International Journal of Plant & Soil Science

Volume 35, Issue 23, Page 560-571 , 2023; Article no.IJPSS.111225
ISSN: 2320-7035

The Effect of Fertilizer Rate and Pruning Material on Growth and Yield of Carrot (*Daucus carota*) under Alley Cropping System

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MRK and TKR conducted the study under the supervision of the author MOS. Authors MOS and MSAT designed the research work. Author MRK performed the experiment. Author BD analyzed the data and author MOS wrote the first draft of the manuscript. Authors UBR and MNZ managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i234274

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/111225

Original Research Article

Received: 15/10/2023
Accepted: 21/12/2023
Published: 23/12/2023

ABSTRACT

The study was conducted at the Agroforestry Farm of Sylhet Agricultural University from October 2020 to March 2021 to evaluate the growth and yield performance of carrot and determine soil fertility status during the hedge establishment period of alley cropping. Hedges for alley cropping

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were established using ipil-ipil (*Leucaena leucocephala*) and vegetable hummingbirds (*Sesbania grandiflora*) tree species. The experiment was laid out in a randomized complete block design (RCBD). During the hedge establishment period, the carrot was cultivated in the alley of the hedgerow using four different treatments with three replications. The treatments were T_0 (No application of fertilizer and pruning materials), T_1 (application of recommended fertilizer dose), T_2 (application of half dose of the recommended fertilizer + pruning materials), and T_3 (application of pruning materials). The results exhibited that growth parameters, viz. plant height (cm), leaf number per plant, root length (cm), and root diameter (cm) of carrot were almost similar in all treated plots, except control (T_0). The carrot yield was statistically similar in all fertilizer and pruning materials treated plots, but it was drastically reduced in the control plots and decreased by about 40-45% compared to fertilizer and pruning materials applied plots. During hedgerow establishment, soil pH among different plots has not changed significantly compared to the initial field, but organic matter (OM), nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) in different alleys found to be increased significantly in treatment T_2 and treatment T_1 after carrot cultivation. Improvement in soil fertility was also found in the alleys between the hedgerows of ipil-ipil and vegetable hummingbirds when only pruning material was applied to the soil. Therefore, an alley cropping system with *Leucaena leucocephala* and *Sesbania grandiflora* may enhance the yield performance of carrot and organically improve soil fertility during the hedge establishment period.

Keywords: Alley cropping; Leucaena leucocephala; Sesbania grandiflora; carrot; hedgerow establishment.

1. INTRODUCTION

Bangladesh is an agricultural country with a vast population, and its economy depends mainly on agriculture. Agriculture contributes about 12.09 percent of Bangladesh's total GDP [1], and about 71 percent of people depend on agriculture. Although the number of contributions of agriculture to the GDP of Bangladesh is decreasing day by day, its importance is increasing. The population of the country is increasing day by day, and due to overpopulation and industrialization, people have to make buildings for their habitat. For this, agricultural land is diminishing as the day passes. In this situation, there is a crying need to produce more food with limited land resources. However, the problem is that cropping intensity has increased to increase food production. As land is used for intensive cultivation, the fertility of the soil decreases gradually and finally reduces the crop yield. Intensive cultivation is also associated with high inputs of chemical fertilizer into the land [2]. This frequent use of chemical fertilizer degrades the soil property and also pollutes our water resources and environment. Bangladesh has various land agroecosystems; among them, the upland/highland ecosystem comprises areas characterized by low soil fertility and poor crop productivity. In rain-fed farming, production is diverse and unpredictable; crop yield is low, unstable, and fluctuates from year to year. Subsistence farmers often do not use costly fertilizers for production due to the yield instability. Besides this, many farmers cannot afford to buy agricultural inputs to improve the physical and biological properties of soil [3].

Recently, alley cropping has emerged as a sound technology for sustainable crop production. Alley cropping is a form of agroforestry in which crops are grown in the interspace between rows of planted shrubs or tree species. Usually, legumes and shrub/tree species are pruned at intervals to add nutrient materials to the soil [4]. Pruned materials are added to the soil as green manure so that pruned leaves and branches can release nutrients to the soil, improve the soil's physiochemical properties, and ultimately improve the growth and development of associated crops [5]. Tree legumes can to return nitrogen to the soil through leaf or root decomposition and nitrogen-fixing nodules, which improve crop productivity and soil fertility [6]. As nutrients are added to the soil through the decomposition of leaves and nitrogen is added through nodulation by roots, the cost of chemical fertilizer is reduced through this production system [7].

