American Journal of Agriculture and Forestry
2025, Vol. 13, No. 1, pp. 38-48
https://doi.org/10.11648/j.ajaf.20251301.15

Research Article

Supplementary Biomass Addition Enhances the Crop Productivity: Evidence from a *Gliricidia sepium* - Based Alley Cropping Practices in Gazipur District of Bangladesh

Abu Syed Md. Jobaydul Alam[1, 4], Satya Ranjan Saha[1], Md. Suhag[1, *], Md. Giashuddin Miah[1], Md. Mizanur Rahman[2], Md. Rafiqul Islam[3], Zabid Al Riyadh[1, 5], Apple Mahmud[3]

[1]Department of Agroforestry and Environment, Gazipur Agricultural University, Gazipur, Bangladesh
[2]Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh
[3]Department of Agronomy, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh
[4]Department of Agriculture Extension, Khamarbari, Barguna, Bangladesh
[5]Department of Horticulture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh

Abstract

Two consecutive experiments were conducted to investigate the effect of alley cropping practices on the productivity of cauliflower during the winter season of 2016-2017 and 2017-2018. An eleven-year-old *G. sepium*-established alley cropping field was used as the experimental site located in Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh. The experiments were done using a split-plot design. Three alley widths of *G. sepium viz*. $W_{3.0}$, $W_{4.5}$, and $W_{6.0}$ (3.0 m, 4.5 m, and 6.0 m) comprised factor A, the main plot factor. Within each main plot, five nitrogen (N) doses namely N_0, N_{25}, N_{50}, N_{75}, and N_{100} contributed the five levels of factor B (sub-plot factor) each replicated thrice. Control plots received allied N doses without pruned biomass to facilitate comparison with the alley cropping. The data from the two seasons on cauliflower were subjected to pooled analysis using R-statistics. Results revealed that, growth and yield attributes of cauliflower thrived in all the alley cropping plots compared to control (absence of tree), and increased along with the increase in applied N. Further, we assessed what combinations of alley width and N level provide the highest yield and found that, $W_{6.0} \times N_{100}$ treatment combination yielded the highest cauliflower yield (33.55 t ha^{-1}) which was statistically equivalent to the yields of $W_{6.0} \times N_{75}$ and $W_{6.0} \times N_{50}$ combinations. It was also observed that all the alley cropped plots given higher economic benefit compared to control, specifically with the first three highest Benefit-to-Cost Ratios (BCRs) calculated in $W_{6.0} \times N_{100}$ (3.27), $W_{6.0} \times N_{50}$ (3.23), and in $W_{6.0} \times N_{75}$ (3.21) treatment combinations. The outcome suggests that using pruned materials can be a viable alternative to enhance crop productivity, profitability and reduce the reliance on nitrogenous fertilizer.

Keywords

Alley Cropping, Benefit Cost Ratio, Cauliflower, *Gliricidia sepium*, Pruned Biomass

[*]Corresponding author: suhag@bsmrau.edu.bd (Md. Suhag)

Received: 23 January 2025; **Accepted:** 5 February 2025; **Published:** 20 February 2025

1. Introduction

Bangladesh is a small deltaic nation with a predominantly agrarian economy which harbors a tremendous population of 169.83 million with an arable land of 8.09 million hectares [1, 2]. Shockingly, development projects such as housing for the growing population, the establishment of new industries, and infrastructure are collectively leading to the gradual reduction of cultivable land [3]. To feed the ever increasing population, farmers are compelled to practice intensive agriculture on their limited land resources and consequently, soil fertility is diminishing rapidly with simultaneous reduction of crop yields. It is well known that organic matter (OM) is the storehouse of plant nutrients and the soil necessitates an amount of 2.5% OM but unfortunately, most of the soils of Bangladesh are deficient in organic matter which is around 0.5-1.15% [4]. Additionally, the climate change and environmental pollutions have created a dilemma for the sustainable agriculture. In spite of enormous challenges, viable farming practices should be looked up and adopted to address the above-mentioned facts. Many farming techniques have been emerged to resolve the problems of crop productivity and soil environment; of which, agroforestry may be a good choice to guarantee sustainable production and get past upcoming obstacles [5].

The practice of integrating trees with crops or vegetables on the same plot of land, known as agroforestry, involves growing annual crops alongside woody perennials in a way that maintains a balanced spatial and temporal arrangement. It offers a solid ecological foundation for improving the systems overall productivity, soil fertility, and agricultural communities' socioeconomic conditions [6, 7]. Alley cropping, which incorporates leguminous tree species into cropping systems, is a beneficial method among different agroforestry systems [8]. In this approach, tree legumes regularly cut down to minimize competition with crops, and pruned materials are added to the soil to enhance its physico-chemical qualities, which in turn increase crop yield. Alley cropping techniques employ a variety of legume species, including *Gliricidia sepium*, *Indigofera tysmanii*, *Senna siamea*, *Leucaena leucocephala*, *Cassia siamea*, *Cajanus cajan*, and others, with *Gliricidia sepium* being the most appropriate one [9-12]. It’s a multifunctional, fast-growing tree species that sequestrate carbon, fixes nitrogen, conserves soil, enhances soil health, recycle nutrients, and thrives in a variety of soil types, ranging acidic to alkaline [13, 14]. The biomass is rich in minerals and recognized to be effective in improving soil health [15].

According to a number of studies, the use of *G. sepium* tree legume in cropping systems improved soil health, including soil minerals, organic matter, and beneficial soil microbes [16-18]. Besides, it is evident that cotton, soybean, maize, groundnut, and tomato etc. thrive when cultivated alongside this particular legume species [19-21]; but still the utilization of this species is limited in Bangladesh, and demanding further research to determine its usefulness. In Bangladesh, a large variety of vegetables are cultivated, with approximately 70% of them are grown in winter [22], and cauliflower (*Brassica oleracea* var. *botrytis*) is the most important nutritious one, as its curd is the richest source of B vitamins, vitamin A, C, E and minerals like Ca, Fe and Iodine [23, 24]. Additionally, it has adequate levels of dietary fiber, potassium, phosphorus, magnesium, manganese, and omega-3 fatty acids, all of which may help prevent a number of chronic diseases, such as cardiovascular disease, type II diabetes, immunological dysfunction, age-related macular degeneration, obesity, and some types of cancer [25, 26]. Fascinatingly, the consumption of vegetables has increased in Bangladesh, but the yield of cauliflower per unit area is quite low compared to other affluent nations; and out of many reasons, nutrient supply is the most limiting factor.

The aim of the experiment was to evaluate the growth and yield of cauliflower cultivated in different alley widths of G. *sepium*, combined with varying nitrogen levels, building upon the nutritional significance and cultivation practices of cauliflower as outlined.

