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Strategic Enhancements in Onion Cultivation Through Evaluating Plant Density and Harvest Intervals for Superior Yield and Profitability

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ABSTRACT

The experiment was conducted at the agricultural research farm of the Department of Agronomy and Agricultural Extension, University of Rajshahi, Bangladesh from December 2020 to April 2021. The aim was to investigate the impact of plant density per hill and harvesting time on the growth, yield, and economic benefits of onions. Three plant densities were tested: one plant per hill (P1), two plants per hill (P2), and three plants per hill (P3). Additionally, two harvesting times were evaluated: 110 days after transplanting (H1) and 125 days after transplanting (H2). The experiment followed a Randomized Completely Block Design (RCBD) with three replications. Both plant density and harvesting time significantly influenced most growth and yield parameters. The highest values for leaf diameter, neck diameter, bulb length, bulb diameter, fresh bulb weight, dry bulb weight, and yields per hectare were observed with two plants per hill (P2). Similarly, the highest values for those parameters were found with the later harvest time of 125 days (H2). The combination of two plants per hill and harvesting at 125 days (P2H2) produced the best results, including the highest leaf and neck diameters, bulb dimensions, fresh and dry bulb weights, and yields per hectare. This combination also achieved the highest Benefit-Cost Ratio (BCR) of 2.12, compared to 1.71 for the one plant per hill and 110-day harvest combination (P1H1). Therefore, the study concludes that planting two onions per hill and harvesting at 125 days after transplanting yield the best growth, yield, and economic benefits.

INTRODUCTION

Onion (*Allium cepa L.*), often celebrated as the "Queen of the Kitchen," holds a prominent place as one of the earliest and most vital spice crops globally (El-Waseef *et al.*, 2023), including in Bangladesh. Originating from Central Asia, specifically the regions between Turkmenistan and Afghanistan, onions have been widely used for cultivation worldwide. Major production hubs now include countries such as China, India, the Netherlands, Turkey, and Egypt (Chaudhry *et al.*, 2023). In the culinary world, onions are indispensable, extensively used as spices and in condiments that elevate the taste of food. Beyond their culinary significance, onions are prized for their medicinal properties. They contribute positively to cardiovascular health by enhancing blood vessel flexibility and reducing the risk of heart disease (Kumar *et al.*, 2023). Nutritionally, onions are a powerhouse, rich in proteins, carbohydrates, minerals such as calcium, iron, phosphorus, magnesium, and potassium, and vitamins including B1, B2, B3, B5, B6, B9, and C (Kupaeva *et al.*, 2023). Despite their importance, onion production in Bangladesh faces several challenges. The country produced 2.33 million metric tons of onions in the 2018-2019 period, which was insufficient to meet the annual demand of 3.60 million metric tons (BBS, 2019). Boosting onion production in Bangladesh is critical to bridging this gap. However, several factors contribute to the low yield, including limited access to high-quality seeds, ineffective cultural management practices, insufficient seedlings per hill, imbalanced fertilizer use, improper harvesting times, inadequate storage methods, and disease infestations. Traditionally, Bangladeshi farmers grow a single plant per hill. However, research indicates that increasing the number of plants per hill can significantly enhance yields, similar to other crops like tomatoes, sweet potatoes, and carrots (Omari *et al.*, 2023; Gonzaga *et al.*, 2020). To address these challenges, adopting improved agricultural practices, including optimal plant density and updated management techniques, is essential to boost production (Elouattassi *et al.*, 2024). The timing of harvest is also crucial in determining the quality and storability of onion bulbs. Premature harvesting can lead to economic losses due to poor storage potential. The optimal harvest time varies by variety, typically ranging from 100 to 120 days after transplanting (DAT) (Prasad *et al.*, 2017). The timing of harvest impacts the marketability and demand for onions (Ko *et al.*, 2016), making it imperative for farmers to carefully consider the harvest period. Therefore, the current research aims to investigate the effects of varying the number of plants per hill and the timing of harvesting on the growth, yield, and economic benefits of onions.

MATERIALS AND METHODS

The experiment was conducted at the Agronomy Field Laboratory, Department of Agronomy and Agricultural Extension, University of Rajshahi in Bangladesh during

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the period from October 2020 to January 2021 to study the effects of varying the number of plants per hill and the timing of harvesting on the growth, yield, and economic benefits of onions. The experimental field was situated on the western side of the Agronomy and Agricultural Extension Department. Geographically the experimental field was located at 24022'36" N latitude and 88038' 36"E longitude at an elevation of 20m above the sea level belonging to the agro-ecological zone (AEZ-11). The land of the experimental field was flat, well-drained, and above flood level (Medium high land). The soil was sandy loam textured having pH value of 8.1 composite soil sample was collected from 0-15cm depth of the experimental plot before applying any fertilizer and was analyzed for physical and chemical properties. The experimental field was under subtropical climate characterized by moderately high temperature and heavy rainfall during the Boro season (October to Mar) and scantly rainfall with moderately low temperature during the rabi season (October to March).

Planting material used for the experiment

Seeds of onion cultivar namely "BARI Piaz1" was used for the experiment. The seeds were collected from Khorkhori bazar, Rajshahi. The experiment consists of two factors which are – Factor A: Plants per hill viz 1) P_1= One plant per hill 2) P_2= Two plants per hill 3) P_3= Three plants per hill and Factor B: Harvesting time 1) H_1 = 110 DAT 2) H_2= 125 DAT. The two-factor experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications.

