Economic feasibility of potato production influenced by intra-row plant spacing under mango-based agroforestry system

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Abstract

For ensuring the food security and maximum use of land, the potato production under a mango-based agroforestry system is an effective production approach. The purpose of this study was to assess the yield potential and the economic benefits of potato production under a mango-based agroforestry system. The potato tubers were planted in a 10-year-old mango orchard and open field condition. The experiment was laid out following a split plot design with three (3) replications. Potato production system under mango orchard and open field were arranged in main plots T_0 = potato sole cropping (control) and T_1 = potato under mango-based agroforestry system. On the other hand, potato intra-row plant spacing were in sub-plots S_0 = 60 × 20 cm^2, S_1 = 60 × 25 cm^2 and S_2 = 60 × 30 cm^2. The data of yield characters of potatoes were investigated. The cost of production, gross & net return and benefit-cost ratio was calculated for economic analysis. The results show that the closest (60 x 20 cm^2) intra-row plant spacing produced the highest yield while the economic returns from potatoes grown under the mango-based agroforestry system were higher than those derived from cropped grown as a sole crop or potatoes cultivation alone (gross returns US$3508/ha, net returns US$1642/ha). Further, the benefit-cost ratio from the combined cultivation of potatoes and mangos was 2.14, which was 20 % higher than growing potatoes as a sole crop. Thus, the cultivation of potatoes under a mango-based agroforestry system offers a significant financial benefit to farmers while ensuring the sustainable use of vacant space in mango orchards.

Keywords: *Mangifera indica* L.; Monetary potentiality; Multi-production approach; Row spacing; *Solanum tuberosum* L.
Abbreviations: ANOVA_Analysis of Variance; BADC_Bangladesh Agricultural Development Corporation; BARI_Bangladesh Agricultural Research Institute; CEC_Cation Exchange Capacity; DMRT_Duncan's Multiple Range Test; DAP_Days After Planting; MEQ_ Milliequivalent; MP_Muriate of Potash; SPSS_Statistical Package for the Social Sciences; TSP_Triple Super Phosphate; US_United States; µg_microgram.

Introduction

Bangladesh is a small area of land with high demography having 163.7 million individuals (BBS, 2018). The country chiefly depends on agriculture to meet the food requirements of its inhabitants. However, the current land uses frameworks of farming and forest deficient to fulfil the needs of the 21st century. Basic circumstances, expanding interest for sustenance, human diet, animal feed and wood for construction materials are able to be filled up by customary and non-traditional agroforestry. The issue of maintaining the balance of the environment in association with food security, woody perennials combined with annual crops cultivation is an inevitable production system while keeping up or improving profitability, (Bargali et al., 2004;

Bargali et al., 2009; Pandey et al., 2011; Padalia et al., 2015) strength or in other words sustainability. Multipurpose tree-based agroforestry practices are more popular production systems in recent time (Kajal et al., 2015; Amin et al., 2017). It emphasizes the cultivation of agronomic crops together with perennial trees and shrubs (Chowdhury 1997; Miah et al., 2002). Fruit tree-based agroforestry is very popular in tropical and subtropical countries and it brings in a considerable amount of money (Zaman et al., 2016; Rahman et al., 2016; Ali et al., 2018). Potato (*Solanum tuberosum* L.) has popularity with highly demandable vegetable crops in the world (Solomon-Blackburn and Barker, 2001). It is grown well in a short-day, though it is a C_3 plant grown in the winter period, requires minimum sunlight (Demagante and

Vander Zaag, 1988). It is devoured as vegetables contributing alone as much as 54% of the complete yearly vegetable production of this nation because of its various uses. The production of potato in Bangladesh is 86,03,000 metric tons with a total area of cultivation of 4,44,000 hectares. The average yield is 19.37 metric tons per hectare and ranks first among Bangladesh's vegetables in terms of area and output (AIS, 2014). (Dagar and Singh, 2004) reported that potato yield was higher under partial shade when the crops were grown during the second year compared with control (without trees). (Yenagi et al., 2010) was conveyed that higher potato yield was found with A-grade tuber (45 cm) row spacing while the highest percentage of market yield was recorded with a row spacing of 66 and 75 cm (Bernik et al., 2002). So, both shade and spacing are the important factors for the production and marketing of the tuber potato. In recent years, farmers are more attracted to establish fruit orchards, mainly mango, due to the maximum benefits within 6 to 7 years, as it is the national tree of Bangladesh. There are more than 100 species of the genus *Mangifera* that bear edible fruit turned out to be adopted and adjusted all through the tropics and subtropics. It has a significant role in the menu of diet charts among different nations. This heavenly organic product is especially wealthy in supplements, for example, protein, nutrients, fiber, thiamine, ascorbic acid and so on. The organic product is taken as young, processed pickles, juice, bars, iced or hard products. Mango orchard covered 78196 acres of land in fruit plantation with overall production of 304187 metric tonnes in 2017 (BBS, 2017). Day by day mango orchards are increasing, especially in the northern part of Bangladesh. Most of the vacant spaces are fallow in between lines and this is the opportunity to grow vegetables like potatoes on the floor of mango orchards. The information about the production potentiality and profitability of growing potatoes under the mango trees in the northern part of Bangladesh is scant. Focusing on this point, the research work was undertaken to investigate the potatoes potentiality under the young mango orchards maintaining the intra-row plant spacing for both yield and financial benefits from a mango potato-based agroforestry approach.