2. Materials and Methods

2.1. Geographical and Climatic Description of the Study Area

An established alley cropping field of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh was used for the completion of present experiment. The study site is located at 8.5 meters above sea level under the Madhupur Tract (Agroecological zone-28) which is presented in Figure 1. The experiment was set up on the soil under Salna Series, characterized as shallow red-brown terrace soil [27]. Two consecutive experiments were conducted during the winter seasons (November-February) of 2016-2017 and 2017-2018. The study site has a subtropical climate with mild-winter and summer. The mean monthly air temperature ranging from 16.9 ℃ to 23.8 ℃ and humidity levels between 80.56-90.62% during the cropping seasons. The area receives an average annual rainfall of 2031.14 millimeter (mm) with heavy rainfall predominantly occurring in July-August.

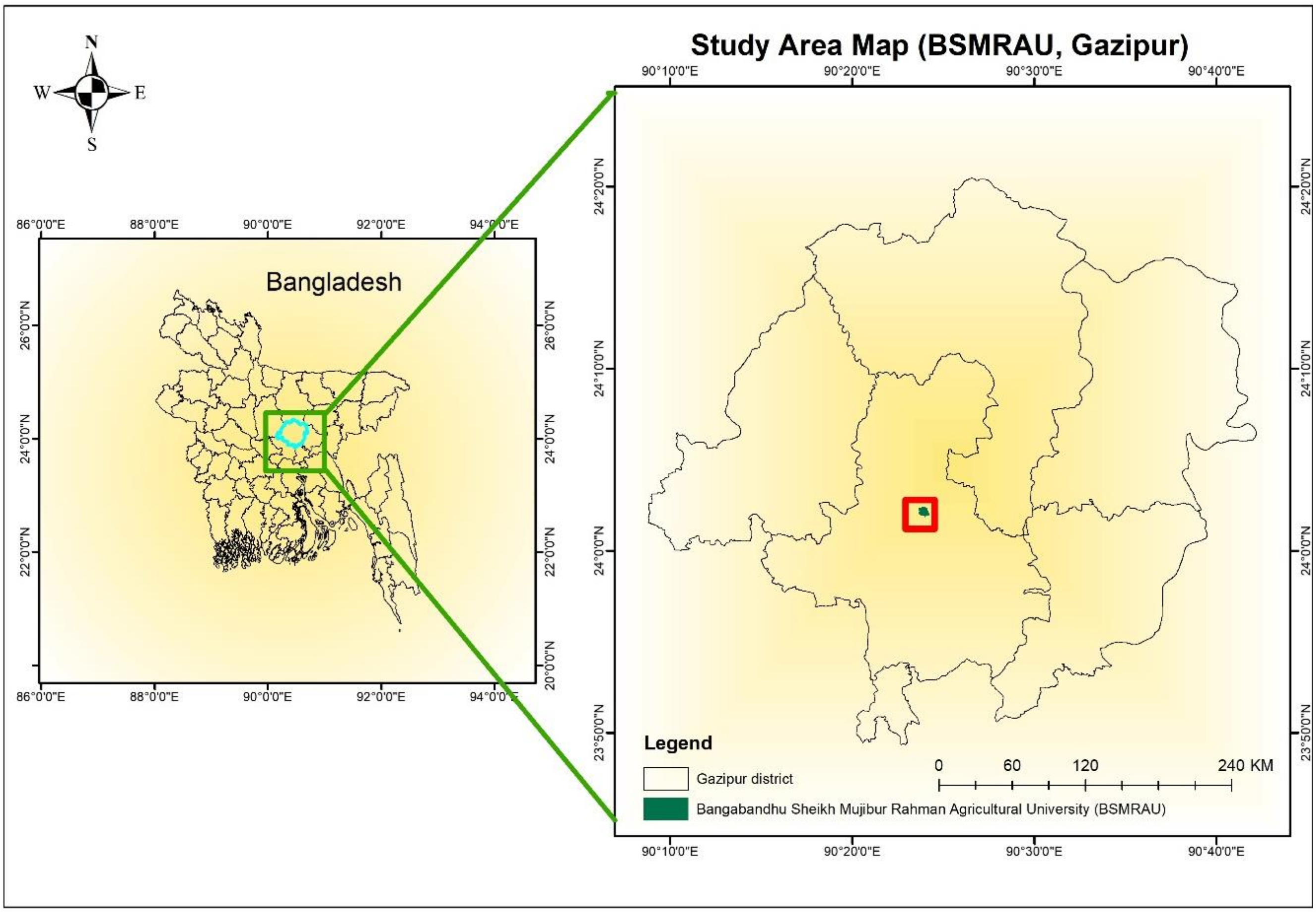

Figure 1. Location of the study area.

2.2. Establishment of Alley Cropping Field and Pruning of *G. sepium* Legumes

In September 2005, *G. sepium* tree seedlings were planted into the experimental field, keeping a 50 centimeters (cm) gap between trees in each row. Each seedling was fertilized with 2 Kg cowdung, 20 g TSP, and 10 g MoP fertilizers, alongside the implementation of suitable management practices to facilitate the proper establishment of the hedgerow. Therefore, in this study, an eleven-year-old *G. sepium* alley field was chosen. Pruning was carried out on the 2nd of October, 2016 for the first season trial and the 7th of October, 2017 for the second season in order to incorporate the fresh green biomass of *G. sepium* into the soil in various alleyways. With the aid of a rotavator and disc plow, the harvested pruned materials were spread out into the soil between the alleys of varying widths and thoroughly mixed with the soil. Table 1 showing the quantity of trimmed materials collected from various alley widths during the two studies. Irrigation was provided to facilitate the complete breakdown of biomass, thereby ensuring the release and integration of nutrients into the soil, ultimately enhancing the fertility status of the plots.

Table 1. Pruned materials obtained from different alley widths of Gliricidia sepium during the cropping seasons of 2017 and 2018.

Alley width	Fresh biomass (t ha^{-1})	
	2016-2017	2017-2018
3.0 m	12.55	11.95
4.5 m	8.66	8.19
6.0 m	6.65	6.09

2.3. Experimental Design and Treatments

The field experiment on cauliflower in the alley cropping system was conducted using a split-plot design with three replications. The main plot treatments included three different alley widths *viz*. $W_{3.0}$, $W_{4.5}$, and $W_{6.0}$ (3.0 m, 4.5 m, and 6.0 m) and sub-plot treatments comprised five different N doses such as N_0, N_{25}, N_{50}, N_{75}, and N_{100} (representing 0%, 25%, 50%, 75%, and 100% of the recommended N dose plus fresh biomass from *G. sepium*). Besides, control plots (without tree) were arranged to receive identical inorganic N doses without pruned biomass. Initially, 15 unit plots were created for each alley and control area, taking into account the five distinct nitrogen levels with three replications. As a result, there were 60 unit plots in the current study. The total area of each unit plot was 3.0 × 5.0 m, 4.5 × 5.0 m, and 6.0 × 5.0 m for 3.0, 4.5, and 6.0 m alleys, respectively, as each unit plot was 5.0 m long. The individual control plot had dimensions of 3.0 x 5.0 m. The experiment used Snow White, a prominent variety of Cauliflower from ACI Seed Ltd. as a test crop.