There are many trees and shrub legumes that can restore the nutrients in alley cropping in many parts of the world. Leguminous tree species also provide food, fuel, fodder, and timber harvested from dwindling forests [8]. Ipil-ipil (*Leucaena leucocephala*) and Vegetable hummingbird (*Sesbania grandiflora*) are suitable tree species used worldwide. The vegetable hummingbird is also known as Bakphul in Bangladesh. These two species biologically fix N, can withstand repeated pruning, produce a large amount of pruning materials and nutrients, and are relatively long-lived [9,10]. During the evaluation of the alley cropping system in a flat upland ecosystem, the assessment of commercially grown vegetables on that land type should be given emphasis. The carrot (*Daucus carota*) is an important winter vegetable in terms of production and area in Bangladesh. It might be suitable to grow in a flat ecosystem and can tolerate partial shade when cultivated as intercrop with tree saplings. Carrots are plentiful in nutrients, minerals, and antioxidant compounds. As a component of a decent eating routine, they can support immune function, reduce the risk of some cancers, and advance injury mending and stomach-related well-being [11]. Since the use of carrots is increasing day by day, its economic value is also growing.

To fulfill the demand for vegetables for the growing population of Bangladesh, a sustainable production system that has the potential to yield more food from limited land resources needs to be developed. In these circumstances, alley cropping could be an important practice for maintaining vegetable production and soil health. Since there is scope to spread this suitable production system throughout the country, it is necessary to undertake a study to explore the potentiality of this practice on the productivity of vegetables and soil health that could be further tested in farmer fields in the different ecosystems of Bangladesh for wider use of the farmers. Till now, there have been few studies in Bangladesh about the effect of alley cropping with N-fixing and non-N-fixing leguminous species on the performance of winter vegetables and their role in improving soil fertility during hedgerow establishment. This study attempts to determine the effectiveness of hedgerow intercropping in increasing the growth and yield of carrots and improving soil fertility during the establishment period of hedgerows.

2. MATERIALS AND METHODS

2.1 Location, Climate, and Soil of the Study Area

The experiment was conducted at the experimental farm, Department of Agroforestry and Environmental Science, Sylhet Agricultural University, Sylhet, from October 2020 to March 2021. The site was located in the subtropical climatic zone, characterized by scanty rainfall from October 2020 to April 2021. The average high temperature was 25.5°c, and the average low temperature was 13.5°C during October 2020. On the other hand, the average high temperature was 34.4°C, and the average low temperature was 22.8℃ during April 2021. The average relative humidity of 75% was recorded during December 2020. The experimental site was close to the ‘small tillahs,’ and the soils were grey, heavy, silty clay loams on the ridges and clays in the basins. It belongs to the ‘Noncalcareous Grey Soils’ under the 20th agroecological zone of the Eastern Surma-Kushiyara Floodplain. The OM content of soils is moderate. The reaction of soils ranges from slightly acidic to somewhat alkaline [12].

2.2 Hedge Establishment

Six-month-old seedlings of two leguminous tree species, i.e., Ipil-ipil (*Leucaena leucocephala*) and Vegetable hummingbird (*Sesbania grandiflora*), were collected from a nursery situated in Sylhet to grow in the hedgerow. Winter vegetables, i.e., carrots (*Daucus carota*), were used to grow in the interspace or alley between the hedgerows of trees. Two fields were used to cultivate carrots with the hedgerows of two leguminous trees. The first field was used for carrot cultivation with vegetable hummingbirds, and the second was used for carrot cultivation with ipil-ipil.

The hedge of each tree species was established in a field of 425 square feet. At first, the land was prepared by ploughing and cross-ploughing several times to make the soil loose and friable. Weeds and stubbles were removed from the beds, and seedlings of ipil-ipil and vegetable hummingbirds were planted. Irrigation was done thrice a week by the watering cane, and weeding was done every 15 days. Thinning and gap-filling were also done in the early days of hedge establishment. A total of five hedgerows of each species were established, and the length of each hedgerow was 17 feet. The hedgerows were pruned at 1m height above the ground level.

2.3 Experimental Design and Layout

This study was laid out in Randomized Complete Block Design (RCBD) with four treatments and three replications separately. Therefore, the four different treatments in association with fertilizer status were as follows: T_0= Control (No application of fertilizer and pruning materials),

T_1= Application of recommended fertilizer dose, T_2= Application of half dose of the recommended fertilizer and pruning materials, and T_3= Application of pruning materials. The size of each field of the study was 25ft × 17ft. In each field, six alleys were created, and a total of 4 beds (3ft × 3ft) were made inside each alley (Fig. 1). The plant-to-plant and row-to-row distances for carrots were 10 cm and 25 cm, respectively. The tree legumes were planted in the hedgerows 3 ft apart from each other.

2.4 Collection of Soil Samples Before Cultivation

After bed preparation, a soil sample was collected from each seed bed. A total of 2 composite samples were collected from two fields in 30 cm soil depth, and the samples were sent to the SRDI (Soil Resource Development Institute) in the Sylhet region to analyze soil. Soil samples were analyzed to determine soil pH, soil organic matter (OM), nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) to compare the soil fertility status with soil nutrient status after harvesting.

