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Original article

Effects of planting times and plant densities of top-shoot cuttings on multiplication of breeder seed potato

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ABSTRACT

Top-shoot cuttings were planted with the whole tuber (as a control) at different dates using three spacings at the Horticultural Research Farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University to evaluate the performance of top-shoots as planting material and to determine the optimum time of planting and the optimum spacing for top-shoot cuttings as planting material for breeder seed production. The survival of top shoot cuttings was more than 97.8% irrespective of the planting time and plant spacing. Significant variations were found among the treatment combinations for plant height at 45 and 60 days after planting (DAP), foliage coverage at 45 and 60 DAP, number of branches per plant, number of tubers per plant, individual tuber weight, tuber yields per plant and per hectare yield. The highest mean yield (46.57 t/ha) was produced by whole tubers planted on 10 November with 50 × 10 cm spacing which was similar to whole tubers planted on 1 November with 50 × 10 cm spacing. On the other hand, plants from top-shoot cuttings yielded 34.82 t/ha in T_3S_2 followed by T_1S_1 (33.34 t/ha), T_3S_3 (30.70 t/ha). The total yield of potato increased 122.8% from a single, early crop due to taking two repeated cuttings compared with 89.6% from a single late crop. Early planting of top-shoot cuttings with closer spacing (50 × 10 cm and 50 × 15 cm) is recommended for the multiplication of breeder seed potato.

Introduction

Potato (*Solanum tuberosum* L.) is the most important food crop following wheat and rice in the world (Camire et al., 2009). In Bangladesh, it ranks first among vegetables with an area, production and average yield of 0.46 million ha, 8.33 million t and 18.10 t/ha, respectively (Hortex Newsletter, 2011). Increased yields from potato cultivation mostly depend on the availability of sufficient quantities of good quality seed potatoes and the annual seed potato requirement of the country is about 0.60 million t (Bangladesh Agriculture Development Corporation, 2012). Out of the total requirement, the Bangladesh Agriculture Development Corporation (BADC) supplied only 18,899 t (3.16%) in 2010–2011 that was used by the farmers as replacement stock (Bangladesh Agriculture Development Corporation, 2012). Seed tuber is the most important planting material used in the country (Sarath et al., 2001). Potato can be grown from several types of propagating material including sprout cutting (Hossain et al., 1999) top-shoot cutting or stem segments with at least one bud in true potato seed (Hossain, 1995). In Bangladesh, as there is a scarcity in production and supply of quality seed potatoes, there is scope for the rapid multiplication of seed potatoes by using top-shoot cuttings as planting material instead of the whole tuber. It has been reported that early-planted, top-shoot cuttings produced more tubers per plant with a greater mean tuber weight than from late planting (Hossain, 1993, 1997). However, top-shoot cuttings are not being used by the farmers for table potato production. Farmers can take top-shoot cuttings from the plants grown at medium to high elevations and can use them as propagating material for cultivating potato on lower land, thus reducing the seed cost. This method

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could be expanded to provide farmers with appropriate production technology.

Potato is grown during winter (from middle of November to middle of February) as a cash crop all over Bangladesh and the length of the growing period is relatively short at around 90 d (Rashid et al., 1986). During the crop growth period, low temperatures after planting as well as during the early growth stages and high temperatures during the tuber bulking stage significantly reduce the growth and yield of potato, respectively, because the winter duration (end of November to end of January) is very short in Bangladesh (Rashid, 1999). Winter lasts longer in northern Bangladesh and this is an advantage in producing potatoes (Rashid et al., 1986). Consequently, the application of proper management practices to enhance vigorous early growth is very important in achieving a higher tuber yield of potato under these environmental conditions. Optimizing the plant density is one of the most important goals of potato production, because it affects the seed cost, plant development, yield and quality of the crop (Bussan et al., 2007). In practice, plant density in the potato crop is manipulated through the number and size of the seed tubers planted (Allen and Wurr, 1992). Therefore, many studies have been conducted to establish the optimal combination of seed size and planting distance for a certain environment (Sultana and Siddique, 1991; Negi et al., 1995; Creamer et al., 1999; Hoque, 2001; Bussan et al., 2007). These authors have reported that in general, larger seed and closer spacing up to a certain limit increase the yield of tubers per unit area. The yield increased with a decrease in spacing from 25 to 20 cm in the rows and 55 cm between rows (Banarjee et al., 1988). However, the optimal planting density differed depending on the environmental conditions and cultivars. Farmers in Bangladesh generally plant cut tubers with one or two eyes at closer densities and the plant density varies from location to location. However, the Tuber Crops Research Centre (TCRC) of Bangladesh Agricultural Research Institute (BARI) recommends planting at 60 × 25 cm for whole tuber planting (Hussain et al., 2006). On the other hand, planting large seed tubers is advantageous under certain circumstances such as unfavorable soil and weather conditions at planting, if the growing season is short (Beukema and Zaag, 1990). Thus the current experiment was designed to evaluate the performance of top-shoot cuttings planted under different plant spacing at different times on the yield of potato. The objectives were: 1) to evaluate the performance of top-shoot cuttings as planting material in seed potato production and 2) to determine the optimal planting time with the optimal spacing of top-shoot cuttings for potato production.