2.4. Field Preparation and Crop Husbandry of Cauliflower

The experimental plots between two tree rows (i.e., alleys) were expertly prepared by harrowing, laddering, and plowing with a small tractor. The field was thoroughly prepped after all the chaff and weeds were eliminated. On October 14, 2016 and October 20, 2017, seeds were sown in seedbed and raised for thirty days'. Seedlings were moved and transplanted in a 60 × 60 cm spacing into the main field on November 12, 2016 for the first season and on November 18, 2017 for the second season trial. In the experimental plots, fertilizers were provided at the following rates: 150 Kilogram per Hectare (Kg ha^{-1}) of urea, 150 Kg ha^{-1} of triple superphosphate (TSP), 120 Kg ha^{-1} of muriate of potash (MoP), 100 Kg ha^{-1} of gypsum, and 3 Kg ha^{-1} of boric acid [28]. At the time of final land preparation, the full amount of gypsum, TSP, and boric acid was applied. At 15 and 35 days after transplanting (DAT), the crops received the MoP fertilizer at two equal installments. As the top dressing in both seasons, urea was given to the crop in two equal installments at 15 and 35 DAT in accordance with the experimental treatments. In both experiments, weeding was done three times at 15, 35, and 50 DAT. Five days after transplanting, first irrigation was provided using a suitable hose pipe, which was continued based on the crops' needs. Regular steps were taken to manage diseases and pests.

2.5. Growth and Yield Attributes of Cauliflower

Curd diameter, curd length, marketable curd weight, and cauliflower yield were measured at 90 days after transplanting in order to evaluate the growth and yield of cauliflower. Ten plants were chosen at random and taken from each unit plot in accordance with treatments to be considered as one replication in order to reduce error.

2.6. Economic Analysis

Cost of production: Initial planting expenses, labor costs, mechanical power costs, material costs (fertilizer, pesticides, seed, manures etc.), cost of land usage, management costs, and interest on used capital were used to determine the total cost of production ha^{-1}.

Gross return: Cauliflower's gross return ha^{-1} was calculated by multiplying the entire production by the corresponding market prices.

Net return: Net return was calculated by deducting the total cost of production from the gross return.

Benefit cost ratio (BCR): BCR, which is computed using the following formula, is the ratio of gross return to total cost of production.

$$BCR = \text{Gross return (Tk ha}^{-1}) \div \text{Total cost of production (Tk ha}^{-1})$$

2.7. Statistical Analysis

With the use of the software program "Statistix 10.0" and Microsoft Excel, the experimental data were statistically examined using the two-way "Analysis of Variance" (ANOVA) technique in order to look for significant differences in the outcomes caused by various treatments. In order to interpret the data, Tukey's HSD test was used to assess the mean differences between the treatment combinations at 5% level of probability. The R-Software package was used to perform a pooled analysis of two year's data.

3. Results and Discussion

3.1. Curd Diameter

Diameter of cauliflower curd was not varied significantly ($p > 0.05$) due to the effect of alley widths. However, it ranged from 15.36 cm to 17.68 cm being the highest in 3.0 m alley and lowest in control (Figure 2A). Though the values within the alley cropping were statistically insignificant, yet the curd diameter of cauliflower when grown in alleys were higher compared to the control which could be attributed to the greater nutrient availability in the alley plots as opposed to control. Nevertheless, different levels of nitrogen had significant effect ($p < 0.05$) on the curd diameter of cauliflower, which ranged from 15.16-18.36 cm. The N_{100} treatment provided the highest curd diameter (18.36 cm) which was statistically comparable to N_{75} and N_{50} treatments, while the lowest diameter of curd (15.16 cm) was recorded in N_0 treatment (Figure 2B). The findings revealed that, diameter of curd has a strong positive correlation with N and increased with higher N doses.

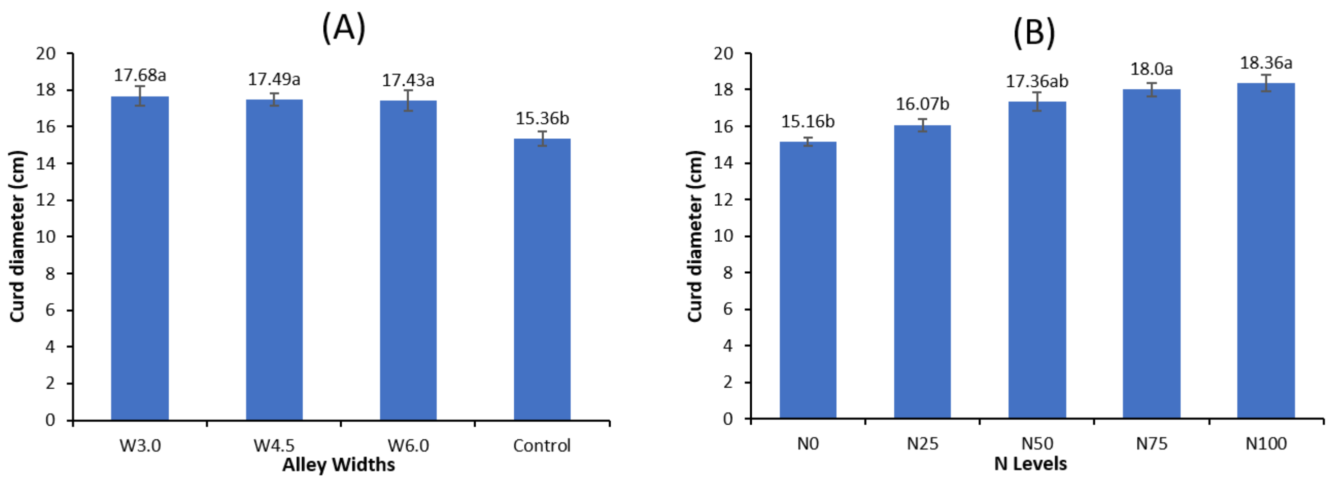

Figure 2. *Effect of alley widths (A) and N levels (B) on curd diameter of cauliflower at harvest (pooled over two years).*

Distinct variation ($p < 0.05$) was noted as to the curd diameter of cauliflower due to the interaction effect of alley widths and N levels. The variation of curd diameter as observed to be very high that ranged from 8.47 cm to 24.11cm. The control plots receiving only the different N doses without pruned biomass exhibited the lower diameter of the cauliflower curd compared to alley cropping plots. The higher curd diameters were measured in all the alley cropping plots irrespective of the different alley widths. However, the maximum curd diameter (24.11 cm) was measured in $W_{3.0} \times N_{100}$ treatment combination which was statistically identical with $W_{3.0} \times N_{75}$, $W_{4.5} \times N_{75}$, $W_{4.5} \times N_{100}$, $W_{6.0} \times N_{75}$, and $W_{6.0} \times N_{100}$ treatment combinations (Table 2). In contrast, Control $\times N_0$ treatment combination measured the lowest curd diameter (8.47 cm). It was evident that the plots where green biomass were added, the curd diameter was observed to be increased with the increase in N level. Giri *et al*. [29] stated that, organic matter and adequate amount of N and P are needed to fulfill the crop requirements and desired crop harvest. Similar findings had also been reported by others [30-32].