Results and discussion

Effect of intra-row plant spacing on potato growth and production potentiality

Intra-row plant spacing is an important factor which focuses on a significant view of various variables like germination to the potato tuber harvest under study. Germination percentage is the most important key issue of crop establishment (Kövendi-Jakó et al., 2017) in the research outcome. The potato tuber germination percentage was significantly varied at 14 and 21 different days after planting (DAP). The highest germination (38.41% at 14 DAP and 98.71% at 21 DAP) was observed in the S_2 treatment (the widest intra-row plant spacing) and the lowest germination (32.56% at 14 DAP, and 96.15% at 21 DAP) was recorded in the S_0 treatment (the closest intra-row plant spacing) presented in Fig 1. The research result was supported by (Akassa et al., 2014) stated that potato top emergence and effective growth and development in association with plants and rows spacing maintaining 70-75 and 20-30 cm. Potato plant height was observed significantly different in 30, 45,

and 60 days after planting (DAP) by the effects of intra-row plant spacing treatments (Table 1). The tallest potato plants (25.89cm, 35.19cm and 43.04cm at 30, 45, and 60 DAP respectively) were recorded from S_2 treatment, whereas the shortest potato plants (22.20 cm, 31.28 cm, and 40.20 cm at 30, 45, and 60 DAP) were observed from S_0 treatment the closest intra-row plant spacing. The results received from the research were almost like the findings of (Garrity et al., 1992); (Bussan et al., 2007); (Zamil et al., 2010) and (Getachew et al., 2012). The leaf length of potatoes was significantly varied with different intra-row plant spacing (Table 1). The longest potato leaf (16.39 cm) was noted in the S_2 treatment and the shortest potato leaf (14.45 cm) was measured of S_0 treatment. Potato leaf breadth was also influenced by different intra-row plant spacing (Table 1). The widest potato leaf (8.28 cm) was determined from the widest plant spacing (S_2) treatment and the narrow potato leaf (6.79 cm) was counted in the S_0 treatment. The maximum number potato shoot per hill (6.17) was found from S_2 treatment and the minimum number potato shoot per hill (4.68) was verified from the S_0 treatment. The potato tuber per hill was counted highest (6.05) from the S_0 treatment and the lowest number of potato tuber per hill (4.73) was detected from the widest intra-row plant spacing (S_2) treatment. The maximum weight of potato tuber per hill (236.20 g) was weighed from the widest intra-row plant spacing (S_2) while, the minimum weight of potato tuber per hill (228.70 g) was found from the S_0 treatment the closest intra-row plant spacing. The results obtained from the research were similar to the outcome of (Rahman and Gaffer, 1991); (Sultana and Siddique 1991). They reported that wider spacing increased potato yield per hill, but the highest yield per unit area was obtained from the closer spacing. The results showed that potato tuber yield varied significantly with various intra-row plant spacing (Table 2). Significantly, the highest potato tuber yield (19.33 tonnes per ha) was found in S_0 treatment conversely the lowest potato tuber yield (16.30 tonnes per ha) was measured from the widest intra-row plant spacing S_2 treatment. The potato tuber yield taken from the research was often in line with the results of the (Sultana and Siddique 1991); (Zamil et al., 2010) and (Getachew et al., 2012). Arega et al., 2018 mentioned that the highest tuber yield was found in (75cm x 30cm) intra row spacing. This agreement was highly supported by the present research work. Intra-row plant spacing influences the dry weight of potato tuber also (Table 2). Significantly, the maximum dry weight (13.98 g) of potatoes was measured from the closest intra-row plant spacing S_0 treatment and the minimum dry weight (11.61 g) of potatoes was taken from the widest intra-row plant spacing S_2 treatment. The three intra-row plant spacing made a difference to potato tuber grade significantly (Table 3). The maximum A Grade (>55mm) potato tuber (1.32) was gathered from the S_2 treatment, the widest intra-row plant spacing besides the minimum A Grade tuber (0.93) most commonly originated from the S_0 treatment. The achievement of the research most related to the outcome of (Yenagi et al., 2010 and Islam et al., 2012). They mentioned that the average size of tuber decreases with a decrease in intra-row plant spacing. The maximum B Grade (46-55mm) potato tuber (2.04) was cumulated from the S_0 treatment, the closest intra-row plant spacing, and the minimum B Grade tuber (1.16) was taken from the S_2 treatment, the widest intra-row plant spacing. C Grade (36-46 mm) potato tuber (1.91) was gotten the maximum grade from S_0

treatment the closest intra-row plant spacing consequently the minimum C Grade tuber (1.15) was gained from the S_2 treatment, the widest intra-row plant spacing. The maximum D Grade (28-35 mm) potato tuber (1.79) was found from the S_2 treatment, the widest intra-row plant spacing whereas the minimum Grade-D tuber (1.11) was noted from the S_0 treatment, the closest intra-row plant spacing, respectively. Ultimately, the maximum E Grade (<28 mm) potato tuber (1.45) was observed from the S_2 treatment and the minimum E Grade tuber (0.99) was obtained from the S_0 treatment. Potato growing is listed as a high potential food safety and cash crop (Hirpa et al., 2010). Plant density needs to be optimized because it affects seed costs, plant growth, yield and crop quality (Bussan et al., 2007). From the results and discussion, the closest (60 x 20 cm^2) intra-row plant spacing gave the highest yield and was effectively applicable in the potato production.