Materials and methods

Top-shoot cuttings were evaluated, as planting material, under different planting times and spacings for rapid multiplication of potato at Bangabandhu Sheikh Muijubur Rahman Agricultural University during winter 2011. Top-shoot cuttings of the standard potato variety Diamant were used in the experiment. The breeder seed tuber was collected from TCRC, BARI, Joydebpur. Whole tubers were used as the control. The experiment was laid out in a randomized complete block design with two factors (planting time and spacing) and three replications. The plot size was 1.50 × 1.20 m. Planting times were: T_1 = whole tuber planting on 1 November (Control1), T_2 = whole tuber planting on 1 November; T_3 = first cutting (from T_2) planted on 25 November; T_4 = second cutting (from T_2) planted on 5 December; T_5 = whole tuber planted on 10 November (Control2); T_6 = whole tuber planted on 10 November; T_7 = first cutting (from T_6) planted on 5 December and T_8 = second cutting (from T_6) planted on 15 December. Three spacings—S_1 (50 × 10 cm), S_2 (50 × 15 cm) and S_3 (50 × 20 cm)—were used for each treatment. The seed tubers were kept in a well-ventilated room and allowed to sprout under light (at night) to obtain healthy, green sprouts prior to planting. It required 8–10 d for sprouting. The sprouted tubers were planted on 1 November (T_1 and T_2) and 10 November (T_5 and T_6). T_1 and T_5 were treated as controls for producing normal crops. T_2 and T_6 were used as sources of top-shoot cuttings. The first top-shoot cuttings with at least two nodes were taken from T_2 at 25 days after planting (DAP) and were used as planting material for T_3. Second cuttings were taken from T_2 at 10 d after first cutting and were used as planting material for T_4. Cuttings were taken using a slant cut with a sharp blade and the cut end was immersed in water immediately. Then, the shoot cuttings were planted in the main plot after being treated with rooting hormone (napthalene acetic acid at 16 parts per million). Before planting the shoot cuttings in the experimental plots, the plots were irrigated properly so that when the cut portion was in contact with the soil it could absorb moisture. Similarly, top-shoot cuttings were taken from T_6 and were used as planting material for T_7 and T_8 on 5 December and 15 December, respectively. Full doses of cow dung (10 t/ha), triple superphosphate (220 kg/ha), muriate of potatsh (270 kg/ha), gypsum (120 kg/ha), boric acid (6 kg/ha) and a half dose of urea (175 kg/ha) were applied at final land preparation. The remaining half dose of urea (175 kg/ha) was applied as top dressing at 30 DAP followed by earthing-up and light irrigation. The ridge method was used for whole tuber planting (T_1, T_2, T_5 and T_6 treatments). Healthy cuttings were used as top-shoot cuttings and were planted in a well-watered flat bed. After establishment of the shoot cuttings, a ridge was made by earthing-up the sides. Intercultural operations such as weeding and earthing-up were done manually. After spading the soil between the rows, weeds were removed. Earthing-up was done twice during the growing period. The first earthing-up was done at 30 DAP when the plants had attained a height of about 15–20 cm from the base; the second was 20 d after the first earthing-up. Before the first earthing-up, urea was applied. Irrigation was applied five times. The first irrigation was applied at 2 wk after planting, the second just after earthing-up (30 DAP), the third at 45 DAP, the fourth at 60 DAP and the last at 75 DAP. During land preparation, Furadan 5G (10 kg/ha) was applied basally during land preparation and Malathion (0.2%) was sprayed in two installments at 45 and 60 DAP to control insects. The crops were also sprayed with Dithane-M 45 (0.2%) and Secure (0.1%) alternately five times (at 30, 40, 50, 60 and 70 DAP, respectively) to prevent late blight infection of potato (Dey et al., 2010). Haulm pulling was done at 80 DAP in every treatment. Hardening of tubers and setting up of the skin of tubers were allowed for 10 d under the soil; thereafter the crop was harvested at 90 DAP. During the growing period, the maximum and minimum temperature was recorded and the results are presented in Table 1. Data on different plant and yield contributing characters were recorded and were analyzed statistically using the computer package MSTATC (developed by the Department of Crop and Soil Sciences, Michigan State University, East Lansing, MI, USA). Significance between treatments and interactions was tested using Duncan's multiple range test at the $p < 0.05$ level.