3.2. Curd Length

Analysis of variance revealed no significant variation ($p > 0.05$) on curd length due to the main effect of different alley widths. However, it ranged from 9.30 cm to 11.48 cm, being the highest in $W_{3.0}$ and the lowest in control (Figure 3A). The curd length produced under alley cropping systems showed no statistical difference. However, an interesting observation was made during the cultivation of cauliflower in open fields without the addition of pruned materials (PM). In this scenario, the length of the curd was notably lower, possibly indicating a lack of nutrients in the control plots. Different N levels showed marked variation as regards to the length of cauliflower curd. The highest curd length was measured to be 11.50 cm found in N_{100} treatment followed by N_{75} and N_{50} treatments, and the lowest curd length (9.99 cm) was measured in N_0 treatment (Figure 3B). It has been observed that, alike the curd diameter, curd length was gradually increased as the N doses were increased.

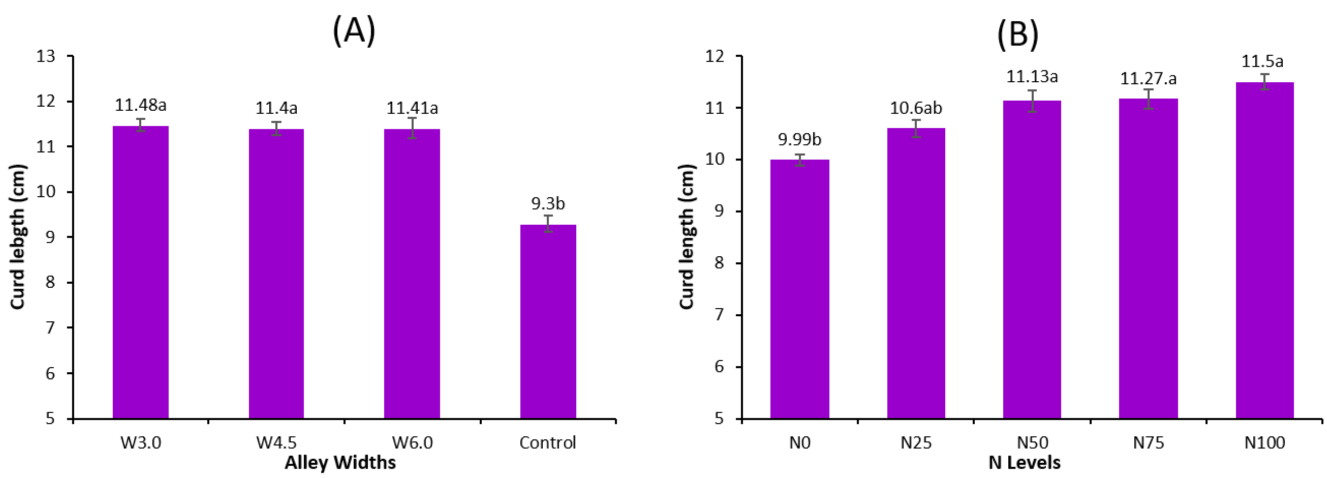

Figure 3. *Effect of alley widths (A) and N levels (B) on curd length of cauliflower at harvest (pooled over two years).*

There was a significant variation ($p < 0.05$) regarding the curd length of cauliflower attributed to the combined effect of alley widths and N levels. Among the treatment combinations, the curd length was found to be the highest (12.03 cm) in the treatment combination of $W_{6.0} \times N_{100}$ which was closely followed by $W_{4.5} \times N_{100}$, $W_{6.0} \times N_{75}$, and $W_{4.5} \times N_{75}$ treatment combinations (Table 2). Actually the curd lengths of nine treatment combinations were statistically at par which was almost 45% of the total treatment combinations. On the other hand, the lowest curd length was measured to be 8.47cm found in Control $\times N_0$ treatment combination. It is to be noted that the cauliflower produced in plots where only different N levels were applied but no PM was added had the lower curd lengths which varied from 8.47 cm to 9.92 cm. It was also observed that the curd lengths were higher in plots where PM was added in addition to the different N doses irrespective of the different alley widths.

Table 2. *Interaction effect of alley widths and N levels on curd diameter, curd length, marketable curd weight, and yield of cauliflower at harvest (pooled over two years).*

Treatment combinations	Curd diameter (cm)	Curd length (cm)	Marketable curd weight (Kg)	Yield (t ha^{-1})
$W_{3.0} \times N_0$	21.40cd	10.70de	1.64bc	26.26f
$W_{3.0} \times N_{25}$	22.33bc	11.17bcd	1.71abc	27.30ef
$W_{3.0} \times N_{50}$	23.33ab	11.67abc	1.85a	29.60cde
$W_{3.0} \times N_{75}$	23.60a	11.80a	1.76ab	28.20c-f
$W_{3.0} \times N_{100}$	24.11a	12.06a	1.85a	29.62cde
$W_{4.5} \times N_0$	20.83d	10.42ef	1.55c	27.57def
$W_{4.5} \times N_{25}$	22.26bc	11.13cd	1.73abc	30.71abc
$W_{4.5} \times N_{50}$	23.33ab	11.67abc	1.69abc	30.05b-e
$W_{4.5} \times N_{75}$	23.60a	11.80a	1.72abc	30.52a-d
$W_{4.5} \times N_{100}$	24.00a	12.00a	1.73abc	30.81abc
$W_{6.0} \times N_0$	20.73d	10.37ef	1.55c	28.93c-f
$W_{6.0} \times N_{25}$	22.26bc	11.13cd	1.63bc	30.51a-d
$W_{6.0} \times N_{50}$	23.40ab	11.70ab	1.75ab	32.74ab
$W_{6.0} \times N_{75}$	23.66a	11.83a	1.75ab	32.73ab
$W_{6.0} \times N_{100}$	24.06a	12.03a	1.80ab	33.55a
Control $\times N_0$	8.47f	8.47i	0.70d	11.12g
Control $\times N_{25}$	8.97ef	8.97hi	0.73d	11.74g
Control $\times N_{50}$	9.47ef	9.47gh	0.79d	12.72g
Control $\times N_{75}$	9.64ef	9.64g	0.80d	12.85g
Control $\times N_{100}$	9.92e	9.92fg	0.80d	12.85g
CV (%)	3.91	3.64	4.03	6.29

In each column, the level of significance among the treatment means were showed by small alphabetical letter(s) at a 5% level of probability by Tukey's HSD test.