2.5 Seed Sowing and Fertilizer Application

Seeds of carrot were sown in line sowing in the experimental plot on 25 November 2020. After emergence, carrot plants were finally thinned out. In treatment T_0 (control plots), no fertilizer and pruning materials were applied, and in treatment T_1, 200 gm of Urea, 50 gm of potash, and 25 gm of boron per bed (3ft × 3ft) were used as a recommended dose. In the case of treatment T_2, half of the recommended fertilizer dose and pruning materials were applied in the field. Only pruning materials were applied in the crop field for treatment T_3. Ipil-ipil and vegetable hummingbird leaf biomass were added in the individual plot @ 2.5 kg/bed. Pruning materials were applied to the plot two months before crop cultivation.

2.6 Intercultural Operation in the Crop Field

Different intercultural operations, such as fertilization, weeding, thinning, gap filling, irrigation, etc., were done for better growth of the carrot. Weeding was done three times for experimental and control plots to keep the plots free from weeds. All the plots were irrigated whenever needed using a watering can to supply sufficient soil moisture for the vegetables.

2.7 Data Collection

Plant samples of carrots were collected randomly from the middle of respective plots. Three carrot plants were selected from each plot for data collection. Data were collected at harvesting time for measuring plant height (cm), number of leaves per plant, root length (cm), root diameter (cm), and weight of root (g) for carrot. Measurement of plant height and root length was done by using measuring tape. Root diameter was measured using slide calipers, and the weight of the root (yield) was measured using a weighing machine.

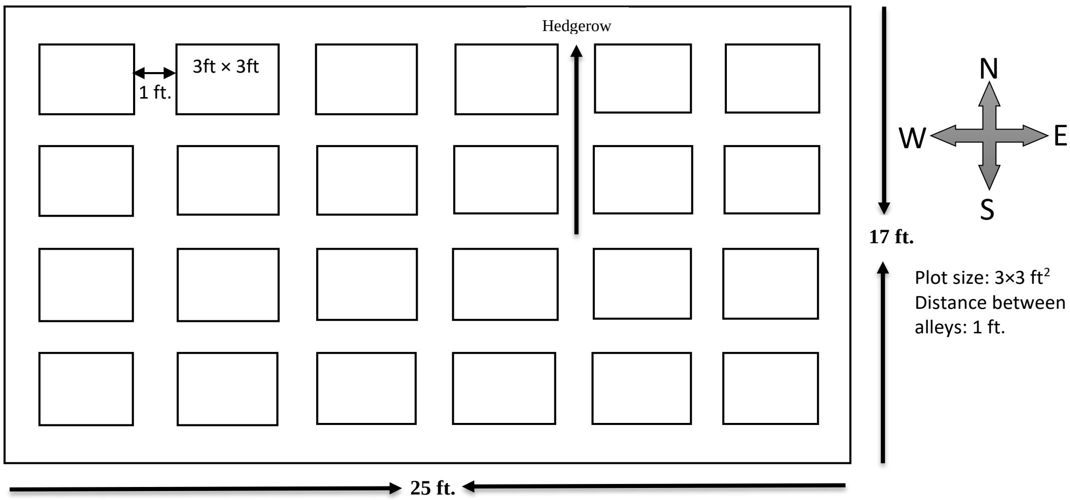

Fig. 1. Layout of the experimental field

2.8 Collection of Soil Samples after Harvesting

After harvesting, a total of 24 composite soil samples were collected from each bed at 30 cm soil depth and sent to the SRDI situated in Sylhet for the analysis of soil pH, soil organic matter (OM), nitrogen (N), phosphorus (P), potassium (K), and sulfur (S).

2.9 Statistical Analysis

Data were analyzed using a standard procedure for one-way analysis of variance (ANOVA) to determine the effects of different treatments. Differences between treatment means were separated by Tukey's test at a significance level $p < 0.05$ using GraphPad software (GraphPad Prism version 8.00, GraphPad Software, California, USA).

3. RESULTS

3.1 Morphological Characteristics of Carrot during the Hedge Establishment of Ipil-ipil and Vegetable Hummingbird

The highest plant height (44.10 cm) and number of leaves plant^{-1} (16.33) of carrot was recorded in treatment T_2 (half of the recommended fertilizer dose and pruning materials) when the carrot was grown in association with ipil-ipil. The root length (16.57 cm) and diameter of the root (4.64 cm) of the carrot were found to be the highest for the treatment T_1 (recommended fertilizer dose) (Table 1). The lowest plant height (28.87 cm), number of leaves plant^{-1} (8), root length (10.87 cm), and diameter of root plant^{-1} (2.90 cm) were recorded in treatment T_0 (Control, without fertilizer and pruning materials) under the ipil-ipil hedge (Table 1).