Effect of production system on potato growth and production potentiality

Germination percentage of potato tubers significantly varied at 14 and 21 different days after planting (DAP) due to the practice of different production systems presented in Fig 2. Significantly, the maximum germination (38.39 % at 14 DAP and 98.29% at 21 DAP) was observed in potatoes under mango-based agroforestry system (T_1). On the other hand, the minimum germination (31.91% at 14 DAP and 96.8% at 21 DAP) was observed from the potato sole cropping production system (T_0). The maximum germination was obtained due to favourable environmental condition i.e. favourable temperature and moisture taken from the mango-based agroforestry system. Gaur and Pandey (1993) reported that soil temperature and moisture influenced the germination of potato tubers. The height of the potato plant was shown to be statistically significant in the effects of two potato production systems (T_0) and (T_1) highlighted in table 4. At the early stage, 30 DAP, the tallest plant (24.90 cm) originated from control treatment (T_0) potato production in the open field, whereas the shortest plant (22.92 cm) was received from T_1 treatment potatoes under the mango-based agroforestry system. In the middle stage at 45 DAP, the tallest plant (33.98 cm) was gained from T_1 treatment whereas the shortest plant (32.09 cm) was found in T_0 treatment. Finally, at 60 DAP, the tallest plant (43.08 cm) was measured in potato T_1 treatment whereas the shortest plant (39.85 cm) was achieved from T_0 treatment (Table 4). The outcome of the research uncovered that the plant tallness expanded with the diminishing of light levels. Plant height relies upon a set of factors, namely accessibility of freshwater, mineral supplements, light amount, light quality and duration, air temperature, a territory of developing space (aerial and edaphic) and plant genetic amendment. Potato developed under the mango-based agroforestry framework was more dynamic than those developed in the control production-meaning, in full daylight conditions. The longest potato leaf (16.37 cm) was isolated in (T_1) treatment whereas the shortest leaf (14.39 cm) was evaluated in the control treatment (T_1). Potato leaf breadth was correspondingly differentiated by mango-based agroforestry system was more vigorous than mono cropping production (Table 4). The widest potato leaf (8.11 cm) was calculated T_1 treatment. Conversely, the leaf with minimum breadth (6.79 cm) was considered in the control treatment of potato (T_0). The eventuality of the result was practically identical to

(Wolf et al., 1990) who narrated that cooler temperature produces larger size leaves that remain photosynthetically active for longer periods. Kirk and Marshall, 1992 detailed that temperature significantly impacts the development and improvement of the potato's shade, leaf appearance, extension, and senescence leaf direction. The maximum number potato shoot per hill (5.92) was found from the T_0 treatment and the minimum number potato shoot per hill (4.75) was received from T_1 treatment. The sunlight of the open field supported the production of supplementary photosynthesis follow-on the higher shoot per hills were getting from the control treatment. The diverse production system affected the number of tubers per hill significantly (Table 5). The maximum number potato tubers per hill (6.31) was counted in potato production in the control treatment (T_0). Then again, the minimum number potato tuber per hill (4.57) was taken from the T_1 treatment. More daylight gave more photosynthesis delivered more carbohydrates gathered in the potato tubers. The statement from (Nandal and Hooda, 2005) announced that the primary development and yield assigning character was accountable for the lower yield of potatoes under poplar-based agroforestry practice. The maximum weight of potato tuber per hill (241.20 g) was weighed in the control treatment (T_0) and the minimum weight of potato tuber per hill (224.71 g) was taken in the T_1 treatment. Remarkably, the highest potato tuber yield (20.25 tonnes per ha) was achieved from the control treatment (T_0) whereas the lowest potato tuber yield (18.55 tonnes per ha) was balanced in the T_1 treatment (Table 5). Limited light (shade) is the most important factor that causes poor performance of understory crops. Kumar and Nandal, 2004 detailed that the potato tubers yield significantly no difference under old eucalyptus-tree-based production system over sole cropping of potatoes. The highest yield was due to the photosynthesis rate that brought higher sustenance ingredients placed in the potato tuber. Significantly, the maximum dry weight (14.50 g) was determined in the T_1 treatment and the minimum dry weight (11.10 g) of potato was achieved from in the T_0 treatment. The maximum A Grade (>55mm) potato tuber (1.25) was counted in the T_0 treatment and the minimum Grade (>55mm) potato tuber (1.07) was taken from the T_1 treatment (Table 6). The maximum B Grade (46 - 55mm) potato tuber (1.63) was gained the T_0 treatment then the minimum B Grade (46-55mm) potato tuber (1.35) was noted from the T_1 treatment. The maximum C Grade (36-46 mm) potato tuber (1.66) was calculated in the T_0 treatment and the minimum C Grade (36-46 mm) potato tuber (1.33) was found in the T_1 treatment. The maximum D Grade (28-35 mm) potato tuber (1.56) was gotten from the T_1 treatment while the minimum D Grade (28-35 mm) potato tuber (1.45) was received in the control treatment (T_0). The maximum E Grade (<28 mm) potato tuber (1.40) was found in the T_1 treatment and the minimum E Grade (<28 mm) potato tuber (1.05) was observed in sole cropping of potatoes (T_0).

Interaction effect of intra-row plant spacing and production system on potato growth and production potentiality

Potato tuber emergence varied significantly at 14 and 21 different days after planting (DAP) by the interaction effect of intra-row plant spacing and production system (Fig 3). Significantly, the highest germination (42.42 % and 99.53 % at 14 DAP and 21 DAP respectively) was observed from the T_1S_2 treatment combination (potato under mango-based

Table 1. Effect of intra-row plant spacing on plant height, leaf length and breadth, and shoots per hill of potato plants 30, 45 and 60 DAP.