Notably, in alley cropping system the curd length was found to be higher compared to the Control which is primarily attributed to the increased nutrient availability in soils of alley cropping due to PM incorporation. Besides, within the alley cropping plots, wider alley width performed better likely due to enhanced sunlight exposure, reduced tree-crop competition, and higher nitrogen availability to the crop. Ahmed et al. [10] discovered that the 75% N plus PM added treatment in *G. sepium* alley produced the longest head among the N levels plus PM added treatments and it was statistically comparable to the 100% and 50% N plus PM added treatments.

3.3. Marketable Curd Weight

Marketable curd weight of cauliflower was significantly ($p< 0.05$) influenced by the main effects of three different alley widths along with control. The highest curd weight (1.76 Kg) was estimated in 3.0 m alley width which was statistically comparable to the curd weights observed in the 4.5 and 6.0 m alley. Significantly, the lowest curd weight (0.77 Kg) was recorded in control (Figure 4A). It is to be noted that the different alley widths influenced the marketable curd weight of cauliflower and produced the curds weighing more than 1 Kg whereas, it was less than 1.00 Kg when grown in control plots. Meanwhile, the marketable curd weight of cauliflower when produced in different alley widths did not vary among themselves indicating the science that alley widths had the contribution to increase the curd weight as the alley width plots received the green biomass of the pruned materials compared to control plots. Statistically significant variation ($p< 0.05$) was noted regarding marketable curd weight of cauliflower due to the main effect of different N doses. Marketable curd weights of five N doses ranged from as low as 1.36 Kg in N_0 to as high as 1.55 Kg in N_{100} treatment (Figure 4B). A general trend was observed that with the increase in the doses of nitrogen, higher marketable curd weights were obtained which indicated that N fertilizer plays a significant role in the plant growth of the cauliflower which had been reflected in this experiment.

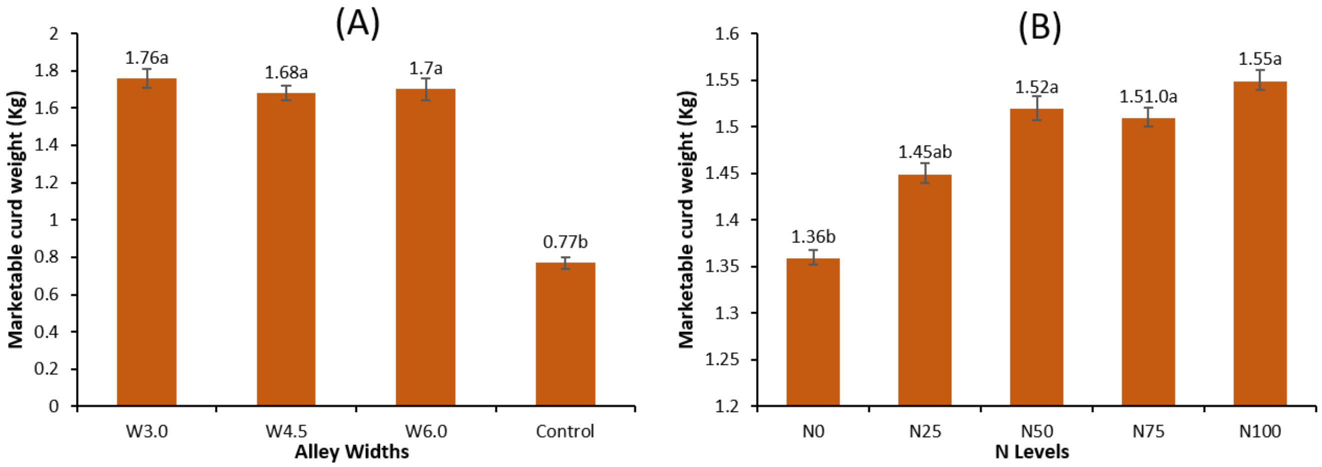

Figure 4. *Effect of alley widths (A) and N levels (B) on marketable curd weight of cauliflower at harvest (pooled over two years).*

The combined effect of alley widths and N levels on curd weight was also found significant ($p< 0.05$). It differed from 0.70 Kg to 1.85 Kg; being the highest in $W_{3.0}\times N_{100}$ treatment combination and the lowest in Control$\times N_0$ (Table 2). As like as other parameters, the marketable curd weight was also found lower in case of the control five treatments compared to the rest 15 treatment combinations with addition of green biomass. It is important to note that, the 11 different treatment combinations showed no significant differences in marketable curd weight among the 15 treatment combinations received the pruned materials and it was calculated to be 73.33% of the total treatment combinations. The findings revealed that, combined application of organic and inorganic N fertilizers successfully augmented the curd weight of cauliflower. The findings are in best agreement with Bozkurt *et al*. [33].

3.4. Yield of Cauliflower

Cauliflower yield was significantly varied ($p< 0.05$) due to the main effect of alley widths, and ranged from 12.26-31.69 t ha^{-1} (Figure 5A). The highest yield was calculated to be 31.69 t ha^{-1} in 6.0 m alley width which was comparable to 4.5 m (29.93 t ha^{-1}) alley. Conversely, significantly the lowest cauliflower yield (12.26 t ha^{-1}) was obtained from control plot where pruned materials were not incorporated into the soil. It was observed that, cauliflower yield increased in a linear direction with the simultaneous increase in alley widths. The application of organic biomass in alley cropped plots increased the availability of macro and micro nutrients in the soil due to which the crop yield might have increased [34]. Besides, wide variation was seen in the yield of cauliflower with the variation of different N levels. The five different levels of N including control exhibited yields varying from 23.47 (t ha^{-1}) to 26.71 (t ha^{-1}). The highest yield (26.71 t ha^{-1}) was found in the N_{100} treatment swiftly followed by N_{75} and N_{50} treatments, and the lowest (23.47 t ha^{-1}) in control plots (Figure 5B).