Different morphological features of carrots were found to be higher in the fertilizer and pruning material treated plot compared to the control plot when the carrot was grown in association with vegetable hummingbirds. The highest plant height (46.23 cm), root length (16.23 cm), and diameter of root (4.50 cm) of carrot were recorded in treatment T_1 (recommended fertilizer dose) (Table 1). The highest number of leaves plant^{-1} (13.33) was found in treatment T_2 (half of the recommended fertilizer dose and pruning materials) when the carrot was grown under the vegetable hummingbird hedge (Table 1). On the other hand, the lowest plant height (cm), number of leaves plant^{-1}, root length (cm), and diameter of root plant^{-1} (cm) of carrots were 28.80, 8.00, 10.03, and 2.73, respectively (Table 1) in the control plot (T_0) under the hedge of vegetable hummingbird.

3.2 Yield of Carrot During the Hedge Establishment of Ipil-ipil and Vegetable Hummingbird in the Alley Cropping System

The highest fresh weight of carrot (123.50 g/plant) was recorded in treatment T_2, followed by treatment T_1 (104.43 g) when carrot was grown in the alley between the hedgerow of ipil-ipil (Fig. 2). On the other hand, the highest fresh weight of carrot (120.70 g/plant) was recorded in treatment T_1, followed by treatment T_2 (94.40 g/plant) when carrot was cultivated under the hedge of vegetable hummingbird (Fig. 3). The carrot yield was found to be the lowest in the control plot when grown under the hedge of ipil-ipil and vegetable hummingbird (45.17 g/plant and 42.37 g/plant, respectively). There was no significant difference when the carrot yield was compared at different treatments between ipil-ipil and vegetable hummingbird (Table 2). The yield was found to be higher under the vegetable hummingbird hedge compared to the ipil-ipil hedge at treatment T_1, but carrot yield under the ipil-ipil hedge showed better performance than the vegetable hummingbird hedge in all other treatments (Table 2).

3.3 Soil Nutrient Status of the Experimental Field Before Carrot Cultivation

The pH, organic matter (OM), total nitrogen (N), available phosphorus (P), Sulfur (S), and exchangeable potassium (K) of the soil of the experimental field were determined before and after the vegetable cultivation to examine the effect of hedgerow intercropping on soil fertility during the establishment of hedgerows. The initial soil fertility status of the experimental field was very low, as shown in Table 3.

3.4 Soil Fertility Status of the Experimental Field After Carrot Cultivation During the Hedge Establishment of Ipil-ipil

Different soil fertility characteristics under carrot cultivation with ipil-ipil were found higher in the fertilizer and pruning material treated plot compared to the control plot. The highest increase of total N, available P, and K were found in treatment T_1 (recommended fertilizer dose), and soil pH, organic matter, and S were recorded in treatment T_2 (half of the recommended fertilizer dose and pruning materials) (Table 4). The highest soil pH, organic matter, total N, available P, K, and S were 5.0, 2.44%, 0.14%, 63.21 ppm, 0.34 me/100g, and 37.24 ppm, respectively (Table 4). The lowest increase of soil pH and organic matter was found in treatment T_3 (pruning materials), and other parameters were found to be lowest in the control plot.

Table 1. Effect of fertilizer rate and green manure on the morphological characters of carrot in the alley cropping with Ipil-ipil and Vegetable hummingbird (Mean±SD)

*Hedgerow	Treatments	Plant height (cm)	Number of leaves/plants	Root length (cm)	Diameter of root/ plant (cm)
Ipil-ipil	T_0	28.87±3.70^{b}	8.00±1^{b}	10.87±2.31^{b}	2.90±0.75^{c}
	T_1	41.53±2.75^{a}	14.67±1.52^{a}	16.57±0.72^{a}	4.64±0.25^{a}
	T_2	44.10±5.06^{a}	16.33±0.57^{a}	14.50±1.35^{ab}	4.17±0.20^{ab}
	T_3	35.10±1.76^{ab}	10.00±1^{b}	11.90±1.4^{b}	3.29±0.22^{bc}
Vegetable hummingbird	T_0	28.80±5.43^{bc}	8.00±1^{b}	10.03±2.25^{b}	2.73±0.72^{b}
	T_1	46.23±5.06^{a}	11.67±1.52^{a}	16.23±0.86^{a}	4.50±0.37^{a}
	T_2	41.23±4.29^{ab}	13.33±0.57^{a}	13.57±0.86^{ab}	3.95±0.11^{a}
	T_3	33.77±2.66^{b}	8.33±1.52^{b}	12.00±1.11^{b}	3.79±0.32^{ab}