Results and discussion

Plant survival

The planting time and plant density of top-shoot cuttings had no significant effect on plant survival. The survival of top-shoot cuttings was more than 97.8% irrespective of the planting time and plant density while for whole tubers, survival was 100%. There were no significant interaction effects on plant survival (Table 2). The higher survival percentage might have been due to the use of the

Table 1
Soil and air temperatures and other climatic conditions inside the vinyl house during growing period.

Month	Air temperature (°C)			Soil temperature (°C)			Humidity (%)	Rainfall (mm)	Evaporation (mm)
				Soil depth					
	Max.	Min.	Ave.	10 cm	20 cm	30 cm			
November	27.76	23.76	25.76	26.55	26.91	27.33	85.66	0.00	55.06
December	24.80	16.58	20.69	22.72	23.17	23.56	90.70	5.19	208.15
January	22.32	11.53	16.93	18.85	19.34	19.84	89.81	0.00	1.37
February	27.31	13.24	20.28	20.03	20.45	20.83	87.66	0.00	3.60
March	32.58	20.68	26.63	23.53	23.97	24.42	83.94	0.00	4.03

hormone for rapid rooting of top-shoot cuttings which helped with quicker establishment. Proper care and intensive management during the establishment period resulted in high plant survival. A similar finding of plant survival for top-shoot cuttings was reported by Yasmin (2008).

Plant vigor

Plant vigor decreased with delaying of planting. The plants produced from whole tubers had more benefits than cuttings because whole tubers had more reserve food which was utilized by the plant for its early growth. On the other hand, the plants produced from the top-shoot cuttings did not get such support and it took more time to establish roots, after which nutrient was absorbed from soil. There was no significant variation in plant vigor due to the interaction effect of planting time and the density of top-shoot cuttings (Table 2). The highest plant vigor (8.0) was found in T_1S_1, T_5S_1, T_6S_3 and T_7S_2 while the lowest vigor (5.0) was obtained from T_8S_2. In the T8 treatment, plant vigor ranged from 5.0 to 5.5—these values were comparatively lower than in other treatments due to late planting of the top-shoot cuttings and the low temperature.

Plant height

A significant interaction between planting time and spacing was found with plant height at 45 and 60 DAP (Table 3). During the growth period of 45 d, the tallest plants (mean 58.9 cm) were in T_1S_1 followed by other treatment combinations and there were no significant differences between T_1S_1 (58.9 cm), T_1S_3 (57.9 cm) and T_5S_1 (55.5 cm). The smallest plants were observed in T_8S_3 (27.5 cm) which were similar to T_8S_1 (28.1 cm) and T_8S_2 (29.4 cm). However, at 60 DAP, the greatest mean plant height was observed in T_5S_3 (74.6 cm) which was similar to T_5S_2 (72.1 cm), T_5S_1 (71.0 cm) and T_1S_1 (69.8 cm). The variation in plant height due to the influences of different treatment combinations may have been due to the variation in temperature and light during the growing periods. The tallest plant height at the closest spacing might have been due to the irradiation effect on plant population density. Similar findings were also reported by Yasmin (2008).