Treatment	Plant height (cm)			Leaf length (cm)	Leaf breadth (cm)	No. of shoots per hill
	30 DAP	45 DAP	60 DAP			
S_0	22.20c	31.28b	40.20b	14.45b	6.79b	4.68c
S_1	23.65b	32.64b	41.16ab	15.30b	7.27b	5.16b
S_2	25.89a	35.19a	43.04a	16.39a	8.28a	6.17a
Level of Significance	**	**	*	**	**	**
CV (%)	3.93	3.00	4.83	3.77	5.31	3.50

Notes: S_0, S_1 and S_2 indicate intra-row plant spacings of 60 × 20 cm^2, 60 × 25 cm^2 and 60 × 30 cm^2, respectively. Columns with the same letters are not significantly different. Columns with dissimilar letters indicate treatments, which are significantly different based on DMRT. * Significant at p ≤ 0.05; ** significant at p ≤ 0.01. The coefficient of variation (CV) indicates the ratio of the standard deviation (SD) to the mean value.

Table 2. Effect of intra-row plant spacing on yield characteristics of potatoes.

Treatment	Number of potato tubers per hill	Weight of potato tubers per hill (g)	Yield of potato tubers per ha (tonnes)	Dry weight (g)
S_0	6.05a	228.70b	19.33a	13.98a
S_1	5.56a	234.00a	17.82b	12.74b
S_2	4.73b	236.20a	16.30c	11.61c
Level of Significance	*	**	**	**
CV (%)	10.02	0.75	2.24	3.61

Notes: S_0, S_1 and S_2 indicate intra-row plant spacings of 60 × 20 cm^2, 60 × 25 cm^2 and 60 × 30 cm^2, respectively. Columns with the same letter are not significantly different. Columns with dissimilar letters indicate treatments, which are different significantly.

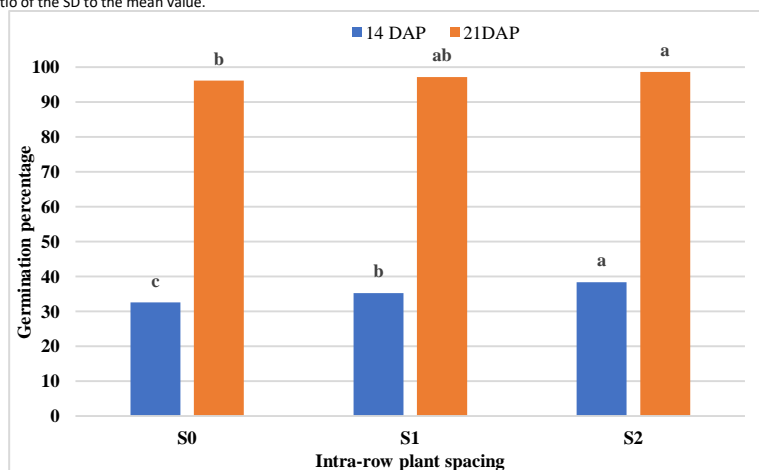**Table 3.** Effect of intra-row plant spacing on potato tuber grades.

Treatment	Mean number of potato tubers per hill by grade				
	A Grade (>55 mm)	B Grade (46-55 mm)	C Grade (36-46 mm)	D Grade (28 –35 mm)	E Grade (<28 mm)
S_0	0.93b	2.04a	1.91a	1.11c	0.99c
S_1	1.25a	1.27b	1.43b	1.61b	1.23b
S_2	1.32a	1.16c	1.15c	1.79a	1.45a
Level of Significance	**	**	**	**	**
CV (%)	9.57	2.47	0.49	0.53	0.72

Notes: S_0, S_1 and S_2 indicate intra-row plant spacings of 60 × 20 cm^2, 60 × 25 cm^2 and 60 × 30 cm^2, respectively. Columns with the same letter are not significantly different. Columns with dissimilar letters indicate treatments, which differ significantly based on DMRT. * Significant at p ≤ 0.05; ** significant at p ≤ 0.01. The CV indicates the ratio of the SD to the mean. Bars having similar letters mean treatments do not differ significantly and dissimilar letters mean treatments significantly differ by (DMRT) Duncan's Multiple Range Test.
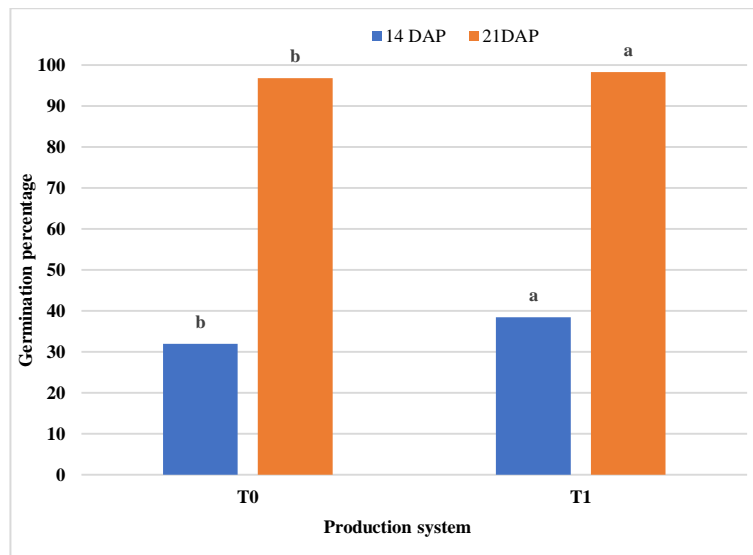
Table 4. Effect of production system on plant height, leaf length and breadth and shoots per hill of potato plants 30, 45 and 60 DAP.