Details of the field operations

The selected land for raising seedlings was fine-textured and well-drained. The land was opened and drying for 10 days. Seedbed was made on 10 October, 2020 for raising seedlings and the size of the seedbed was 3 m with a height of about 20 cm. For making seedbed, the soil was prepared by ploughing and cross ploughing along with removal of weeds, stubbles and other impurities. Cowdung @9 t/ha was applied to the prepared seedbed. Applying Furadan 3G @ 20 kg/ha was covered by polythene for two days. Onion seeds were soaked overnight (12 hours) in water and allowed to sprout in a piece of moist cloth keeping in the sun shade for one day. Seeds were treated by Vitavax-200 @ 5g/1kg seeds to protect some seed borne diseases. The date of the seed sowing was 20 October, 2020. Seeds were sown on in the seedbed to get 35 days old seedlings. Seeds was sown at a depth of 0.6 cm and covered with a fine layer of soil followed by light watering by water can. Shade was given over the seedbed to retain soil moisture and to save the seedlings from direct sun and rain. Light watering and weeding were done several times. No chemical fertilizers were applied for rising of seedlings. When the seedlings of the seedbeds attained a height of about 10 cm, thinning operation was done. Healthy and 35 days old seedlings were transplanted into the main field on 25 November, 2020. Besides, some other cultural operations like final land preparation and application of manures and fertilizers on it, transplanting of seedlings, irrigation, harvesting and storage also done consecutively. Some intercultural operations i.e. weeding, thinning, mulching, earthing up and most importantly staking are notable around the whole cultivation and production period. Data were collected on the growth, yield contributing parameters and yield of onion.

Statistical Analysis

The data recorded were compiled and tabulated for statically analysis. The collected data were analyzed statistically using the statistical package "STATVIEW" (Gomez & Gomez, 1984). The mean differences were adjudged by Duncan's multiple range test (DMRT).

Economic Analysis

The economic analysis was conducted to assess the cost-effectiveness of different treatments, including varying levels of fertilizer and the bending process. The analysis followed the methodology of Alam *et al.* (1989).

- Total Cost of Production: The total cost of onion production included both material and non-material inputs, interest on fixed capital (land), and miscellaneous expenses. This comprehensive calculation covered input costs and overhead costs.
- Gross Income: Gross income was calculated based on the sale of mature bulbs. The price was set at Tk. 45/kg, reflecting the current market value at Saheb Bazar, Rajshahi, after harvesting.
- Net Return: Net return was determined by subtracting the total production cost from the gross income for each treatment combination.
- Benefit-Cost Ratio (BCR): The Benefit-Cost Ratio (BCR), an important economic indicator, was calculated for each treatment combination using the following formula:

$$\text{Benefit Cost Ratio (BCR)} = \frac{\text{Gross income per hectare}}{\text{Total cost of production per hectare}}$$

RESULTS AND DISCUSSION

Growth parameters

Plant height(cm): A tremendous difference in the plant height was observed among different numbers of plants per hill at 35, 65, and 95 days after transplanting (DAS), and P_1 produced comparatively taller plants than P_2 and P_3. At 35 DAT, the tallest plant (36.41 cm) was observed in P_1 and the smallest plant (30.42 cm) was observed in P_3 (Table 01). A similar trend was also observed at 65 and 95 DAT among the treatments. At 65 DAT, the tallest plant (60.02cm) was found in P_1 which was significantly reduced by 8.48%, and 17.2% in P_2 and P_3, respectively. At 95 DAT, the maximum plant height (69.25cm) was found in P_1 which was significantly reduced by 9.24% and 14.59% in P_2 and P_3, respectively. At all growth stages, the P_2 treatment produced intermediate results in terms of plant height compared to treatments P_1 and P_3. Such result from

Table 1: Effect of plants per hill and harvesting time on plant height (cm) at different days after transplanting (DAT) of onion.

Treatments	Plant height (cm) at different days after transplanting		
	35 DAT	65 DAT	95 DAT
Effect of plants per hill			
P_1	36.41±2.54a	60.06±3.60a	69.25±4.48a
P_2	33.60±1.90a	54.97±2.62b	62.85±3.28b
P_3	30.42±1.51b	49.73±2.74c	59.15±3.01b
LS	0.01	0.01	0.01
CV (%)	7.31	6.33	7.21
Effect of harvesting time			
H_1	29.53±.80b	48.89±1.58b	56.63±1.49b
H_2	37.42±1.45a	60.94±2.07a	70.87±2.47a
LS	0.01	0.01	0.01
CV (%)	7.31	6.33	7.21
Combined effect of plant per hill and harvesting time			
P_1H_1	31.09±1.14cd	52.45±1.81c	60.35±2.30cd
P_1H_2	41.72±1.67a	67.66±1.95a	78.16±3.96a
P_2H_1	29.92±1.13cd	49.77±1.91cd	56.38±2.36d
P_2H_2	37.28±1.79b	60.16±1.94b	69.32±2.48b
P_3H_1	27.59±1.40d	44.45±2.53d	53.17±1.68d
P_3H_2	33.25±1.21bc	55.01±1.82bc	65.12±2.61bc
LS	0.05	0.05	0.05
CV (%)	7.31	6.33	7.21

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly by LS at P <0.05 level of probability P_1= One plant per hill, P_2= Two plants per hill, P_3= Three plants per hill H_1 = 110 DAT, H_2= 125 DAT, LS= Level of significant, CV=Coefficient of variation.