** a, b, c indicates significant differences among mean values. Mean values (± standard deviation) in the same row followed by the different letters are significantly different from each other by the Tukey test at the 5% probability level (p ≤ 0.05). Note: T_0= Control (without fertilizer and pruning materials), T_1= Recommended fertilizer dose, T_2= Half of the recommended fertilizer dose and pruning materials, T_3= Pruning materials*

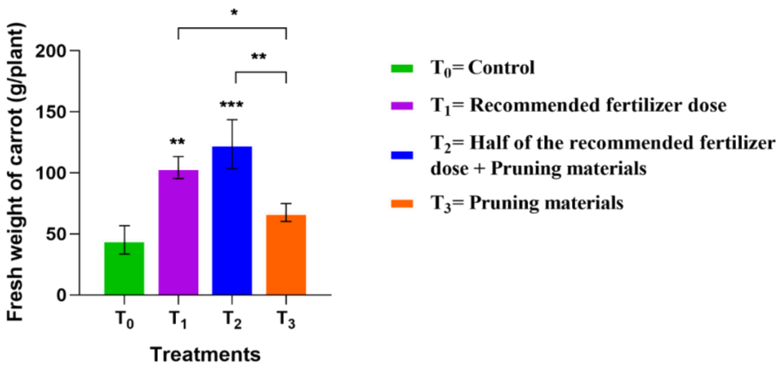

Fig. 2. Effect of fertilizer rate and green manure on the yield of carrot during the hedge establishment of ipil-ipil. Asterisk signs indicate significant differences with control and between treatments (* indicate $p \le 0.05$, ** indicate $p \le 0.01$, * indicate $p \le 0.001$)**

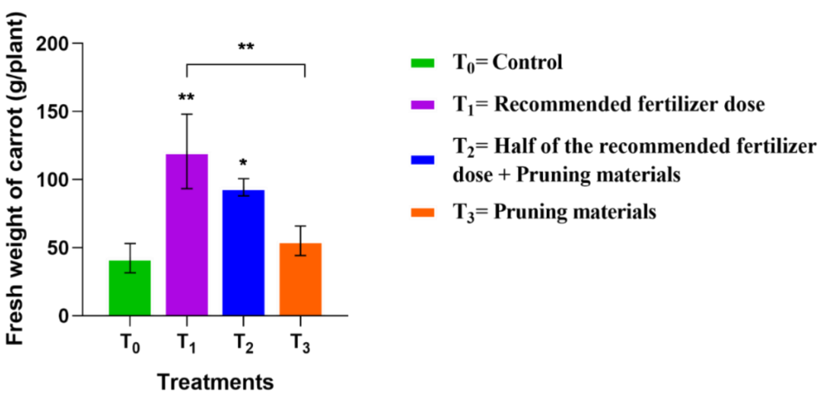

Fig. 3. Effect of fertilizer rate and green manure on the yield of carrot during the hedge establishment of vegetable hummingbird. Asterisk signs indicate significant differences between treatments (* indicate $p \le 0.05$, ** indicate $p \le 0.01$)

Table 2. Comparison between the carrot yield under Ipil-ipil and Vegetable hummingbird based alley cropping systems at different treatments

*Treatments	Hedgerow	Fresh weight of carrot (g/plant)
T_0	Ipil-ipil	45.17^{d}
	Vegetable hummingbird	42.37^{d}
T_1	Ipil-ipil	104.43^{a}
	Vegetable hummingbird	120.70^{a}
T_2	Ipil-ipil	123.50^{a}
	Vegetable hummingbird	94.40^{ab}
T_3	Ipil-ipil	67.60^{bc}
	Vegetable hummingbird	55.07^{cd}

** a, b, c, d indicates significant differences among mean values. Mean values (± standard deviation) in the same row followed by the different letters are significantly different from each other by the Tukey test at the 5% probability level ($p \leq 0.05$). Note: T_0= Control (without fertilizer and pruning materials), T_1= Recommended fertilizer dose, T_2= Half of the recommended fertilizer dose and pruning materials, T_3= Pruning materials*

Table 3. Soil fertility status of the study field before the establishment of hedgerows

Hedgerow	pH	Organic matter (%)	N (%)	P (ppm)	K (me/100g)	S (ppm)
Ipil-ipil	5.4	1.35	0.07	18	0.16	24
Vegetable hummingbird	5.2	1.75	0.1	9	0.11	62

Table 4. Soil fertility status of the experimental field under carrot cultivation during the hedge establishment of Ipil-ipil (Mean±SD)