| Treatment	Plant height (cm)			Leaf length (cm)	Leaf breadth (cm)	No. of shoots per hill
	30 DAP	45 DAP	60 DAP			
T_0	24.90a	32.09b	39.85b	14.39b	6.79b	5.92a
T_1	22.92b	33.98a	43.08a	16.37a	8.11a	4.75b
Level of Significance	**	**	**	**	**	**
CV (%)	3.93	3.00	4.83	3.77	5.31	3.50

Notes: T_0 indicates sole-crop/open field production system (control); T_1 represents potatoes grown under the mango-based agroforestry production system. Columns with the same letter are not significantly different. Columns with dissimilar letters indicate treatments which differ significantly based on DMRT.
** Significant at p ≤ 0.01. The CV indicates the ratio of the SD to the mean value.

Fig 1. Effect of intra-row plant spacing on the germination (%) of potatoes at 14 and 21 DAP. Notes: S0, S1 and S2 indicate intra-row plant spacings of 60 × 20 cm^2, 60 × 25 cm^2 and 60 × 30 cm^2, respectively. Bars with the same letter are not significantly different; bars with dissimilar letters indicate treatments which significantly differ based on DMRT.

Fig 2. Effect of production system on the germination % of potatoes at 14 and 21 DAP. Notes: T0 indicates sole-crop/open field production system (control); T1 represents potatoes grown under the mango-based agroforestry production system.nificantly based on DMRT. * Significant at p ≤ 0.05; ** significant at p ≤ 0.01. The CV indicates the ratio of the SD to the mean.
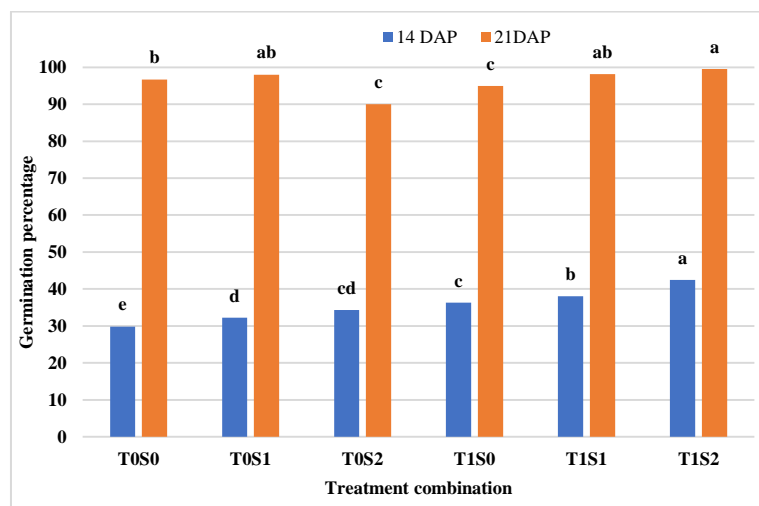
Fig 3. Interaction effect of intra-row plant spacing and production system on germination of potatoes at 14 and 21 DAP.
Notes: T0S0, T0S1 andT0S2, indicate intra-row spacings of 60 x 20 cm^2, 60 x 25 cm^2 and 60 x 30 cm^2, respectively, of potatoes under monocropping; T1S0, T1S1 and T1S2 indicate intra-row spacings of 60 x 20 cm^2, 60 x 25 cm^2 and 60 x 30 cm^2, respectively, of potatoes under mango trees. Bars with the same letter do not differ significantly. Bars with dissimilar letters indicate treatments that differ significantly based on DMRT.

Table 5. Effect of production system on yield characteristics of potatoes.

Treatment	Number of potato tubers per hill	Weight of potato tubers per hill (g)	Yield of potato tubers per ha (tonnes)	Dry weight (g)
T_0	6.31a	241.20a	20.25a	11.10b
T_1	4.57b	224.71b	18.55b	14.50a
Level of Significance	**	**	**	**
CV (%)	10.02	0.75	2.24	3.61

Notes: T_0 indicates sole-crop/open field production system (control); T_1 represents potatoes grown under the mango-based agroforestry production system.
Columns with the same letter are not significantly different. Columns with dissimilar letters indicate treatments which differ significantly based on DMRT.
** Significant at p ≤ 0.01. The CV indicates the ratio of the SD to the mean value.

Table 6. Effect of production system on potato tuber grades.

Treatment	Mean number of potato tubers of each grade per hill				
	A Grade (>55 mm)	B Grade (46-55 mm)	C Grade (36-46 mm)	D Grade (28-35 mm)	E Grade (<28 mm)
T_0	1.25a	1.63a	1.66a	1.45b	1.05b
T_1	1.07b	1.35b	1.33b	1.56a	1.40a
Level of Significance	**	**	**	**	**
CV (%)	9.57	2.47	0.49	0.53	0.72

Notes: T_0 indicates sole-crop/open field production system (control); T_1 represents potatoes grown under the mango-based agroforestry production system. Columns with the same letter are not significantly different. Columns with dissimilar letters indicate treatments which differ significantly based on DMRT. ** Significant at p ≤ 0.01.
The CV indicates the ratio of the SD to the mean value.

Table 7. Interaction effects of intra-row plant spacing and production system on plant height, leaf length and breadth and number of shoots per hill of potato plants 30, 45 and 60 DAP.

