at this population density. Few, but larger tubers were produced here and tuber initiation occurred later compared to plants established at 90 by 30 cm and 90 by 45 cm density levels. Tuber yield was the least for plants established at the highest density (90 by 15 cm) level across all seed sizes, because of the greater competition for growth resources and can also be attributed to mutual shading among leaves (Evans, 1975). Lower shaded leaves produce less metabolites compared to upper leaves, which directly intercepted light (Kooman *et al*., 1996). The net productivity of plots with plants established at 90 by 30 cm in terms of yield performance was greater than that exhibited at 90 by 45 cm, because at 90 by 45 cm, there is wastage of space and no maximization of productivity.

In order to maximize yield performance in potatoes, it is recommended that specific seed sizes should be planted at specific plant population densities (Entz & LaCroix, 1984; Creamer *et al*., 1999; Bussan *et al*., 2007). Results from this experiment showed the importance of lengthening the tuber-bulking period by ensuring that the crop establishes earlier in the growing season and was able to produce a superior photosynthetic surface that can support tuber growth. At the same time haulm growth should not be excessive, as this will have negative effects on normal growth of potato tubers (Baker *at al*., 1980; MacLean, 1984). It can be recommended that preference be put on medium to large seed potato tubers that have greater meristematic capital and are able to facilitate quick haulm establishment.

The potato cultivar B.P.1 is recommended for both commercial and small-holder production because it is high yielding, medium maturing (95-105 days), sprouts evenly and is fairly resistant to serious potato diseases like late blight (*Phytophthora infestans)* and potato viruses, X and Y (PVX & PVY). Zimbabwe's growing season is 110 days long under rain-fed conditions (Barnes, 1981). For these reasons, the crop variety fits well into the growing season and fits well into the summer growing season and can be produced on an economical level, with less irrigation costs and less chances of crop failure through disease occurrences.

Knowing the interval between tuber initiation in a seed crop and the subsequent commercial crop gives the growers more control over tuber size and number (Barnes, 1981; Carvalho, 1989). The seeding rate for potato production is based on weight (2 t/ha), and as such maximum yield performance is achieved through the selection of medium (S2), large (S3) to very large (S4) seed tubers. Crops growing from this size establish earlier and result in the production of numerous but smaller tubers. Crops derived from these three categories of seed size have a longer gap between tuber initiation and maturity, which results in the production of more stems and tubers. Hence, farmers need to have a bias towards these three seed tubers sizes if they intend to get maximum returns from their crop.

Leaf area: Higher leaf area values for medium density (90 by 30 cm) treatments and for sparse/ low density (90 by 45 cm) treatments was related to the seed size. It suffices to say that there was a significant ($p < 0.05$) difference in leaf area for the three planting density levels, with crops established at high density (90 by 15 cm) having the lowest mean leaf area values, followed by plants grown at medium population density level (Table II). Very large (S4) seed contributed the highest leaf area values across all population density levels in comparison to S1, S2 and S3 seed classes. The trend was such that the bigger the seed piece, the greater the leaf area (Table I).

Leaf area values were significantly ($P<0.05$) different at 30, 60 and 90 days after planting for the three population density levels (app. 12, 15 & 18) and gradually increased with time. Higher leaf area values corresponded with yield performance across all seed sizes and plant density level (Table I, II & IV). Leaf area increased gradually up to 60 DAE but slightly decreased at 90 DAE. Leaf area increased gradually up to 60 DAE. Leaf area values decreased at 90 DAE as the crop reached maturity (Table I & II). This was a result of leaf senescence as the crop reached maturity. Generally, yield was positively correlated to leaf area and increased linearly as leaf area increased. Lowest leaf area values were recorded across all seed sizes planted at the highest crop density (90 by 15 cm) whereas highest values were recorded at 90 by 30 cm for all seed classes.

Since the size of seed tubers had an effect on crop establishment, it followed that plants from larger seed tubers had greater leaf area values compared to smaller seed. Leaf area at 10 DAE was significantly ($p<0.001$) affected by seed size, while population density had no significant effect on leaf area at 10 DAE. It follows that large seed potato tubers, with their relatively larger food reserves, produced large plants, which established faster and produced vigorous seedlings. Leaf area production was highest in plants from very large seed tubers, decreasing almost uniformly as we moved from large, medium to small seed tubers. This phenomenon was attributed to the efficient allocation of more biomass in larger than in small seed tubers.