Table 2
Interaction effects of planting time and plant spacing on survival and plant vigor at 45 days after planting (DAP).

Treatment combination	Survival (%)			Plant vigor at 45 DAP		
	S_1	S_2	S_3	S_1	S_2	S_3
T_1	100.0	100.0	100.0	8.0	7.8	7.8
T_2	100.0	100.0	100.0	7.8	7.6	7.3
T_3	100.0	100.0	100.0	6.6	6.3	6.3
T_4	98.1	97.2	100.0	7.8	7.6	7.6
T_5	100.0	100.0	100.0	8.0	7.6	7.8
T_6	100.0	100.0	100.0	7.8	7.5	8.0
T_7	100.0	97.2	98.1	7.6	8.0	7.5
T_8	93.5	100.0	100.0	5.3	5.0	5.5
Level of significance	NS			NS		
CV (%)	2.02			7.23		

T_1 = Whole tuber planting on 1 November (Control1), T_2 = Whole tuber planting on 1 November; T_3 = First cutting (from T_2) planted on 25 November; T_4 = Second cutting (from T_2) planted on 5 December; T_5 = Whole tuber planted on 10 November (Control2); T_6 = Whole tuber planted on 10 November; T_7 = First cutting (from T_6) planted on 5 December and T_8 = Second cutting (from T_6) planted on 15 December.
NS = Not significant at $p < 0.05$.
Spacing: S1 = 50 × 10 cm, S2 = 50 × 15 cm and S3 = 50 × 20 cm.
CV = Coefficient of variation.

Foliage coverage at 45 and 60 days after planting

Well-developed foliage with maximum ground coverage of a plant indicates its good growth and development (Mahmud, 2012). The interaction effects of planting time and plant density (spacing) on foliage coverage were not significant at 45 DAP and were significant at 60 DAP and the effect increased with the progression of days after planting (Table 4). Foliage coverage varied from 44.85 to 95.67% at 45 DAP. The maximum foliage coverage (95.67%) was observed in T_1S_1 and T_5S_1 followed by T_6S_1 (93.33%), T_6S_2 (91.0%) and T_3S_1 (90.0%). At 60 DAP, plants produced from different treatment combinations showed 100% foliage coverage except for T_8S_1, T_8S_3 and T_8S_2 which produced 74.0%, 63.3% and 60.0% foliage coverage, respectively. The highest foliage coverage at the closest spacing might have been due to the presence of more plants compared to the wider spacing. The result was in agreement with those of Rashid (1999) and Ranalli et al. (1994) who found higher foliage coverage with closer spacing compared to wider spacing. However, at 60 DAP, the plants at all spacing levels produced similar foliage coverage.

Branches per plant

Significant variation in the number of branches per plant was observed due to the interaction effect of planting time and planting density (Table 5). The highest mean number of branches (7.4) was found in T_2S_3 (1 November planting with 50 × 20 cm spacing) which was similar to T_6S_3 at 60 DAP. The third highest mean number of branches per plant (6.4) produced by T_2S_1 (1 November planting with 50 × 10 cm spacing) was similar to T_2S_2 (1 November with 50 × 15 cm spacing) and was followed by T_3S_3 (5.2) which was similar to T_3S_2 (5.0). The lowest mean number of branches (2.1) was found in T_5S_1, T_5S_2 and T_5S_3. November planting occurred in a congenial environment in terms of temperature and sunny days which might have influenced the vegetative growth as well as the emergence of a higher number of branches per plant in the plants from which two consecutive cuttings were taken (T_2). There was a tendency to produce higher numbers of branches per plant at lower plant density with wider spacing which may have been due to the

Table 3
Interaction effects of planting time and plant spacing on plant height at 45 and 60 days after planting (DAP).