the current study on plant height might be due to the cause of nutrient availability and free growing space. A greater number of seedlings will compete with one another for the available nutrients. In addition, the accessible area for growth characteristics will diminish, which will result in a shorter plant with a higher concentration in P_3 treatment. Variation in plant height, which was affected by the number of plants on each hill, may be due to inefficient use of nutrients, moisture, and light. At every stage of development, harvesting time had a significant impact on plant height of onion (Table 01). At 35 DAT, the highest plant height (37.42 cm) was recorded in H_2 (125 DAT), and the lowest 29.53 cm in H_1 (110 DAT). At 65 DAT, the plant height in H_2 was measured the maximum (60.94 cm), which was considerably 19.78% greater than the plant height in H_1. At 95 DAT, the highest plant height was recorded in H_2 (70.87cm) and the lowest plant height was (56.63 cm) observed in H_1 which was 20.1 % lower than H_2. It has been demonstrated that the onion plant is growing taller with each passing day. From this point of view, it became clear that the significance of plant height in relation to harvesting time under conditions of similar care was demonstrated across all treatments. The combined effect of plants per hill and harvesting time had a substantial influence on plant height at all phases of development (Table 01). At 35 DAT, the highest plant height (41.72 cm) was observed in P_1H_2 and the lowest plant height (27.59 cm) was recorded in P_3H_1. At 65 DAT, the maximum plant height (67.66 cm) was found in P_1H_2 which was significantly reduced by 22.48%, 26.44%, 10.59%, 34.30% and 18.70 % in P_1H_1, P_2H_1, P_2H_2, P_3H_1 and P_3H_2, respectively. At 95 DAT, the P_1H_2 treatment combination yielded the tallest plants (78.16 cm), where the P_3H_1 treatment combination resulted in a substantial reduction of 31.97%.

Leaf length(cm)

Leaf length was significantly affected due to the different number of plants per hill at various growth stages (Table 02). The highest leaf length (30.35 cm) was discovered in P_1 treatment at 35 DAT, whereas the minimum leaf length (21.30 cm) was obtained in P_3 treatment. At 65 DAT, P_1 had the longest leaf (47.49cm), which was significantly reduced by 15.06% in P_3, which had the shortest. At 95 DAT, it was proved that the shortest leaf (46.25 cm) was discovered in P_3, while P_1 and P_2 showed substantial increases of 12.72% and 3.70%, respectively. It was demonstrated that a higher number of plants per hill resulted in shorter leaf length, possibly as a result of dry matter accumulation and the same nutrient supply management during the growing period.

Leaf length of onion was significantly influenced by time of harvest in all growth stages (Table 02). At 35 DAT, H_2 had the longest leaf (31.41 cm), while H_1 had the shortest leaf (25.61 cm). At 65 DAT, the leaf length in H_2 was measured 48.23 cm, which was 17.40% longer than H_1. At 95 DAT, the longest leaf length was measured in H_2 (54.04cm) and the shortest leaf length was (46.15 cm) detected in H_1 which was 14.60 % lower than H_2. It was proved that leaf length of onion was increasing day by day. From this point of view leaf length was significant with harvesting time under equal management of all treatments. The interaction between the number of plants per hill and the harvesting time had a significant impact on the leaf length at every stage of development (Table 02). At 35 DAT, P_1H_2 had the longest leaf (34.03 cm), while P_3H_1 had the shortest leaf (24.12 cm). At 65 DAT, the maximum leaf length (52.68 cm) was found in P_1H_2 which was significantly reduced by 8.90% and 16.41 % in P_2H_2 and P_3H_2, respectively. At 95 DAT, the maximum leaf length (58.95 cm) was found in P_1H_2 which was significantly reduced by 28.60% in P_3H_1.

Root length (cm)

The number of plants per hill had a substantial impact on the root length of onion (Table 02). At 35 DAT, the longest root length (8.00 cm) was recorded in P_1 treatment, while the shortest root length (6.03 cm) was recorded in the P_3 treatment. At 65 DAT, the longest root length (8.43 cm) was recorded in P_1 treatment, which was significantly reduced 14.82% and 23.72% in P_2 and P_3, respectively. At 95 DAT, the shortest root length (7.08 cm) was recorded in P_3 treatment, which was significantly increased by 21.07% and 12.37% in P_1 and P_2, respectively. The highest root length from this treatment might be due to cause of higher nutrient availability to plants because of lower plant number per hill where same fertilizer doses were used for all the treatment. Root length was significantly affected due to the effect of harvesting time at different growth stages of crops duration (Table 02). It was observed that the lowest root length were at 35 DAT (5.84cm), at 65 DAT (6.21cm) and at 95 DAT (6.61cm) achieved in H_1. It was also observed that the root length observed in H_2 (7.99cm), (8.49cm) and (9.47cm) which was significantly reduced in H_1 26.91%, 26.86% and 30.20% at 35 DAT, 65 DAT and 95 DAT, respectively. Root length was significantly influenced due to the combined effect of number of plants per hill and the time of harvesting (Table 02). At 35 DAT, the results showed that the treatment combination P_1H_2 produced the longest root length (9.40 cm), whereas the treatment P_3H_1 produced the shortest root length (5.03 cm), which was significantly reduced by 46.48%.At 65 DAT, The highest root length (10.03 cm) was found in P_1H_2 and the lowest root length (5.64 cm) was recorded from P_3H_1.At 95 DAT, the lowest root length (5.94 cm) was observed in P_3H_1 which was significantly increased by 17.85%, 44.48%, 10.81%, 37.47% and 27.74% in P_1H_1, P_1H_2, P_2H_1, P_2H_2 and P_3H_2, respectively.

Leaf Diameter (cm)

The different number of plants per hill at various phases

Table 2: Effect of plants per hill and harvesting time on growth parameters at different days after transplanting (DAT) of onion.