*Hedgerow	Treatments	pH	Organic Matter (%)	N (%)	P (ppm)	K (me/100g)	S (ppm)
Ipil-ipil	T_0	4.87 ± 0.05^{a}	1.57 ± 0.1^{b}	0.08 ± 0.01^{b}	43.27 ± 2.1^{c}	0.19 ± 0.02^{b}	24.80 ± 1.5^{b}
	T_1	4.90 ± 0.1^{a}	2.21 ± 0.1^{a}	0.14 ± 0.005^{a}	63.21 ± 3.8^{a}	0.34 ± 0.03^{a}	36.15 ± 3.01^{a}
	T_2	5.0 ± 0.1^{a}	2.44 ± 0.08^{a}	0.12 ± 0.01^{a}	57.75 ± 5^{ab}	0.29 ± 0.04^{a}	37.24 ± 3.6^{a}
	T_3	4.83 ± 0.75^{a}	1.50 ± 0.11^{b}	0.08 ± 0.005^{b}	48.79 ± 4^{bc}	0.18 ± 0.01^{b}	26.3 ± 2.98^{b}

** a, b, c indicates significant differences among mean values. Mean values (± standard deviation) in the same row followed by the different letters are significantly different from each other by the Tukey test at the 5% probability level ($p \leq 0.05$). Note: T_0= Control (without fertilizer and pruning materials), T_1= Recommended fertilizer dose, T_2= Half of the recommended fertilizer dose and pruning materials, T_3= Pruning materials*

Table 5. Soil fertility status of the experimental field under carrot cultivation during the hedge establishment of Vegetable hummingbird (Mean±SD)

*Hedgerow	Treatments	pH	Organic Matter (%)	N (%)	P (ppm)	K (me/100g)	S (ppm)
Vegetable hummingbird	T_0	5.03 ± 0.5^{a}	2.68 ± 0.18^{c}	0.15 ± 0.01^{b}	45.02 ± 5.3^{b}	0.25 ± 0.02^{b}	63.74 ± 5.6^{c}
	T_1	5.17 ± 0.05^{a}	3.42 ± 0.14^{a}	0.26 ± 0.01^{a}	70.73 ± 5.2^{a}	0.43 ± 0.05^{a}	86.72 ± 6.1^{a}
	T_2	5.10 ± 0^{a}	3.20 ± 0.1^{ab}	0.27 ± 0.03^{a}	65.10 ± 3^{a}	0.51 ± 0.06^{a}	79.70 ± 3.9^{ab}
	T_3	5.10 ± 0.1^{a}	2.87 ± 0.09^{bc}	0.15 ± 0.01^{b}	48.86 ± 5.5^{b}	0.25 ± 0.02^{b}	67.98 ± 4.8^{bc}

** a, b, c indicates significant differences among mean values. Mean values (± standard deviation) in the same row followed by the different letters are significantly different from each other by the Tukey test at the 5% probability level ($p \leq 0.05$). Note: T_0= Control (without fertilizer and pruning materials), T_1= Recommended fertilizer dose, T_2= Half of the recommended fertilizer dose and pruning materials, T_3= Pruning materials*

3.5 Soil Fertility Status of the Experimental Field After Carrot Cultivation during the Hedge Establishment of Vegetable Hummingbird

Different soil fertility parameters under carrot cultivation were found higher in the fertilizer and pruning material treated plot than in the control plot. The highest soil pH (5.17), organic matter (3.42%), available P (70.73 ppm), and S (86.72 ppm) were found in treatment T_1, and total N (0.15%) and available K (0.51 me/100g) were recorded in treatment T_2 when carrot was grown in association with vegetable hummingbird (Table 5). Lowest soil pH (5.03), organic matter (2.68%), total N (0.15%), available P (45.02 ppm), K (0.25 me/100g), and S (63.74 ppm) were found in treatment T_0 (Control). The lowest value of total N (0.15%) and available K (0.25me/100g) was found in treatment T_3 (Table 5). Except for soil pH, all parameters were found to increase significantly at treatments T_1 and T_2 compared to T_0 (control).

Table 6. Effect of fertilizer rate and green manure on the increasing soil nutrients under the hedge of Ipil-ipil and Vegetable hummingbird at different treatments

Soil nutrient parameter	*Treatments	Increasing soil nutrient concentration under the hedge of tree legumes	
		Ipil-ipil	Vegetable hummingbird
Organic matter (%)	T_0	0.22	0.93
	T_1	0.86	1.67
	T_2	1.09	1.45
	T_3	0.15	1.12
N (%)	T_0	0.01	0.05
	T_1	0.07	0.16
	T_2	0.05	0.17
	T_3	0.01	0.05
P (ppm)	T_0	25.27	36.02
	T_1	45.21	61.73
	T_2	39.75	56.10
	T_3	30.79	39.86
K (me/100g)	T_0	0.03	0.14
	T_1	0.18	0.32
	T_2	0.13	0.40
	T_3	0.02	0.14
S (ppm)	T_0	0.80	1.74
	T_1	12.15	24.72
	T_2	13.24	17.70
	T_3	2.30	5.98