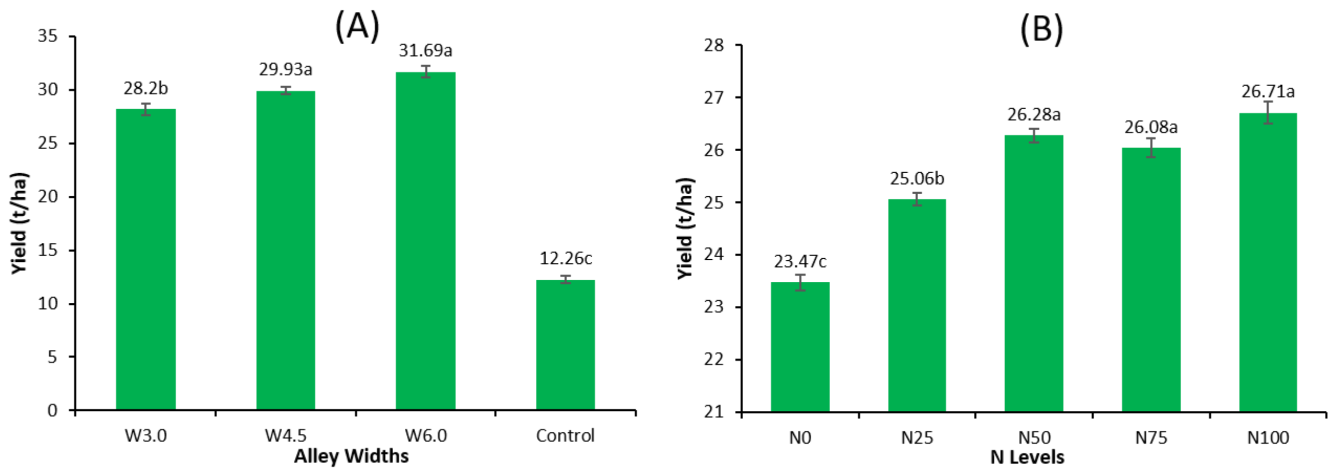

Figure 5. *Effect of alley widths (A) and N levels (B) on yield of cauliflower at harvest (pooled over two years).*

The interaction effect of alley width and different N levels showed significant variation ($p< 0.05$) pertaining to the yield of cauliflower. In response to different treatment combinations, the highest yield (33.55 t ha^{-1}) was recorded in $W_{6.0}\times N_{100}$ treatment combination which was swiftly followed by $W_{6.0}\times N_{75}$, and $W_{6.0}\times N_{50}$ treatment combinations (Table 2). In contrast, the lowest yield of cauliflower (11.12 t ha^{-1}) was calculated in Control$\times N_0$. The lower yields of the crop were found in the five different treatments where only N fertilizers of variable doses were applied and all of these were statistically at par. The higher yields were observed in the remaining 15 treatment combinations compared to the control five plots which might due to the combined addition of organic and inorganic nitrogen. Within the alley cropped plots, the yields were augmented with the increase in N levels irrespective of alley widths where along with N doses, the treatments also received the pruned materials before planting of the crop which ultimately improved the availability of soil nutrients. Different alley widths and nitrogen levels attained the level of significance for cauliflower production, with wider alleys and greater N levels performing favorably, according to the data provided on the yield of cauliflower. This might have occurred as a result of higher nutrients availability from added PM and increased nitrogen input via inorganic N fertilizer along with pruned biomass from *G. sepium*. Moreover, maximum number of cauliflower arrangement in the 6.0 m alley width augmented the per hectare yield of cauliflower compared to other alleys. As nitrogen is the necessary component of nucleic acid, it improved the plant's reproductive system, which in turn improved the yield-attributing characteristics and, ultimately, the yield of cauliflower [35]. The present findings are in best agreement with others specifically when cabbage, rice, tomato, brinjal, soybean, maize, cotton etc. were cultivated under *G. sepium* established alley cropping practices [9, 20, 36, 37].

3.5. Economic Performance of Cauliflower

To determine the economic performance of cauliflower cultivated under different systems, net return and BCR were estimated (Table 3). The results showed that, 6.0 m alley width with 100% of recommended N plus pruned biomass added system provided the highest net return (466,000 Tk ha^{-1}) and BCR (3.27). Notably, it was found that all the alley cropping systems showed higher economic performances by generating higher net return and BCR compared to control. As the fifteen treatment combinations under alley cropping received pruned materials of *G. sepium* which increased the soil fertility and thus increased production resulting the higher economic return.

Table 3. *Economics of cauliflower production under different production systems.*

Treatment combinations	Cost of production (Tk ha^{-1})	Gross return (Tk ha^{-1})	Net return (Tk ha^{-1})	Benefit Cost Ratio
$W_{3.0}\times N_0$	200,000	525,200	325,200	2.63
$W_{3.0}\times N_{25}$	201,250	546,000	344,750	2.71
$W_{3.0}\times N_{50}$	202,500	592,000	389,500	2.92
$W_{3.0}\times N_{75}$	203,750	564,000	360,250	2.77
$W_{3.0}\times N_{100}$	205,000	592,400	387,400	2.89

Treatment combinations	Cost of production (Tk ha^{-1})	Gross return (Tk ha^{-1})	Net return (Tk ha^{-1})	Benefit Cost Ratio
$W_{4.5} \times N_0$	200,000	551,400	351,400	2.76
$W_{4.5} \times N_{25}$	201,250	614,200	412,950	3.05
$W_{4.5} \times N_{50}$	202,500	601,000	398,500	2.97
$W_{4.5} \times N_{75}$	203,750	610,400	406,650	2.99
$W_{4.5} \times N_{100}$	205,000	616,200	411,200	3.01
$W_{6.0} \times N_0$	200,000	578,600	378,600	2.89
$W_{6.0} \times N_{25}$	201,250	610,200	408,950	3.03
$W_{6.0} \times N_{50}$	202,500	654,800	452,300	3.23
$W_{6.0} \times N_{75}$	203,750	654,600	450,850	3.21
$W_{6.0} \times N_{100}$	205,000	671,000	466,000	3.27
Control $\times N_0$	200,000	222,400	22,400	1.11
Control $\times N_{25}$	201,250	234,800	33,550	1.17
Control $\times N_{50}$	202,500	254,400	51,900	1.26
Control $\times N_{75}$	203,750	257,000	53,250	1.26
Control $\times N_{100}$	205,000	257,000	52,000	1.25

Cauliflower price (Tk. 20 Kg^{-1})

4. Conclusion

Alley cropping systems established with *G. sepium* showed a positive impact on cauliflower yield and yield attributes as compared to the control. The results demonstrated that the combined use of inorganic N along with green biomass from the *G. sepium* tree increased the yields of cauliflower. As a result, 90%, 75%, and 50% of the recommended N doses produced the highest and statistically equivalent yields in 6.0 m alley width, suggesting that up to 50% of inorganic N fertilizer can be saved without sacrificing the cauliflower production. The considerable decrease in inorganic nitrogenous fertilizer surely provide economic benefit to our farming communities as well as to the agro-ecosystems. Moreover, the net return and BCR showed that all the alley cropping systems were more profitable compared to control, specifically 6.0 m alley width with 100% N level provided the highest economic return. Based on the findings, farmers may be advised to adopt alley cropping system on their farming landscape; however, it is needed to conduct similar research in other location of the country to validate the potentiality of this system.