Treatments	Leaf length (cm)			Root length (cm)			Leaf diameter (cm)		
	35 DAT	65 DAT	95 DAT	35 DAT	65 DAT	95 DAT	35 DAT	65 DAT	95 DAT
Effect of plants per hill									
P_1	30.35±2.00a	47.49±2.65a	52.99±3.33a	8.00±.68a	8.43±.72a	8.97±.82a	0.29±.03b	0.43±.04b	1.57±.17b
P_2	28.88±1.75a	44.28±2.13ab	51.03±1.77ab	6.72±.43b	7.18±.47b	8.08±.68a	0.41±.07a	0.63±.09a	1.96±.12a
P_3	26.29±1.47a	40.34±2.22b	46.25±2.29a	6.03±.51b	6.43±.36c	7.08±.60b	0.35±.04ab	0.57±.04a	1.81±.12ab
LS	NS	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.01
CV (%)	11.01	8.53	9.09	9.87	3.1	9.58	17.99	14.31	11.24
Effect of harvesting time									
H_1	25.61±.92b	39.84±1.41b	46.15±1.56b	5.84±.30b	6.21±.18b	6.61±.27b	0.27±.02b	0.43±.03b	1.52±.10b
H_2	31.41±1.26a	48.23±1.62a	54.04±1.95a	7.99±.41a	8.49±.42a	9.47±.43a	0.43±.04a	0.65±.06a	2.04±.07a
LS	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CV (%)	11.01	8.53	9.09	9.87	3.1	9.58	17.99	14.31	11.24
Combined effect of plant per hill and harvesting time									
P_1H_1	26.68±1.58bc	42.30±2.02bcd	47.04±2.45bc	6.60±.36bc	6.83±.06c	7.23±.39cd	0.24±.03c	0.37±.04c	1.23±.13d
P_1H_2	34.03±2.02a	52.68±2.03a	58.95±3.72a	9.40±.49a	10.03±.12a	10.70±.47a	0.34±.03bc	0.50±.06bc	1.90±.09abc
P_2H_1	26.02±1.58bc	40.57±2.11cd	49.32±2.61bc	5.90±.35cd	6.15±.05d	6.66±.31d	0.27±.03c	0.43±.03c	1.76±1.10bc
P_2H_2	31.74±2.13ab	47.99±2.13ab	52.75±2.44ab	7.55±.37b	8.20±.27b	9.50±.45ab	0.55±.04a	0.83±.05a	2.16±.14a
P_3H_1	24.12±1.82c	36.65±2.63d	42.09±1.64d	5.03±.43d	5.64±.11e	5.94±.46d	0.23±.03bc	0.50±.04bc	1.58±.13cd
P_3H_2	28.47±1.66abc	44.03±2.03bc	50.41±2.48bc	7.03±.35bc	7.23±.00c	8.22±.56bc	0.41±.04b	0.64±.06b	2.04±.09ab
LS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CV (%)	11.01	8.53	9.09	9.87	3.1	9.58	17.99	14.31	11.24

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly by LS at P <0.05 level of probability P_1= One plant per hill, P_2= Two plants per hill, P_3= Three plants per hill H_1 = 110 DAT, H_2= 125 DAT, LS= Level of significant, CV=Coefficient of variation.

of development of the test crops had a substantial impact on leaf diameter (Table 02). According to the findings, the P_2 treatment had the largest leaf diameter (0.41cm) at 35 DAT, whereas the P_1 treatment had the smallest leaf diameter (0.29 cm) at same stage. At 65 DAT, the highest leaf diameter was found in P_2 (0.63 cm) which was significantly reduced by 31.74% and 9.52% in P_1 and P_3, respectively. The maximum leaf diameter (1.96 cm) was found in P_2 at 95 DAT which was significantly decreased by 19.89% and 7.65% in P_1 and P_3, respectively. Leaf diameter of onion was significantly influenced by harvesting time in all growth phases (Table 02). At 35 DAT, it was discovered that H_2 had the largest leaf diameter (0.43 cm), while H1 had the smallest leaf diameter (0.27 cm). At 65 DAT, The highest leaf diameter (0.65 cm) was observed in H_2 which was 33.85% higher than H_1. At 95 DAT, the highest leaf diameter was recorded in H_2 (2.04 cm) and the lowest leaf diameter was (1.52 cm) observed in H_1 which was 25.49% lower than H_2. The interaction between the number of plants per hill and the time of harvest had a significant impact on the leaf diameter at every stage of development (Table 02). At 35 DAT, the highest leaf diameter (0.55 cm) was recorded in P_2H_2 and the lowest leaf diameter (0.23 cm) which was significantly reduced by 55.18% in P_3H_1. At 65 DAT, the highest leaf diameter (0.83 cm) was observed in P_2H_2 which was significantly reduced by 55.42%, 39.76%, 48.19%, 39.76% and 22.89 % in P_1H_1, P_1H_2, P_2H_1, P_3H_1 and P_3H_2, respectively. The result at 95 DAT showed that, the highest leaf diameter (2.16 cm) was found in P_2H_2 which was significantly reduced by 43.06%, 12.04%, 18.52%, 26.85% and 5.56% in P_1H_1, P_1H_2, P_2H_1, P_3H_1 and P_3H_2, respectively.