Treatment combination	Plant height (cm) at 45 DAP			Plant height (cm) at 60 DAP		
	S_1	S_2	S_3	S_1	S_2	S_3
T_1	58.7^{a}	47.2^{bc}	57.9^{a}	69.8^{ab}	62.0^{cd}	66.5^{bc}
T_2	38.87^{fgh}	36.5^{ghi}	38.2^{fghi}	48.6^{h}	50.2^{fgh}	48.7^{gh}
T_3	45.6^{cde}	47.2^{bc}	46.8^{bcd}	53.7^{efgh}	56.2^{e}	57.6^{de}
T_4	41.2^{efg}	41.8^{def}	36.0^{ghi}	51.9^{efgh}	52.2^{efgh}	48.4^{h}
T_5	57.6^{a}	51.7^{b}	51.8^{b}	71.0^{ab}	72.1^{a}	74.6^{a}
T_6	42.2^{cdef}	36.4^{ghi}	33.47^{ij}	53.9^{efgh}	49.7^{gh}	54.6^{efg}
T_7	42.5^{cdef}	44.1^{cde}	35.2^{hi}	49.2^{gh}	55.5^{ef}	49.3^{gh}
T_8	28.1^{k}	29.4^{ijk}	27.5^{k}	34.0^{i}	35.2^{i}	32.0^{i}
Level of significance	**			**		
CV (%)	6.65			5.62		

T_1 = Whole tuber planting on 1 November (Control1), T_2 = Whole tuber planting on 1 November; T_3 = First cutting (from T_2) planted on 25 November; T_4 = Second cutting (from T_2) planted on 5 December; T_5 = Whole tuber planted on 10 November (Control2); T_6 = Whole tuber planted on 10 November; T_7 = First cutting (from T_6) planted on 5 December and T_8 = Second cutting (from T_6) planted on 15 December.
Spacing: S_1 = 50 × 10 cm, S_2 = 50 × 15 cm and S_3 = 50 × 20 cm.
Means with the same letter do not differ significantly. ** = Significant at $p < 0.01$.
CV = Coefficient of variation.

Table 4
Interaction effects of planting time and plant spacing on foliage coverage at 45 and 60 days after planting (DAP).

Treatment combination	Foliage coverage at 45 DAP			Foliage coverage at 60 DAP		
	S_1	S_2	S_3	S_1	S_2	S_3
T_1	95.67	87.67	83.33	100.0^{a} (90)	100.0^{a} (90)	100.0^{a} (90)
T_2	89.33	87.00	80.67	100.0^{a} (90)	100.0^{a} (90)	100.0^{a} (90)
T_3	90.00	72.33	66.00	100.0^{a} (90)	100.0^{a} (90)	100.0^{a} (90)
T_4	83.33	81.67	66.67	100.0^{a} (90)	100.0^{a} (90)	100.0^{a} (90)
T_5	95.67	91.67	86.67	100.0^{a} (90)	100.0^{a} (90)	100.0^{a} (90)
T_6	93.33	91.00	84.00	100.0^{a} (90)	100.0^{a} (90)	100.0^{a} (90)
T_7	88.33	80.00	66.67	100.0^{a} (90)	100.0^{a} (90)	100.0^{a} (90)
T_8	63.33	51.00	48.33	74.0^{b} (59.3)	60.0^{d} (50.8)	63.3^{c} (52.8)
Level of significance	NS			**		
CV (%)	7.24			10.70		

T_1 = Whole tuber planting on 1 November (Control1), T_2 = Whole tuber planting on 1 November; T_3 = First cutting (from T_2) planted on 25 November; T_4 = Second cutting (from T_2) planted on 5 December; T_5 = Whole tuber planted on 10 November (Control2); T_6 = Whole tuber planted on 10 November; T_7 = First cutting (from T_6) planted on 5 December and T_8 = Second cutting (from T_6) planted on 15 December.
Spacing: S_1 = 50 × 10 cm, S_2 = 50 × 15 cm and S_3 = 50 × 20 cm.
Figures in parentheses indicates the arcsine value.
Means with the same letter do not differ significantly. ** = significant at $p < 0.01$; NS = not significant at $p < 0.01$; CV = coefficient of variation.

Table 5
Interaction effects of planting time and plant spacing on number of branches and tuber per plant.