Abbreviations

BCR	Benefit-to-Cost Ratios
OM	Organic Matter
mm	Millimeter
cm	Centimeter
t ha^{-1}	Ton per Hectare
N	Nitrogen
Kg ha^{-1}	Kilogram per Hectare
TSP	Triple Superphosphate
MoP	Muriate of Potash
DAT	Days After Transplanting
PM	Pruned Materials

Acknowledgments

The department of Agroforestry and Environment at BSMRAU, Bangladesh, has provided the facilities required for the effective completion of this research project, for which the authors are incredibly grateful.

Author Contributions

Abu Syed Md. Jobaydul Alam: Investigation, Formal Analysis, Writing – original draft

Satya Ranjan Saha: Conceptualization, Supervision, Validation, Resources

Md. Suhag: Conceptualization, Methodology, Visualization, Writing – review & editing

Md. Giashuddin Miah: Conceptualization, Supervision, Writing – review & editing

Md. Mizanur Rahman: Conceptualization, Supervision, Writing – review & editing

Md. Rafiqul Islam: Conceptualization, Supervision, Writing – review & editing

Zabid Al Riyadh: Data Curation, Visualization

Apple Mahmud: Formal Analysis, Writing – review & editing

Conflicts of Interest

No conflicts of interest are disclosed by the authors.

References

[1] BBS. (2022a). *Statistical Year Book of Bangladesh*. Bangladesh Bureau of Statistics, Ministry of Planning, Govt. of the Peoples Republic of Bangladesh, Dhaka, Bangladesh.

[2] BBS. (2022b). Yearbook of Agricultural Statistics of Bangladesh. 34th edition, Bangladesh Bureau of Statistics, Chapter 05: *Land Use Statistics* (pp. 425-426). Statistics and Informatics Division, Ministry of Planning, Govt. of the People's Republic of Bangladesh, Dhaka, Bangladesh.

[3] Pingki, L. S., Ahamed, T., Miah, M. M. U., Khan, M. A. R., Suhag, M., & Mondal, S. (2023). Growth and yield of cabbage in aonla based multistoried agroforestry. *Ann. Plant Sci*. *12*(10): 6038–48. http://dx.doi.org/10.21746/aps.2023.12.10.3

[4] Hasan, M. M., Islam, M. M., & Rahman, H. M. S. (2014). Performance of Kangkong and Indian spinach in ipil-ipil based alley cropping system. *J. Agrofor. Environ*, *8*(1): 99-103.

[5] Rita, T. Y., Saha, S. R., Miah, M. M. U., Hoque, M. A., Al Riyadh, Z., Ahammed, S., & Suhag, M. (2024). Productivity and Profitability Assessment of Stem Amaranth and Changes in Soil Chemical Properties under Aonla-Based Multistoried Agroforestry. *European Journal of Agriculture and Food Sciences*, *6*(6): 40-49. http://dx.doi.org/10.24018/ejfood.2024.6.6.880

[6] Miah, M. M. U., Uddin, M. H., Miah, M. G., Rahman, M. M., Ahmed, M., & Matsumoto, M. (2022). Changes of soil physical and chemical properties in aonla (*Phyllanthus emblica* L.) based multistoried agroforestry system. *Journal of the Faculty of Agriculture, Kyushu University*, *67*(1): 39-51. https://doi.org/10.5109/4772340

[7] Rahman, M. A., Das, A. K., Al Riyadh, Z., Suhag, M., & Rahman, M. M. (2024). Eucalyptus in Agriculture: Friend or Foe? Analyzing its impact on crop yields, soil dynamics, and farmers' perceptions in Bangladesh. *Agroforestry Systems*, *98*(8): 3109-3128. https://doi.org/10.1007/s10457-024-01077-5

[8] Tuan, V. D., Hilger, T., MacDonald, L., Clemens, G., Shiraishi, E., Vien, T. D., & Cadisch, G. (2014). Mitigation potential of soil conservation in maize cropping on steep slopes. *Field Crops Research*, *156*: 91-102. https://doi.org/10.1016/j.fcr.2013.11.002

[9] Rahman, M. A., Miah, M. G., & Yahata, H. (2009). Maize production and soil properties change in alley cropping system at different nitrogen levels. *The Agriculturists*, *7*(1&2): 41-49.

[10] Ahmed, S., Chowdhury, A. H. M. R. H., Ghosh, S. C., Islam, S. M. A. S., & Parven, A. (2010). Performance of tomato, brinjal and cabbage in alley cropping system as affected by four tree species and levels of nitrogen in upland ecosystem. *J. Soil Nature*, *4*(1): 17-24.

[11] Sirohi, C., Dhillon, R. S., Chavan, S. B., Handa, A. K., Balyan, P., Bhardwaj, K. K., & Ahlawat, K. S. (2022). Development of poplar-based alley crop system for fodder production and soil improvements in semi-arid tropics. *Agroforestry Systems*, *96*(4): 731-745. https://doi.org/10.1007/s10457-022-00735-w

[12] Koyejo, A. O., Okpara, D. A., & Agugo, B. A. C. (2023). Effect of alley cropping on soil, maize and mungbean grown under different maize spatial arrangements and mungbean spacing's in south east Nigeria. *Agroforestry Systems*, *97*(7): 1337-1346. https://doi.org/10.1007/s10457-021-00635-5

[13] Medinski, T., & Freese, D. (2012). Soil carbon stabilization and turnover at alley-cropping systems, eastern Germany. In EGU *general assembly conference abstracts* (p. 9532).

[14] Braga, Í D. O., Carvalho da Silva, T. L., Belo Silva, V. N., Rodrigues Neto, J. C., Ribeiro, J. A. D. A., Abdelnur, P. V., & Souza Jr, M. T. (2022). Deep untargeted metabolomics analysis to further characterize the adaptation response of *Gliricidia sepium* (Jacq.) Walp. to very high salinity stress. *Frontiers in Plant Science*, *13*: 869105. https://doi.org/10.3389/fpls.2022.869105

[15] Wartenberg, A. C., Blaser, W. J., Gattinger, A., Roshetko, J. M., Van Noordwijk, M., & Six, J. (2017). Does shade tree diversity increase soil fertility in cocoa plantations? *Agriculture, Ecosystems & Environment*, *248*: 190-199. https://doi.org/10.1016/j.agee.2017.07.033

[16] Dinesh, R., Srinivasan, V., Hamza, S., Parthasarathy, V. A., & Aipe, K. C. (2010). Physico-chemical, biochemical and microbial properties of the rhizospheric soils of tree species used as supports for black pepper cultivation in the humid tropics. *Geoderma*, *158*(3-4): 252-258. https://doi.org/10.1016/j.geoderma.2010.04.034