Yield Contributing Parameters

Neck Diameter (cm): The effect of plant number per hill had a substantial influence on : the neck diameter at various stages of development for the test crops (Table 03). At 35 DAT, P_2 showed the largest neck diameter (0.99 cm), whereas P_1 showed the smallest neck diameter (0.80 cm). At 65 DAT, the lowest neck diameter was observed in P1 and the highest neck diameter (1.04 cm) was recorded in P_2 which was 13.46% higher than P_1. At 95 DAT, the highest neck diameter (1.77 cm) was observed in P_2 which was reduced by 16.38% and 19.21 % in P_1 and P_3, respectively. Significant influence was found in the neck diameter of the onion affected by the harvesting time in all growth phases (Table 03). At 35 DAT, it revealed that H_2 had the largest neck diameter (1.05 cm), whereas H_1 had the smallest neck diameter (0.73 cm). At 65 DAT, The highest neck diameter (1.11 cm) was observed in H_2 which was 23.42% higher than H_1. At 95 DAT, the lowest neck diameter (1.27cm) was recorded in H_1 and the highest neck diameter was (1.85cm) observed in H_2 which was 31.35 % higher than H_1.

The combined effect of plants per hill and harvesting time had significant influence on the neck diameter of onion in all growth stages (Table 03). At 35 DAT, the

Table 3: Effect of plants per hill and harvesting time on yield parameters at different days after transplanting (DAT) of onion.

Treatments	Neck diameter (cm)			Bulb length (cm)			Bulb diameter (cm)		
	35 DAT	65 DAT	95 DAT	35 DAT	65 DAT	95 DAT	35 DAT	65 DAT	95 DAT
Effect of plants per hill									
P_1	0.80±.07b	0.90±.06a	1.48±.14b	3.23±.20a	3.60±.34b	5.82±.40b	1.88±.21b	2.06±.20b	3.77±.27a
P_2	0.99±.09a	1.04±.09a	1.77±.10a	3.85±.38a	5.38±.78a	7.30±.63a	2.46±.23a	2.74±.27a	4.31±.23a
P_3	0.89±.09ab	1.00±.07a	1.43±.19b	3.45±.31a	4.16±.37b	6.38±.40ab	2.30±.15a	2.58±.11a	4.04±.22a
LS	0.05	NS	0.01	NS	0.01	0.01	0.01	0.01	NS
CV (%)	13.27	12.07	8.11	13.73	14.31	11.53	9.89	8.43	10.96
Effect of harvesting time									
H_1	0.73±.04b	0.85±.03b	1.27±.09b	3.00±.15b	3.41±.19b	5.63±.23b	1.82±.11b	2.06±.13b	3.64±.16b
H_2	1.05±.05a	1.11±.05a	1.85±.04a	4.02±.22a	5.35±.47a	7.36±.39a	2.62±.11a	2.86±.14a	4.44±.14a
LS	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CV (%)	13.27	12.07	8.11	13.73	14.31	11.53	9.89	8.43	10.96
Combined effect of plant per hill and harvesting time									
P_1H_1	0.69±.10b	0.82±.06c	1.19±.06c	3.03±.31c	3.01±.34c	5.14±.43c	1.46±.17d	1.65±.15d	3.31±.33c
P_1H_2	0.91±.05bc	0.98±.07bc	1.76±.07ab	3.43±.27bc	4.18±.35bc	6.49±.40bc	2.31±.09bc	2.48±.08bc	4.23±.22ab
P_2H_1	0.81±.05c	0.88±.06c	1.60±.10b	3.09±.27c	3.75±.33bc	6.08±.30bc	1.98±.08c	2.14±.13c	3.92±.21abc
P_2H_2	1.17±.07a	1.21±.10a	1.95±.08a	4.61±.27a	7.01±.48a	8.51±.62a	2.94±.16a	3.33±.12a	4.70±.28a
P_3H_1	0.70±.06c	0.86±.06c	1.01±.06c	2.87±.27c	3.47±.30c	5.68±.35bc	2.02±.13c	2.39±.09bc	3.69±.23bc
P_3H_2	1.07±.07ab	1.13±.05ab	1.85±.07a	4.02±.27ab	4.86±.34b	7.08±.42b	2.59±.10ab	2.77±.14b	4.39±.25ab
LS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CV (%)	13.27	12.07	8.11	13.73	14.31	11.53	9.89	8.43	10.96

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly by LS at P <0.05 level of probability P_1= One plant per hill, P_2= Two plants per hill, P_3= Three plants per hill H_1 = 110 DAT, H_2= 125 DAT, LS= Level of significant, CV=Coefficient of variation.

results revealed that the treatment combination of P_2H_2 produced the largest neck diameter (1.17 cm), whereas P_1H_1 produced the smallest (0.69 cm). At 65 DAT, the lowest neck diameter (0.82 cm) was observed in P_1H_1 and the highest neck diameter (1.21 cm) was found in P_2H_2 which was 32.23 % higher than P_1H_1. At 95 DAT, the neck diameter of P_2H_2 was the largest (1.95 cm), which was significantly reduced by P_1H_1, P_1H_2, P_2H_1, P_2H_2, P_3H_1,n and P_3H_2, respectively.

Bulb Length (cm): Significant influence was noted on bulb length of onion affected by the number of plants per hill (Table 03) It was found that the P_2 treatment had the longest bulb length (3.85 cm) at 35 DAT, whereas the P_1 treatment had the shortest, which was considerably reduced by 16.10%. At 65 DAT, it was determined that P_2 had the longest bulb length (5.38 cm), while P_1 was 33.09% shorter than P_2. At 95 DAT, the bulb length in P_2 was the longest (7.30 cm), which was significantly decreased by 20.27% and 12.60% in P_1 and P_3, respectively. At every stage of development, there was a significant effect of harvesting time on leaf length of onion (Table 03). At 35 DAT, it was noted that the highest bulb length (4.02 cm) was observed in H_2 treatment where the shortest bulb length (3.00 cm) was found in H_1 treatment. At 65 DAT, the highest bulb length (5.35 cm) was found in H_2 which was 36.26% higher than H_1. At 95 DAT, the lowest bulb length (5.63cm) was observed in H_1 which was significantly increased by 23.51% in H_2. The interactions between plants per hill and harvesting time had a significant impact on bulb length (Table 03). The interactions between plants per hill and harvesting time had a significant impact on bulb length. According to the findings, at 35 DAT, the bulb length in P_2H_2 was the longest (4.61 cm), while the bulb length in P_3H_1 was the shortest (2.87 cm). At 65 DAT, the highest bulb length (7.01cm) was found in P_2H_2 which was significantly reduced by 57.03% in P_1H_1 which was the lowest. At 95 DAT, it was determined that P_2H_2 had the highest bulb length (8.51 cm), while bulb length in P_3H_1 was significantly reduced by 39.60%.