Treatment	Plant height (cm)			Leaf length (cm)	Leaf breadth (cm)	No. of shoots per hill
	30 DAP	45 DAP	60 DAP			
T_0S_0	23.06bc	30.58d	38.65b	13.40d	6.09c	5.31c
T_0S_1	24.67bc	31.63cd	39.48b	14.57cd	6.57c	5.75b
T_0S_2	26.97a	34.06b	41.41ab	15.21bc	7.21b	6.70a
T_1S_0	21.33d	31.98b-d	41.74ab	15.50bc	7.78b	4.04e
T_1S_1	22.63cd	33.65bc	42.83ab	16.04b	7.97b	4.57d
T_1S_2	24.81b	36.32a	44.67a	17.58a	8.86a	5.65bc
Level of Significance	**	**	**	**	*	**
CV (%)	3.93	3.00	4.83	3.77	5.31	3.50

Notes: T_0S_0, T_0S_1 and T_0S_2, indicate intra-row spacings of 60 x 20 cm^2, 60 x 25 cm^2 and 60 x 30 cm^2, respectively, of potatoes grown as a sole crop; T_1S_0, T_1S_1 and T_1S_2 indicate intra-row spacings of 60 x 20 cm^2, 60 x 25 cm^2 and 60 x 30 cm^2, respectively, of potatoes under mango trees. Columns with the same letter are not significantly different. Columns with dissimilar letters indicate treatments which differ significantly based on DMRT. * Significant at p ≤ 0.05; ** significant at p ≤ 0.01. The CV indicates the ratio of the SD to the mean.

Table 8. Interaction effect of intra-row plant spacing and production system on the yield characteristics of potatoes.

Treatment	Number of potato tubers per hill	Weight of potato tubers per hill (g)	Yield of potato tubers per ha (tonnes)	Dry weight (g)
T_0S_0	5.45bc	236.80b	20.22a	12.07d
T_0S_1	6.49ab	242.00a	18.42b	11.11e
T_0S_2	7.02a	244.80a	17.63c	10.12f
T_1S_0	4.23d	220.60d	18.43b	15.89a
T_1S_1	4.61cd	225.90c	17.23c	14.36b
T_1S_2	5.07cd	227.60c	14.97d	13.10c
Level of Significance	**	**	**	*
CV (%)	10.02	0.75	2.24	3.61

Notes: T_0S_0, T_0S_1 and T_0S_2, indicate intra-row spacings of 60 x 20 cm^2, 60 x 25 cm^2 and 60 x 30 cm^2, respectively, of potatoes grown as a sole crop; T_1S_0, T_1S_1 and T_1S_2 indicate intra-row spacings of 60 x 20 cm^2, 60 x 25 cm^2 and 60 x 30 cm^2, respectively, of potatoes under mango trees. Columns with the same letter are not significantly different. Columns with dissimilar letters indicate treatments which differ significantly based on DMRT. * Significant at p ≤ 0.05; ** significant at p ≤ 0.01. The CV indicates the ratio of the SD to the mean.

Table 9. Interaction effect of intra-row plant spacing and production system on potato tuber grades.

Treatment	Mean number of potato tubers in each grade per hill				
	A Grade (>55 mm)	B Grade (46-55 mm)	C Grade (36-46 mm)	D Grade (28 –35 mm)	E Grade (<28 mm)
T_0S_0	0.99cd	2.19a	2.12a	1.06f	0.84d
T_0S_1	1.35a	1.40c	1.64b	1.54d	1.10c
T_0S_2	1.39a	1.28d	1.22c	1.74b	1.20c
T_1S_0	0.87d	1.88b	1.70b	1.16e	1.13c
T_1S_1	1.10bc	1.13e	1.21c	1.67c	1.36b
T_1S_2	1.25ab	1.04f	1.08d	1.83a	1.70a
Level of Significance	*	*	**	**	**
CV (%)	9.57	2.47	0.49	0.53	0.72

Notes: T_0S_0, T_0S_1 and T_0S_2, indicate intra-row spacings of 60 x 20 cm^2, 60 x 25 cm^2 and 60 x 30 cm^2, respectively, of potatoes grown as a sole crop; T_1S_0, T_1S_1 and T_1S_2 indicate intra-row spacings of 60 x 20 cm^2, 60 x 25 cm^2 and 60 x 30 cm^2, respectively, of potatoes under mango trees. Columns with the same letter are not significantly different. Columns with dissimilar letters indicate treatments which differ significantly based on DMRT. * Significant at p ≤ 0.05; ** significant at p ≤ 0.01. The CV indicates the ratio of the SD to the mean.

Table 10. Economic returns of potatoes under mango-based agroforestry and potatoes as sole-crop production systems.

Treatments	Outcome (US$/ha)		Gross Return ($./ha)	Total cost of Production ($./ha)	Net Return ($./ha)	BCR
	Potato tuber	Mango fruit tree				
Open field/sole-crop potatoes (T_0)	2858.00	-	2858.00	1600.00	1258.00	1.78
Potatoes under mango trees (T_1)	2618.00	890.00	3508.00	1642.00	1866.00	2.14

Note: Potato price US$0.14/kg; mango price US$0.71/kg.