Here, T_0= Control (without fertilizer and pruning materials), T_1= Recommended fertilizer dose, T_2= Half of the recommended fertilizer dose and pruning materials, T_3= Pruning materials

3.6 Comparison Between the Increasing Soil Fertility Status under Ipil-ipil and Vegetable Hummingbird based Alley Cropping System

Table 6 shows the effect of different treatments on the increasing concentration of different soil nutrient parameters under the hedge of ipil-ipil and vegetable hummingbird after carrot cultivation. It was observed that increasing concentrations of OM, N, P, K, and S in the vegetable-cultivated soil under the vegetable hummingbird hedge were higher compared to the ipil-ipil hedge at all applied treatments (Table 6). The concentration of these parameters was found to increase in a very small amount, even in the control treatment, where no fertilizer and pruning materials were applied (Table 6).

4. DISCUSSION

The effects of pruning materials of ipil-ipil (*Leucaena leucocephala*) and vegetable hummingbird or bakphul (*Sesbania grandiflora*) trees and fertilizer rate on carrot (*Daucus carota*) during hedgerow establishment are discussed in this section as the morphological features and yield of carrot.

4.1 Plant Height

The highest plant height was recorded in treatment T_2, and the lowest was observed in T_0 when the carrot was grown in association with ipil-ipil. The plant height in fertilized and pruning material treated plots was significantly higher compared to the control. A similar result was found when the carrot was grown with vegetable hummingbird. The reason for the highest plant height in treatment T_2 might be due to the addition of sufficient soil nutrients through this treatment. The difference in the plant height of the carrot under the hedge ipil-ipil and vegetable hummingbird is non-significant at different treatments. These outcomes are in agreement with the outcomes of Rahman et al. [13], who observed yield improvement in different winter vegetables under the alley cropping system, and the result also agreed with Bithi et al. [14]. Sharma et al. [15] showed that the addition of organic manure significantly increased plant length.

4.2 Number of Leaf Plant^{-1}

The number of leaf plant^{-1} of carrot was found to be the maximum in the treatment T_2 (half of the recommended fertilizer dose and pruning materials) when grown under the hedge of ipil-ipil and vegetable hummingbird. The second maximum was in T_1 (recommended fertilizer dose), and the minimum number of leaves per plant was in T_0 treatment (without fertilizer and pruning materials). There was no significant difference between T_1 and T_2, but both have a significant difference with T_0 because there was no source for adding nutrients in the control (T_0). The number of leaf plant^{-1} was higher under the ipil-ipil tree compared to the vegetative hummingbird at treatments T_1, T_2 and T_3. Saha et al., [16] got the same results when spinach was grown with ipil-ipil.

4.3 Root Length

The root length of the carrot was significantly changed by different treatments. After harvesting, the smaller root length of the carrot was found when there was no application of fertilizer and pruning materials. The largest root length was found in treatment T_1 (recommended fertilizer dose), and the second largest root length was found in T_2 (half of the recommended fertilizer dose and pruning materials). The significant differences in the soil nutrient contents in treatments T_1 and T_2 compared to T_0 and T_3 may be the reason for the largest root length in T_1 followed by T_2. The root length was higher under the ipil-ipil tree at treatments T_1 and T_2 and under the vegetative hummingbird at treatments T_0 and T_3. Emon et al. [17] got similar results when radish was grown in association with ipil-ipil.

4.4 Root Diameter

Different treatments also influenced the root diameter of the carrot. The Smaller root diameter of carrot was found in treatment T_0 (without manure and fertilizer), and the highest root diameter was found in treatment T_1 (half of the recommended fertilizer dose) when it was grown in the alleys between the hedgerows of both ipil-ipil and vegetable hummingbird. The ipil-ipil hedge showed better performance than the vegetable hummingbird hedge in the case of increasing the root diameter of carrots at all treatments except T_3. The result of root diameter, shown by Emon et al. [17], is in accordance with the outcome of this study.

4.5 Yield of Carrot

The highest fresh weight of carrot was recorded in treatment T_2 (half of the recommended fertilizer dose and pruning materials), followed by treatment T_1 (recommended fertilizer dose) in the case of ipil-ipil hedge. On the other hand, the highest carrot fresh weight was recorded in treatment T_1, followed by treatment T_2 in the case of the vegetable hummingbird hedge. The carrot yield at different treatments was higher in the fertilizer and pruning material treated plot than in the control plot because there was no source of nutrients in the control. There was no significant difference between treatments T_2 and T_1, but both treatments have substantial differences with treatments T_0 (without fertilizer and pruning materials) and T_3 (with pruning materials) due to the sufficient supply of nutrients in treatments T_1 and T_2 through fertilization and green manuring. The carrot yield under the hedge of ipil-ipil was a little bit higher than that of the vegetable hummingbird hedge at T_0, T_2 and T_3, but the difference was found to be non-significant. Similar results were also observed by Rahman et al. [13] in different winter vegetables, Zoysa et al. [18], Arefin et al. [19] and Tanzi et al. [20] in rice, and Basak et al. [21] in soybean and wheat under alley cropping system.