Bulb Diameter (cm): The number of plants per hill had a significant impact on bulb diameter of onion (Table 03). At 35 DAT, the P_2 treatment produced the maximum bulb diameter (2.46 cm), whereas the P_1 produced the minimum bulb diameter (1.88 cm). The P_2 treatment produced the largest bulb diameter (2.74 cm), whereas the P_1 treatment produced the smallest bulb diameter (2.06 cm) at 65DAT. At 95 DAT, the P_1 treatment resulted in the smallest bulb diameter (3.77 cm), but the P_2 treatment and P_3 treatment both resulted in significantly increased by 12.53% and 6.68%, respectively. It is eminent that bulb diameter was significantly increased at different growth stages. Bulb diameter was significantly influenced due to the harvesting time (Table 03). According to the findings, the H_2 had the largest bulb diameter (4.44 cm) at 95 DAT, while H_1 had the smallest bulb diameter (1.82 cm) at 35 DAT. In H_1, bulb diameter was found (1.82cm), (2.06cm) and (3.64cm) which was significantly increased by 30.53%, 27.97% and 18.02% in H_2 at 35 DAT, 65 DAT and 95 DAT, respectively. The combined effect of number of plants per hill and harvesting time had a significant influence on bulb diameter (Table 03). It was found that the smallest bulb diameter (1.46 cm) was obtained in P_1H_1, which was 11.52% and 55.89% lower than that was in 65 DAT and 95 DAT, respectively. At 95 DAT, the highest bulb diameter (4.70 cm) was remarked in P_2H_2 which was significantly reduced by 29.57%, 10.00%, 16.60%, 21.49% and 6.60% in P_1H_1, P_1H_2, P_2H_1 P_3H_1 and P_3H_2 , respectively.

Fresh weight bulb^{-1} (g): There was a significant influence on the fresh weight of onion affected by the number of plants per hill (Table 04). At 35 DAT, the highest fresh weight bulb^{-1} (13.24 g) was obtained in P_2 which was reduced by 18.96% in P_1. At 65 DAT, the P_1 treatment had the lowest fresh weight (38.15 cm) which was significantly increased by 12.24% in P_2. At 95 DAT, P_2 treatment had the highest fresh weight (64.11 g) which was significantly reduced by 12.23% and 5.86 % in P1 and P_3, respectively. Fresh weight bulb^{-1} of onion was significantly impacted by the harvesting time (Table 04). According to the findings, the highest fresh weight per bulb (66.13g) was in H_2 treatment at 95 DAT whereas the lowest fresh weight per bulb (10.19g) was in H_1 at 35 DAT. At 65DAT, the highest fresh weight per bulb (44.84g) was in H_2 which was significantly reduced by 17.81%. The progression of the growth of bulb and maturation resulted in a rise in its fresh weight. This may be explained with a progressive increase of day- length and sunlight intensity during the crop cycle.

Considering the combined effect at 65 DAT, the lowest fresh weight (35.56 g) was observed in P_1H_1 which was significantly increased by 3.65 and 6.61% in P_3H_1 and P_2H_1, respectively. At 95 DAT, The highest fresh weight (72.06 g) was found in P_2H_2 and the lowest fresh weight (52.45g) was recorded in P_1H_1 which was 27.21 % lower. At 95 DAT, the highest dry weight bulb^{-1} (36.84 g) was found in P_2 that was significantly reduced by 4.29 % and 2.14 % in P_1 and P_3, respectively.

Dry Weight Bulb^{-1}: The number of plants per hill had a significant impact on dry weight of onion bulb (Table 04). At 35 DAT, the maximum dry weight bulb^{-1} (8.40 g) was found in P_2 which was slightly reduced by 25.11 % in P_1. At 65 DAT, the lowest dry weight bulb^{-1} (15.81 g) was recorded in P_1 which was increased by 12.31 % in P_2. Significant influence was found on dry weight of onion by the harvesting time (Table 04). At 35 DAT, The highest dry weight bulb^{-1} (9.13 g) was found in H_2 which was significantly 35.27% higher than H_1. The result at 65 DAT showed that the lowest dry weight bulb^{-1} (15.38 g) was found in H_1 which was 16.28 % lower than H_2. At 95 DAT, The highest dry weight bulb^{-1} (37.22 g) was found in H_2 which was significantly 6.31% higher than H_1. Dry weight of onion was significantly influenced by the combined effect of number of plants per hill and harvesting time (Table 04). At 35 DAT, the highest dry weight (10.11 g) was obtained in P_2H_2 which was slightly

Table 4: Effect of plants per hill and harvesting time on yield parameters at different days after transplanting (DAT) of onion.