Treatment combination	Number of branches per plant			Number of tubers per plant		
	S_1	S_2	S_3	S_1	S_2	S_3
T_1	3.1^{ghi}	3.1^{g-i}	2.9^{hi}	10.00^{a}	8.00^{bcd}	8.00^{bcd}
T_2	6.4^{b}	6.1^{b}	7.4^{a}	9.33^{ab}	8.00^{bcd}	7.33^{cd}
T_3	3.8^{defg}	5.0^{c}	5.2^{c}	3.67^{ef}	3.33^{ef}	4.00^{e}
T_4	3.0^{hi}	3.5^{f-h}	4.3^{d}	3.67^{ef}	3.33^{ef}	4.00^{e}
T_5	2.1^{k}	2.1^{k}	2.1^{k}	10.00^{a}	7.00^{cd}	6.67^{d}
T_6	4.2^{de}	5.3^{c}	7.1^{a}	8.67^{a-c}	7.67^{b-d}	8.33^{abcd}
T_7	3.2^{fghi}	3.6^{efgh}	3.3^{fghi}	3.33^{ef}	3.33^{ef}	3.67^{ef}
T_8	2.8^{ij}	3.5^{efgh}	3.9^{def}	3.67^{ef}	2.67^{ef}	2.00^{f}
Level of significance	*			*		
CV (%)	7.14			10.91		

T_1 = Whole tuber planting on 1 November (Control1), T_2 = Whole tuber planting on 1 November; T_3 = First cutting (from T_2) planted on 25 November; T_4 = Second cutting (from T_2) planted on 5 December; T_5 = Whole tuber planted on 10 November (Control2); T_6 = Whole tuber planted on 10 November; T_7 = First cutting (from T_6) planted on 5 December and T_8 = Second cutting (from T_6) planted on 15 December.
Spacing: S_1 = 50 × 10 cm, S_2 = 50 × 15 cm and S_3 = 50 × 20 cm.
Means with the same letter do not differ significantly. * = Significant at $p < 0.05$.
CV = Coefficient of variation.

availability of nutrients and more space for growth and development. The present findings were in agreement with Sultana and Siddique (1991) and Hossain (1995).

Number of tubers per plant

Different treatment combinations produced a significant effect on the number of tubers per plant (Table 5). The maximum mean numbers of tubers per plant (10.00) were found in T_1S_1 and T_5S_1 which were similar to T_2S_1 (9.33), T_6S_1 (8.67) and T_6S_3 (8.33). A lower number of tubers per plant was obtained from T_8S_3, T_8S_2, T_8S_1, T_7S_3, T_7S_2, T_7S_1, T_4S_1, T_4S_2, T_3S_1 and T_3S_2 which performed similarly. It was clear that plants obtained from whole tubers produced more tubers than did cuttings because plants from whole tubers did not face any obstacles in producing stolons whereas the plants produced from top-shoot cuttings took some time to become established which may have delayed the process of stolonization resulting in a lower number of tubers per plant. This finding was in agreement with Yasmin (2008).

Individual tuber weight

The interaction effect of treatment combination on mean individual tuber weight was significant (Table 6) and varied from 104.9

Table 6
Interaction effects of planting time and spacing on mean individual tuber weight and yield per plant.

Treatment combination	Individual tuber weight (g)			Yield per plant (g)		
	S_1	S_2	S_3	S_1	S_2	S_3
T_1	22.8^{h}	36.2^{efgh}	52.8^{def}	225.5^{gh}	292.1^{e}	415.0^{a}
T_2	18.2^{h}	32.0^{fgh}	50.1^{def}	170.1^{i}	257.4^{f}	355.6^{c}
T_3	47.2^{defg}	83.5^{b}	74.3^{bc}	166.7^{i}	261.1^{f}	307.0^{de}
T_4	36.6^{efgh}	61.2^{cd}	63.2^{cd}	130.9^{j}	207.4^{h}	231.3^{g}
T_5	23.6^{h}	46.8^{defg}	57.6^{cd}	232.9^{g}	323.9^{d}	379.3^{b}
T_6	23.2^{h}	33.9^{fgh}	45.1^{defg}	207.4^{h}	263.9^{f}	358.9^{c}
T_7	34.9^{fgh}	57.7^{cd}	84.4^{b}	110.8^{k}	183.2^{i}	264.3^{f}
T_8	27.6^{gh}	56.2^{cde}	104.9^{a}	86.70^{l}	138.7^{j}	208.3^{h}
Level of significance	*			**		
CV (%)	12.26			11.86		