Plant population density (E) had an impact on above ground biomass production, specifically leaf area production, with plants grown at a spacing of 90 by 45 cm exhibiting highest haulm growth values across all seed sizes. Plant population density also had no significant influence on leaf area at 10 DAE because there was no competition for growth resources, no mutual shading or lower leaf shading in the whole field (app.9). It was only after 30 DAE that both seed size and population density significantly affected leaf area development and consequently leaf number per plant. Leaf area was lower at high density (90 by 15 cm) level, followed by a density level of 90 by 30 cm and was highest at 90 by 45 cm for each seed class. The significant ($p<0.05$) differences in leaf area arose as a result of the increasing inter-plant competition for water, light and nutrients at highest density (90 by 15 cm) level. This resulted in a decrease in plant size, leaf number per plant. This was similarly reported by Kooman *et al*. (1996) and Love and Thompson-Johns (1999), where it was found that plant size significantly decreased as density increased beyond or below an optimal level.

Leaf number: Leaf number was significantly ($p<0.05$) different for the twelve treatment combinations at 30, 60, and 90 DAE (Table IX). Leaf number, which significantly influenced leaf area, also influenced tuber yield (kg/ha) for each seed category where plants from 90 by 45cm density produced higher leaf area values, followed by plants from 90 by 30 cm, with least values recorded for 90 by 15 cm density level.

Number of potato tubers: Seed tuber size significantly influenced the number of potato tubers formed at 30 DAE (Table IV). Number of tubers initiated at 30 days after emergence significantly ($p<0.05$) differed depending on seed size and population density. More tubers were formed from larger seed tubers and the number increased from S1 to S4. As a consequence, the bulking period was greater in larger seed across all plant densities. Similar results were previously reported by Wurr (1974) after the author’s study on some effects of seed size and spacing on yield, grades and bulking rate of two potato varieties. Plants from large and very large seed tubers were not significantly different in terms of the number of tubers formed at 30 DAE. This phenomenon was attributed to more vigorous and rapid growth of larger than smaller seed potato tubers.

Tuber numbers were significantly affected by plant population density, with the highest density (90 by 15 cm) plants having a lower number of tubers per plant at 30 DAE. The highest number of tubers was found from plants spaced at 90 by 45 cm, followed by plants spaced at 90 by 30 cm. Space availability has an imposing effect on number of tubers formed. The greater the space, the higher the number of tubers formed (Gulluoglu & Arioglu, 2009).

Stem number: Stem number significantly ($p<0.001$) differed among the four seed sizes (S) and the three planting density levels (Table V). Higher stem numbers were recorded in plants established from larger than smaller tubers. Stem number was also related to crop density with highest stem numbers being produced at 90 by 30 cm, followed by crop planted at 90 by 45 cm and was lowest at the highest density plantings of 90 by 15 cm. Differences in stem numbers progressively increased with time as there were significant differences in the means for stem number per plant at 30 ($p<0.001$) to 90 ($p<0.001$) DAE compared to 10 ($p<0.05$) and 20 ($p<0.05$) DAE.

There was a significant difference in stem number per plant across the four seed sizes and density levels as small tubers (S1) produced fewer stems per plant than large (S3) and very large (S4) tubers. This phenomenon was due to the initial difference in sprout number between the four seed sizes whereby large and very large seed had a greater number of sprouts compared with small to medium sized seed potato tubers. The phenomenon of varying stem number based on different size tubers was also reported by some researchers, where larger seed tubers were found to produce a greater number of sprouts than smaller seed tubers and a correspondingly greater number of stems per plant (Barry *et al*., 1990; Gulluoglu & Arioglu, 2009). Population density had a highly significant influence on the subsequent development of secondary stems. Stem number was reduced at high plant density level, 90 by 15 cm increasing significantly at 90 by 30 cm and 90 by 45cm respectively. Under more intensive competitive conditions like those experienced at the highest density level of 90 by 15 cm, there is an earlier on set of inter plant competition for growth resources such as light, water and nutrients, this resulted in a decrease in relative growth rate. Limited space for root and tuber expansion consequently reduced stem number and development at the high-density spacing levels (Wurr *et al*., 1993). Differences in stem numbers progressively increased with time, as there were significant differences in the mean stem number at 30 to 90 DAE compared to those recorded at 10 and 20 DAE. Stem number per plant was lower in plants established from small(S1) tubers because of their small initial meristematic 'capital' which significantly reduced the capacity of the plant to produce vigorous main and secondary stems (Evans, 1975).

CONCLUSION

This study showed that the final size and number of tubers produced per plant was governed by seed size. There was a uniform gradation, where by very large (S4) seeds emerged earlier to establish a crop stand followed by large (S3), S2 and lastly S1 seed tubers. Plant population density had no influence on the number of days to emergence. Yield performance (kg/ha) was greatest at a plant population density level of 90 by 30 cm, followed by that of 90 by 45 cm and the least at 90 by 15 cm, across all seed sizes.

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(Received 13 October 2011; Accepted 13 March 2012)