Treatments	Fresh weight bulb-1(g)			Dry weight bulb-1(g)		
	35 DAT	65 DAT	95 DAT	35 DAT	65 DAT	95 DAT
Effect of plants per hill						
P_1	10.73±.92a	38.15±1.47b	56.27±2.24b	6.29±.72b	15.81±.69b	35.26±.63b
P_2	13.24±1.72a	43.47±2.51a	64.11±3.74a	8.40±.95a	18.03±.78a	36.84±.50a
P_3	12.91±1.12a	40.92±1.98ab	60.35±2.96ab	7.88±.89ab	16.80±.80ab	36.05±.74ab
LS	NS	0.01	0.01	0.05	0.01	0.05
CV (%)	16.82	5.53	6.04	16.83	5.77	2.55
Effect of harvesting time						
H_1	10.19±.57b	36.85±.65b	54.35±1.04b	5.91±.41b	15.38±.39b	34.87±.36b
H_2	14.40±.99a	44.84±1.39a	66.13±2.10a	9.13±.55a	18.37±.46a	37.22±.36a
LS	0.01	0.01	0.01	0.01	0.01	0.01
CV (%)	16.82	5.53	6.04	16.83	5.77	2.55
Combined effect of plant per hill and harvesting time						
P_1H_1	9.81±1.15c	35.56±1.17c	52.45±1.90d	4.87±.60d	14.36±.39e	33.95±.38c
P_1H_2	11.66±1.45bc	40.74±1.66b	60.09±2.63bc	7.71±.44bc	17.26±.37bc	36.56±.36a
P_2H_1	9.69±.95c	38.08±.99bc	56.16±1.65cd	6.68±.51cd	16.61±.42cd	35.98±.40ab
P_2H_2	16.79±1.14a	48.86±1.27a	72.06±2.05a	10.11±1.13a	19.44±.94a	37.69±.61a
P_3H_1	11.07±1.06bc	36.91±1.08bc	54.55±1.77cd	6.18±.71cd	15.18±.46de	34.69±.44bc
P_3H_2	14.75±1.34ab	44.92±1.52a	66.25±2.43ab	9.57±.78ab	18.42±.58ab	37.40±.82a
LS	0.05	0.05	0.05	0.05	0.05	0.05
CV (%)	16.82	5.53	6.04	16.83	5.77	2.55

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly by LS at P <0.05 level of probability P_1= One plant per hill, P_2= Two plants per hill, P_3= Three plants per hill H_1 = 110 DAT, H_2= 125 DAT, LS= Level of significant, CV=Coefficient of variation.

reduced by 5.34% in P_3H_2. The result at 65 DAT showed that, the lowest dry weight (14.36g) was recorded in P_1H_1 which was slightly increased by 5.40% in P_3H_1. At 95 DAT, the highest dry weight (37.69 g) was observed in P_2H_2 which was slightly reduced by 9.92 %, 2.99%, 4.54%, 7.96 %and 0.76 % in P_1H_1, P_1H_2, P_2H_1, P_3H_1 and P_3H_2, respectively.

Yield of Onion

Fresh yield per Hectare (t): Significant influence was found on fresh yield per hectare of onion influenced by number of plants per hill (Table 05). According to the findings, the treatment P_2 produced the highest yield per hectare (17.67t), while the treatment P_1 produced the lowest yield per hectare (15.92t), which was 4.49% less than P_2. There was an intermediate result obtained in the treatment P_3 (16.59ton/ha), followed by the treatment P_2 and P_1. Fresh Yield per hectare was significantly influenced due to the harvesting time (Table 05). It was showed that the highest yield per hectare (17.72t) was achieved from H_2 (125 DAT) treatment whereas the lowest yield per hectare (15.73t) was achieved from H_1 (110 DAT) which was 11.23% lower.

Significant influence was observed on fresh yield per hectare affected by combined of number of plants per hill and harvesting time (Table 05). It was verified that the highest yield per hectare (19.14t) was obtained from the treatment combination P_2H_2 which was significantly different from all other treatment combinations except P_3H_2. The second highest yield per hectare (17.42t) was achieved from the treatment combination of P_3H_2. The lowest yield hectare (15.23t) was obtained from the treatment combination of P_1H_1 which was also statistically similar with the treatment combinations except P_1H_2, P_2H_1 and P_3H_1.

Dry yield per hectare (t): Significant influence was found on dry yield per hectare of onion influenced by number of plants per hill (Table 05). According to the findings, the treatment with two plants per hill (P_2) produced the highest dry yield per hectare (15.50 t), while the treatment P_1 produced the lowest dry yield per hectare (13.96 t), which was 9.93% less than P_2. There was an intermediate result obtained (14.55 ton/ha) in the treatment P_3, which was followed by the treatment P_2 and the treatment P_1. Yield per hectare was significantly varied due to harvesting time (Table 05). It was examined that the highest yield per hectare (15.54 t) was achieved from H_2 (125 DAT) treatment whereas the lowest yield per hectare (13.80t) was achieved from H_1 (110 DAT) which was 11.19% lower. Combined effect of number of plants per hill and harvesting time had significant influence on yield per hectare (Table 05). It was verified that the highest yield per hectare (16.79 t) was obtained from the treatment combination of P_2H_2 which was significantly different from all other treatment combinations except P_3H_2. The second highest yield per hectare (15.26 t) was achieved

Table 5: Effect of plants per hill and harvesting time on yield of onion.