T_1 = Whole tuber planting on 1 November (Control1), T_2 = Whole tuber planting on 1 November; T_3 = First cutting (from T_2) planted on 25 November; T_4 = Second cutting (from T_2) planted on 5 December; T_5 = Whole tuber planted on 10 November (Control2); T_6 = Whole tuber planted on 10 November; T_7 = First cutting (from T_6) planted on 5 December and T_8 = Second cutting (from T_6) planted on 15 December.
$S_1 = 50 \times 10$ cm, $S_2 = 50 \times 15$ cm and $S_3 = 50 \times 20$ cm.
Means with the same letter do not differ significantly. ** = Significant at $p < 0.01$ and * = Significant at $p < 0.05$.
CV = Coefficient of variation.

to 18.20 g. The maximum mean individual tuber weight (104.9 g) was found in T_8S_3 followed by T_7S_3 (84.47 g) which was similar to T_3S_2 (83.5 g) and T_3S_3 (74.3 g). The lowest mean individual tuber weight (18.2 g) was found in T_2S_1. The highest mean individual tuber weight may have been the result of fewer tubers being produced after late planting so the tubers had sufficient space and nutrient for bulking up at the wider spacing. On the other hand, the minimum mean individual tuber weight was found in early planting at closer spacing and may have been due to the greater production of tubers per plant where they faced inter-plant competition for space, light and nutrient. Similar findings in individual tuber weight per plant were reported by Mahmud et al. (2012) and Sarker et al. (2011).

Yield per plant

The yield per plant varied significantly due to the different treatment combinations (Table 6). The treatment combination T_1S_3 (1 November planting with 50 × 20 cm spacing) produced the maximum yield (415.0 g) followed by T_5S_3 (379.3 g), T_6S_3 (358.9 g) and T_2S_3 (355.6 g) where whole tubers were used as planting material. When top-shoot cuttings were used as planting material, the highest tuber yield per plant (307.0 g) was obtained from T_3S_3 and the lowest tuber yield per plant (86.77 g) was obtained from the T_8S_1 combination.

Tuber production per plant was directly correlated with the number of main stems per plant and was significantly affected by inter-plant and intra-plant competition (Moorby, 1967; Bussan et al., 2007). Hossain (1995) reported that the weight of tubers per plant increased significantly at wider spacing which corroborates the present findings. Mauromicale et al. (2003) stated that planting of potato at very close spacing resulted in lower tuber yield per plant due to increasing inter- and intra-plant competition. Similar findings of higher yield in whole tubers with wider spacing have been reported by Khurana et al. (1994).

Yield

Significant variation in the yield per hectare was observed due to the influence of planting time and plant spacing (Figs. 1–2). Considering planting times, significant variations were found for tuber yield ranging from 18.89 to 42.56 t/ha. The mean highest tuber yield was found in T_5 (42.56 t/ha) followed by T_1 (41.84 t/ha), with T_8 being the lowest. For crops planted using whole tubers, the highest yield (46.57 t/ha) was produced by T_5S_1 which was similar to T_1S_1. On the other hand, the yield per hectare of crops produced from top-shoot cuttings was highest (34.82 t/ha) in T_3S_2 followed by T_3S_1 (33.34 t/ha), T_3S_3 (30.70 t/ha), T_4S_2 (27.65 t/ha), T_4S_1 (26.17 t/ha) and T_4S_3 (23.13 t/ha) as shown in Fig. 2. The lowest yield per hectare was obtained from T_8S_1 (17.35 t/ha). The highest yield at the closest spacing might have been due to the presence of the greatest number of plants. Foliage coverage increased with an increase in the plant density which was found to be related to higher tuber yield (Bremner and Radley, 1966). Mahmud et al. (2012) reported closer spacing increased the yield and that a higher foliage coverage percentage increased the yield by increasing the leaf area index and the photosynthetic area which favors production and the accumulation of more photosynthates in the tuber. Ranalli et al. (1994) reported a higher yield at close spacing compared to wide spacing which agreed with the present findings. Many authors have reported similar effects of row spacing on yield components and tuber yield under different production systems (Hoque, 2001; Malik et al., 2002; Bussan et al., 2007; Mahmud et al., 2012).