[17] Coser, T. R., de Figueiredo, C. C., Jovanovic, B., Moreira, T. N., Leite, G. G., Cabral Filho, S. L. S., & Marchão, R. L. (2018). Short-term buildup of carbon from a low-productivity pastureland to an agrisilviculture system in the Brazilian savannah. *Agricultural Systems*, *166*: 184-195. https://doi.org/10.1016/j.agsy.2018.01.030

[18] Partey, S. T., Zougmore, R. B., Thevathasan, N. V., & Preziosi, R. F. (2019). Effects of plant residue decomposition on soil N availability, microbial biomass and β-glucosidase activity during soil fertility improvement in Ghana. *Pedosphere*, *29*(5): 608-618. https://doi.org/10.1016/S1002-0160(17)60433-8

[19] Bandara, T., Herath, I., Kumarathilaka, P., Hseu, Z. Y., Ok, Y. S., & Vithanage, M. (2017). Efficacy of woody biomass and biochar for alleviating heavy metal bioavailability in serpentine soil. *Environmental Geochemistry and Health*, *39*: 391-401. https://doi.org/10.1007/s10653-016-9842-0

[20] Mng'omba, S. A., Akinnifesi, F. K., Kerr, A., Salipira, K., & Muchugi, A. (2017). Growth and yield responses of cotton (*Gossypium hirsutum*) to inorganic and organic fertilizers in southern Malawi. *Agroforestry Systems*, *91*: 249-258. https://doi.org/10.1007/s10457-016-9924-0

[21] Nyirenda, H. (2019). Achieving sustainable agricultural production under farmer conditions in maize-gliricidia intercropping in Salima District, central Malawi. *Heliyon*, 5(10): e02632. https://doi.org/10.1016/j.heliyon.2019.e02632

[22] Akter, A., Hoque, F., Mukul, A. Z. A., Kamal, M. R., & Rasha, R. K. (2016). Financial analysis of winter vegetables production in a selected area of Brahmanbaria district in Bangladesh. *International Research Journal of Agricultural and Food Sciences*, *1*(6): 120-127.

[23] Kapusta-Duch, J., Szeląg-Sikora, A., Sikora, J., Niemiec, M., Gródek-Szostak, Z., Kuboń, M., & Borczak, B. (2019). Health-promoting properties of fresh and processed purple cauliflower. *Sustainability*, *11*(15): 4008. https://doi.org/10.3390/su11154008

[24] Voitsekhivskyi, V., Maister, A., Matviienko, A., Slobodyanik, G., Muliarchuk, O., Balitska, L., & Horbatiuk, S. (2022). Nutritional and biological value of cauliflower. *SWorldJournal*, *11*(2): 118-122. https://doi.org/10.30888/2663-5712.2022-11-02-085

[25] Dos Reis, L. C. R., De Oliveira, V. R., Hagen, M. E. K., Jablonski, A., Flôres, S. H., & de Oliveira Rios, A. (2015). Effect of cooking on the concentration of bioactive compounds in broccoli (*Brassica oleracea* var. *Avenger*) and cauliflower (*Brassica oleracea* var. *Alphina* F1) grown in an organic system. *Food Chemistry*, *172*: 770-777. https://doi.org/10.1016/j.foodchem.2014.09.124

[26] Shahidi, F., & Ambigaipalan, P. (2015). Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects–A review. *Journal of functional foods*, *18*: 820-897. https://doi.org/10.1016/j.jff.2015.06.018

[27] Brammer, H. (1996). *The geography of the soils of Bangladesh*. 1st Edition, University Press Limited, 287.

[28] Azad, A. K., Goshwami, B. K., Rahman, M. L, Malakar, P. K., Hasan, M. S., & Rahman, M. H. H. (2017). *Handbook on Agro Technology*. 7th edition, Bangladesh Agricultural Research Institute, BARI. Gazipur, 1701, Bangladesh.

[29] Giri, R. K., Sharma, M. D., Shakya, S. M., GC, Y. D., & Kandel, T. P. (2013). Growth and yield responses of broccoli cultivars to different rates of nitrogen in western Chitwan, Nepal. *Agricultural Sciences*, *4*(7): 8-12. http://dx.doi.org/10.4236/as.2013.47A002

[30] Islam, M. M., Hasan, M. M., & Wadud, M. A. (2014). Performance of amaranth and red amaranth in alley cropping system. *J. Agrofor. Environ*. *8*(1): 11-15.

[31] Ahammed, A. U., Rahman, M. M., & Karim, A. J. M. S. (2015). Response of stem amaranth to different levels of nitrogen, phosphorus and potassium. *Ann. Bangladesh Agric*. *19*(2): 11-21.

[32] Sahito, M. A., Laghari, M. H., Agro, A. H., Hajano, A. A., Kubar, A. A., Khuhro, W. A., & Wahocho, N. A. (2018). Effect of various levels of nitrogen and phosphorus on plant growth and curd yield of cauliflower (*Brassica oleracea* L.). *International Journal of Development Research*, *8*(3): 19184-19184.

[33] Bozkurt, S., Uygur, V., Agca, N., & Yalcin, M. (2011). Yield responses of cauliflower (*Brassica oleracea* L. var. *botrytis*) to different water and nitrogen levels in a Mediterranean coastal area. *Acta Agriculturae Scandinavica Section B–Soil and Plant Science*, *61*(2): 183-194. https://doi.org/10.1080/09064710.2010.539575

[34] Ghuge, T. D., Gore, A. K., & Jadhav, S. B. (2007). Effect of organic and inorganic nutrient sources on growth, yield and quality of cabbage (*Brassica oleracea* var. *capitata*). *Journal of Soils and Crops*, *17*(1): 89-92.

[35] Patel, S. J., Desai, L. J., Keraliya, S. J., & Patel, C. K. (2018). Cabbage (*Brassica oleracea* var. *capitata* L.) Yield, nutrients uptake and soil available nutrients as influenced by nitrogen and foliar nutrients application under South Gujarat condition. *Inter. Jour. Pure App. Biosci*, *6*: 1222-1225.

[36] Mondal, S., Miah, M. G., Elahi, N. E., Saleque, M. A., & Rahman, A. (2013). Effect of nitrogen levels and gliricidia sepium alley widths on rice based agroforestry systems. *Bangladesh Rice J*. *17*(1-2): 26-32.

[37] de Moura-Silva, A. G., Aguiar, A. D. C. F., de Moura, E. G., & Jorge, N. (2016). Influence of soil cover and N and K fertilization on the quality of biofortified QPM in the humid tropics. *Journal of the Science of Food and Agriculture*, *96*(11): 3807-3812. https://doi.org/10.1002/jsfa.7574