agroforestry system with widest intra-row spacing). In contrast, the lowest germination (29.82 % and 96.67 % at 14 DAP and 21 DAP) was noted in the T_0S_0 treatment combination (potato in sole cropping with closest intra-row spacing). The potato plant height was found statistically different from the interaction effect of intra-row plant spacing and production system (Table 7). At 30 DAP, the tallest plant (26.97 cm) was recorded in the T_0S_2 treatment combination followed by T_1S_2, T_0S_1 and T_0S_0 treatment combinations and the shortest plant (21.33 cm) was recorded in the T_1S_0 treatment combination. At 45 DAP, the tallest plant (36.32 cm) was received in the T_1S_2 treatment

combination followed by T_0S_2 and T_1S_1 treatment combinations and the shortest plant of potato (30.58 cm) was obtained in the T_0S_0 treatment combination. Significantly, at 60 DAP the tallest plant (44.67 cm) was achieved in the T_1S_2 treatment combination whereas the shortest plant (38.65 cm) was observed in the T_0S_0 treatment combination, respectively. The longest leaf (17.58 cm) was found in the T_1S_2 treatment combination followed by T_1S_1, T_1S_0 treatment combinations and the shortest leaf (13.40) was collected in the T_0S_0 treatment combination. The widest leaf (8.86 cm) was raised in the T_1S_2 treatment combination and the leaf with minimum breadth (6.09) was

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determined in the T_0S_0 treatment combination. The maximum potato shoot per hill (6.70) was raised in the T_0S_2 treatment combination and the minimum potato shoot per hill (4.04) was observed in the T_1S_0 treatment combination (Table 7). The maximum potato tuber per hill (7.02) was reckoned in the T_0S_2 treatment combination followed by T_0S_1, T_0S_0 treatment combinations, respectively. Then again, the minimum potato tuber per hill (4.23) was calculated in the T_1S_0 treatment combination. The maximum weight of potato tuber (244.80 g) was observed in the T_0S_2 treatment combination followed by the T_0S_1, T_0S_0 treatment combinations, respectively. Alternatively, the minimum weight of potato tuber (220.60 g) was gained in T_1S_0 treatment combination. The interaction effect of the intra-row plant spacing, and production system significantly inclined the yield of potato tuber (Table 8). Significantly, the maximum potato tuber yield (20.22 tonnes per ha) was found in the T_0S_0 treatment combination (potato in mono-cropping with 20 cm intra-row plant spacing) followed by T_1S_0, T_0S_1 treatment combinations respectively. In contrast, the minimum potato tuber yield (14.97 tonnes per ha) was obtained in the T_1S_2 treatment combination (potato under mango-based production system with 30 cm intra-row plant spacing). The maximum dry weight of potato tuber (15.89 g) was noted in the T_1S_0 treatment combination and the minimum dry weight of potato tuber (10.12 g) was weighed in the T_0S_2 treatment combination. The maximum A Grade (>55mm) potato tuber (1.39) was selected in the T_0S_2 treatment combination and the minimum A Grade (>55mm) potato tuber (0.87) was brought from the T_1S_0 treatment combination, respectively (Table 9). The maximum B Grade (46-55mm) potato tuber (2.19) was observed in the T_0S_0 treatment combination, and the minimum B Grade (46-55mm) potato tuber (1.04) was balanced in the T_1S_2 treatment combination. The highest C Grade (36-46 mm) potato tuber (2.12) was determined in the T_0S_0 treatment combination and the lowest C Grade (36-46 mm) potato tuber (1.08) was logged in the T_1S_2. The maximum D Grade (28-35 mm) potato tuber (1.74) was received in the T_1S_2 treatment combination then the minimum D Grade (28-35 mm) potato tuber (1.07) was shown in the T_0S_0 treatment combination. The maximum E Grade (<28 mm) potato tuber (1.70) was observed in the T_1S_2 treatment combination while the minimum E Grade (<28 mm) potato tuber (1.70) was recorded in the T_0S_0 treatment combination.

Economic performance of potato production

The cost of production, gross return and net return of potato as inter-crop in mango-based agroforestry production system and sole cropping were calculated based on local market rates prevailing during experimentation and converted into United States dollars (Table 10). The maximum cost of production (US$1642.00 per ha) was calculated from the T_1 treatment potato production under mango tree the agroforestry practice, while the least production cost (US$1600.00 per ha) was measured from the control treatment (T_0). The maximum return of gross money (US$ 3508.00 per ha) was achieved from the T_1 treatment and the minimum return of gross currency (US$2858.00 per ha) was taken from the T_0 treatment. Net return was maximum in potato growing under mango-based agroforestry practice (T_1) compared to potatoes in mono farming (T_0). It was observed that potato under mango-based agroforestry system (T_1) gave the maximum net

return (US$1866.00 per ha). At the same time, the minimum net return (US$1258.00 per ha) was received from the potato in mono cultivation (T_0). Table 10 indicated that the maximum benefit-cost ratio (2.14) was gained from the T_1 treatment potato under mango-based agroforestry system while the minimum benefit-cost ratio (1.78) was taken in the T_0 potato growing in mono farming practice.

Materials and methods

Plant materials

The 10 years old mango (variety BARI Am 3 *Amropali*) orchard has been used for the present research work. The plant to plant and row to row distance of these mango trees was 5 meters with east-west plant geometry. The average mango tree height, basal diameter and crown diameter was found 4.92meter, 6.53cm and 175cm, respectively. The cardinal variety of seed tubers was the research testing crop. It was collected from the authentic marketing division of Bangladesh Agricultural Development Corporation (BADC).