Treatments	Fresh yield ha^{-1} (t)	Fresh yield ha^{-1} (t)
Effect of plants per hill		
P_1	15.92±.48b	13.96±.42b
P_2	17.67±.76a	15.50±.66ab
P_3	16.59±.55ab	14.55±.48a
LS	0.05	0.01
CV (%)	6.33	6.34
Effect of harvesting time		
H_1	15.73±.32b	13.80±.28b
H_2	17.72±.79a	15.54±.43a
LS	0.05	0.01
CV (%)	6.33	6.34
Combined effect of plant per hill and harvesting time		
P_1H_1	15.23±.59c	13.36±.52c
P_1H_2	16.60±.59bc	14.56±.52bc
P_2H_1	16.21±.57bc	14.22±.50bc
P_2H_2	19.14±.63a	16.79±.55a
P_3H_1	15.76±.56bc	13.83±.49bc
P_3H_2	17.42±.71ab	15.26±.62ab
LS	0.05	0.01
CV (%)	6.33	6.34

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly by LS at P <0.05 level of probability P_1= One plant per hill, P_2= Two plants per hill, P_3= Three plants per hill H_1 = 110 DAT, H_2= 125 DAT, LS= Level of significant, CV=Coefficient of variation.

from the treatment combination of P_3H_2. The lowest yield hectare (13.36 t) was obtained from the treatment combination of P_1H_1 which was also significantly different from all other treatment combinations except P_1H_2, P_2H_1 and P_3H_1.

Economic Analysis: All material and non-material input costs (Table 06) such as land preparation, onion seedling cost, interest on fixed capital of land (loaned land) and miscellaneous costs were considered for calculating the total cost of production from planting seeds to onion bulb harvesting were calculated for cost per hectare. The market price of an onion bulb was evaluated. The following headlines are used to present the economic analysis:

Gross Income: The variable numbers of plants per hill and times of harvesting produced varying degrees of gross return across the treatment combinations (Table 07). The gross income was estimated based on the sale of mature bulbs. The P_2H_2 treatment combination produced the highest gross return (861300Tk), while the P_1H_1 treatment combination produced the lowest gross return (685350Tk).

Net Return: The treatment combinations with varied levels of plants per hill and harvesting time had different net returns (Table 07). The P_2H_2 treatment combination produced the maximum net return (455675Tk), while the P_1H_1 treatment combination produced the lowest net return (287570Tk).

Benefit Cost Ratio (BCR): There was a significant difference in BCR between the various treatment

Table 6: Input cost (Tk. ha^{-1}) of onion production

Treatments	Cultivation	Onion seedlings	Manure and fertilizers				Transplanting cost	Pesticide	Irrigation	Subtotal (A)
			Cowdung	Urea	TSP	MP				
P_1H_1	96154	5767.5	32000	3080	1320	1800	48076	5000	3700	196897
P_1H_2	96154	5767.5	32000	3080	1320	1800	48076	5000	3700	196897
P_2H_1	96154	11535	32000	3080	1320	1800	48076	5000	3700	202665
P_2H_2	96154	11535	32000	3080	1320	1800	48076	5000	3700	202665
P_3H_1	96154	17302.5	32000	3080	1320	1800	48076	5000	3700	208432
P_3H_2	96154	17302.5	32000	3080	1320	1800	48076	5000	3700	208432

Note: P_1= One plant $hill^1$, P_2= Two plants $hill^1$, P_3= Three plants hill-1 H_1 = 110 DAT, H_2= 125 DAT Seed: 250 tk/kg, Cow dung: 4 tk/kg, Urea: 22tk/kg, TSP: 22tk/kg, MP: 15tk/kg.

Table 7: Cost and return benefit of onion production

Treatments	Overhead cost				Subtotal (A)	Total cost of production (A+B)	Yield ha^{-1} (ton)	Gross return (Tk. ha^{-1})	Net return (Tk. ha^{-1})	BCR
	Cost of leased land for 6 months (13% of value of land Tk. 10,00,000/-	Miscellaneous cost (Tk. 5% of the input cost	Interest on running capital for 6 month ((13% of cost year1)	Subtotal (B)						
P_1H_1	65000	9844.8	25596.61	100441.4	196897	397338.4	15.23	685350	287570	1.71
P_1H_2	65000	9844.8	25596.61	100441.4	196897	397338.4	16.6	747000	349220	1.87
P_2H_1	65000	10133.2	26346.45	101479.7	202665	404144.7	16.21	729000	323375	1.79
P_2H_2	65000	10133.2	26346.45	101479.7	202665	404144.7	19.14	861300	455675	2.12
P_3H_1	65000	10421.6	27096.16	102517.8	208432	410949.8	15.76	709200	295732	1.72
P_3H_2	65000	10421.6	27096.16	102517.8	208432	410949.8	17.42	783900	370432	1.89

Note: P_1= One plant hill^{-1}, P_2= Two plants hill^{-1}, P_3= Three plants hill^{-1}, H_1 = 110 DAT, H_2= 125 DAT, Selling price of bulb = 45Tk/kg

combinations of plants per hill and harvesting time that was found (Table 07). The benefit cost ratio (BCR) achieved from the P_2H_2 treatment combination was the highest (2.12), while the Benefit cost ratio obtained from the P_1H_1 treatment combination was the lowest (1.71). It was obvious from the above results, from an economic point of view, that the combination of P_2H_2 (Two plants per hill with harvesting time at 125 DAT) was more profitable than the rest of the treatment combinations. This was determined by comparing P_2H_2 to the other treatment combinations.

CONCLUSION

Based on the experimental results, it can be concluded that the growth, yield, and quality of onions were positively influenced by the number of plants per hill. The combination of two plants per hill (P_2) and harvesting at 125 days after transplanting (H_2) proved to be the most effective for achieving a higher yield. From an economic perspective, the treatment combination of P_2H_2 (two plants per hill with harvesting at 125 DAT) was identified as the most suitable under the conditions of the present study.

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