Early planted top-shoot cuttings performed best with respect to plant vigor, foliage coverage, plant height, number of branches per

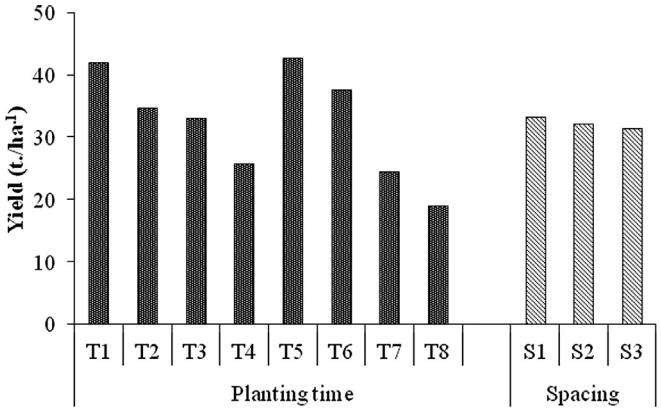

Fig. 1. Effect of planting time and spacing on tuber yield. T_1 = Whole tuber planting on 1 November (Control1), T_2 = Whole tuber planting on 1 November; T_3 = First cutting (from T_2) planted on 25 November; T_4 = Second cutting (from T_2) planted on 5 December; T_5 = Whole tuber planted on 10 November (Control2); T_6 = Whole tuber planted on 10 November; T_7 = First cutting (from T_6) planted on 5 December and T_8 = Second cutting (from T_6) planted on 15 December. Spacing: $S_1 = 50 \times 10$ cm, $S_2 = 50 \times 15$ cm and $S_3 = 50 \times 20$ cm.

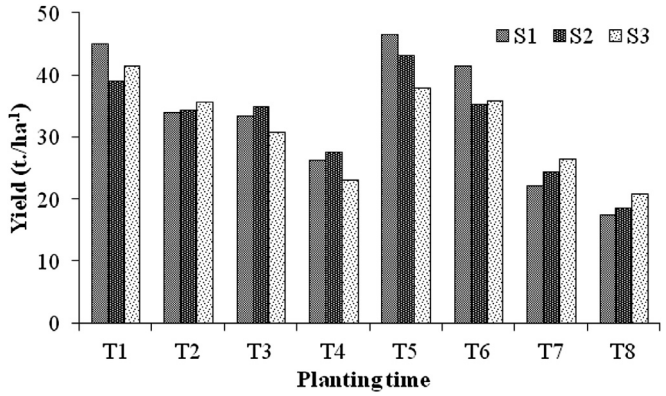

Fig. 2. Interaction effects of planting time and spacing on tuber yield. T_1 = Whole tuber planting on 1 November (Control1), T_2 = Whole tuber planting on 1 November; T_3 = First cutting (from T_2) planted on 25 November; T_4 = Second cutting (from T_2) planted on 5 December; T_5 = Whole tuber planted on 10 November (Control2); T_6 = Whole tuber planted on 10 November; T_7 = First cutting (from T_6) planted on 5 December and T_8 = Second cutting (from T_6) planted on 15 December. Spacing: $S_1 = 50 \times 10$ cm, $S_2 = 50 \times 15$ cm and $S_3 = 50 \times 20$ cm.

plant, number and weight of tubers per plant and yield. Early planting of top-shoot cuttings at the closest spacing performed better with good foliage coverage, plant height and per hectare yield, whereas late planting of top-shoot cuttings at the widest spacing produced inferior results. Earlier planting (25 November) of top-shoot cuttings at closer spacings (50×10 cm and 50×15 cm) is recommended for multiplication of breeder seed potato.

Conflict of interest

No conflict of interest.

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