Experimental sites and description

The experiment was conducted in the research field at the department of Agroforestry & Environment Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. It was located between latitude 25º 13´ & longitude 88º 23´ and 37.5 m above sea level. The soil of the experimental plot was mainly sandy loam (mixture of sand 67%, silt 33% and clay 5%), having organic matter (1.25%) with pH (5.1) and also the chemical properties such as total nitrogen (0.12%), sodium (0.05 meq/100g), calcium (1.33 meq/100g), magnesium (0.41meq/100g), potassium (0.25meq/100g), phosphorus (25.0 µg/g), sulphur (3.1µg/g), boron (0.28µg/g), iron (5.30 µg/g), zinc (0.90µg/g) and CEC (8.0 meq/100g). The climate of the experimental site was quite good. The maximum average temperature (30.1 ^{0}C), minimum average temperature (18.30 ^{0}C), average mean temperature (23.15 ^{0}C), no rainfall, average relative humidity (89.00%) and sunshine (5.6 hrs) was observed in November 2018. A slightly reduce in maximum, minimum and mean temperature, no rainfall average relative humidity (85.00%) and sunshine (4.8 hrs) was recorded in December 2018. In the next month January 2019, it was found cold environment temperature fall 8.5 an average 15.4 ^{0}C, no rainfall, humidity 92% and sunshine 4.2 hrs.

Experimental design

The experiment was laid out following a split plot design with three (3) replications. Potato production system under mango orchard and open field were arranged in main plots T_0 = potato sole cropping (control) and T_1 = potato under mango-based agroforestry system. On the other hand, potato intra-row plant spacing were in sub-plots S_0 = 60 × 20 cm^2, S_1 = 60 × 25 cm^2 and S_2 = 60 × 30 cm^2. Hence, the system-spacing treatment combinations were; T_0S_0 = 60 x 20 cm^2 intra-row spacing of potato in sole cropping, T_0S_1 = 60 x 25 cm^2 intra-row spacing of potato in sole cropping, T_0S_2 = 60 x 30 cm^2 intra-row spacing of potato in sole cropping, T_1S_0 =60 x 20 cm^2 intra-row spacing of potato mango-based agroforestry system, T_1S_1 = 60 x 25 cm^2 intra-row spacing of potato under mango-based agroforestry system and T_1S_2 = 60 x 30 cm^2 intra-row spacing in potato under mango-based

agroforestry system. The total numbers of experimental plots were 18. The individual plot area was 4.5 m x 4.5 m = 20.25 m^2. Nine (9) plots were laid under the mango orchard and 9 plots were laid in the control (open field). The field research work was started in November 2018 and was completed in March 2019.

Crop establishment

The land in the experimental plots was ploughed using a tillage machine on 30 November 2018. The corners of the land not reached by the tillage machine were dug with a spade, and visibly larger clods were hammered to break them into small pieces. All weeds and stubble were removed from the field. The layout was prepared according to the experimental design and made ready for planting. The well-sprouted seed tubers were planted on the 12 December 2018 at a depth of 10 cm in furrows 60 cm apart with spacings of 20 cm, 25 cm and 30 cm in each line according to which treatment they represented. Therefore, the 210 seed potato tubers were planted in each T_1S_0 plot, 168 tubers in each T_1S_1 plot, 140 tubers in each T_1S_2 plot, 240 tubers in each T_0S_0 plot, 192 tubers in each T_0S_1 plot and 160 tubers in each T_0S_2 plot.

Fertilizer application and after care

The plant nutrients organic matter, N, P_2O_5, K_2O were supplied in the form of dried cow-dung 4.5 tonnes per ha, Urea 150.0 kg per ha, TSP 100.0 kg per ha and MP 160.0 kg per ha. Half of Urea and full doses of cow-dung, TSP, MP were applied as the basal dose in furrows made on both sides of the seed rows and mixed properly with soil at planting time. In addition, the remaining urea was applied at 40 DAP during the second earthing-up at the side of the rows and covered with soil. Three irrigations were provided throughout the growing period. The first one was done at 30 days after planting. Subsequently, two irrigations were given at 20 days interval. After each irrigation, the soil was mulched by breaking the crust for aeration and to conserve soil moisture. Manual weeding was done as and when necessary to keep the plots completely free from all weeds. Earthing up was done at 25 days and 40 days after planting.

Data collection

From the experiment, germination percentage, plant height, leaf length, leaf breadth, number of shoots per hill, numbers of potato tubers per hill, weight of potato tubers per hill, tuber yield of potato, dry matter and tuber grade data were recorded. For the economic performance of the production systems, the economic yield of potato and mango was calculated by production cost, gross & net returns and benefit-cost ratio. The production cost, gross & net returns were calculated based on the prevailing market prices and transformed into United States dollars.

Statistical analysis

The statistical test ANOVA (Analysis of Variance) was done with the help of the SPSS (22.0) statistical data analysis software while the data mean separations were adjusted by the DMRT (Duncan's Multiple Range Test) (Gomez and Gomez, 1984).

Conclusion

Agroforestry practices facilitates to ensure sustainable crop production by increasing soil organic matter, maintaining proper management, diminishing the hazard of crop losses, confirming the highest utilization of natural resources. It creates a balanced and sustainable production system. The findings from experimental results reveal that potatoes can cultivate the most under the mango-based agroforestry system with the closest (60 x 20 cm^2) intra-row plant spacing for better yield. Potato under mango-based agroforestry practice brings a positive significant return of money using the pitch of land. In conclusion, the research finding indicates the benefit-cost ratio (2.14) from the combined cultivation of potatoes and mangos which was 20 % higher than growing potatoes as a sole crop. This production technique ensures not only the food safety, but also increases the income of the farmers and ensures the long-term sustainability.

Acknowledgements

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