4.6 Change in Soil Nutrient Status

After vegetable cultivation, there was no significant change in the soil pH of alleys after carrot cultivation under the hedge of ipil-ipil and vegetable hummingbird. After harvesting, almost all treatments have the same soil pH with no significant difference. The maximum soil pH was 5.17 in treatment T_1 when the carrot was cultivated under the hedge of vegetable hummingbird. Koyejo et al. [22] found the same results but reported that soil pH increased significantly when long-term alley cropping was done.

Organic matter (OM), nitrogen (N), phosphorus (P), potassium (K), and Sulphur (S) in different alleys between the hedgerows of ipil-ipil and vegetable hummingbird was found to be increased significantly in treatment T_1 (recommended fertilizer dose and pruning materials) and treatment T_2 (half of the recommended fertilizer dose and pruning materials) under the carrot field. Improvement in soil fertility was also found in the alleys between the hedgerows of ipil-ipil and vegetable hummingbird when only pruning material was applied to the soil, but the improvement was not significant. After harvesting the carrot, the highest organic matter was recorded in treatment T_1 when the carrot was grown under the vegetable hummingbird hedge. Again, all control treatments show the lowest organic matter content. Other fertilizer and pruning materials treated treatments also contain a higher amount of organic matter, which significantly differs from the control treatment. The increasing contents of OM, N, P, K and S at different fertilizers and pruning materials applied treatments after carrot cultivation were recorded to be better under the vegetable hummingbird (*Sesbania grandiflora*) hedgerow compared to the ipil-ipil (*Leucaena leucocephala*) hedgerow. Though ipil-ipil is a nitrogen-fixing leguminous tree species, it could not add sufficient N to the soil during the early hedgerow establishment period [21].

In the case of nitrogen (N), phosphorus (P), and potassium (K), the highest values were found in treatment $T_{2,}$ and the maximum concentration of sulfur (S) was recorded in treatment T_1. There was no significant difference among fertilizer and pruning material treated treatments (T_1, T_2, T_3), but all of these treatments showed significant differences with treatment T_0 (control). These results agreed with Basak et al. [21] and Koyejo et al. [22], who stated that alley cropping increased the soil phosphorus content substantially, but from year 1 to year 2, its content decreased, indicating that the tree species recycled greater phosphorus through litter decomposition. Koyejo et al. [23] reported that litter-fall production in *A. floribunda* occurred throughout the year, with a higher quantity produced in the dry season, while Cai et al. [24] observed an increase in total phosphorus and available phosphorus from organic materials. Ano and Agwu [25] attributed the non-significant improvement in soil pH by organic materials to a non-significant effect on exchangeable cations (calcium and magnesium) and total exchangeable acidity. Generally, soil pH, potassium, magnesium, and calcium increased remarkably with tree age, probably due to greater litter production. The slight increases in organic matter and N contents may be attributable to the fact that nitrogen is required or absorbed in larger amounts by plants for growth and yield [26]. The enhanced nutrient contents (especially K, Mg, and Ca) in the alley system did not reflect positively on maize and mungbean seed yields in the tree-based intercropping system, probably due to the tree shading effect. Unlike other elements, phosphorus content decreased drastically with tree age, indicating greater uptake of the element by the tree and crops. Iwuagwu et al. [27] made a similar observation and attributed the decrease in soil phosphorus to uptake by cocoyam, which had higher phosphorus content in the cormel relative to other mineral elements.

5. CONCLUSION

From the present study, conclusions could be made that the use of inorganic fertilizer may be reduced by adopting hedgerow intercropping with vegetables. The application of organic materials, along with the reduced amount of chemical fertilizer, has a positive impact on the yield performance of carrots during the early hedgerow establishment of ipil-ipil (*Leucaena leucocephala*) and vegetable hummingbird (*Sesbania grandiflora*). Alley cropping with these leguminous tree species could also play an important role in improving soil fertility under carrot cultivation. Organic matter, nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) in different alleys were found to be increased significantly in treatment T_2 and treatment T_1 under the carrot field. During the hedge establishment period, vegetable hummingbird showed a slightly better capacity to improve soil fertility in the experimental field compared to ipil-ipil. Therefore, an alley cropping system with ipil-ipil and vegetable hummingbird may enhance the yield performance of carrot and organically improve soil fertility during the hedge establishment period. Further research with large agroecological regions and different crops is needed to test the efficiency of alley cropping. Long-term trials are also required to find out the accurate effect of alley cropping on soil fertility.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratefulness to the “Sylhet Agricultural University Research System (SAURES)” for providing research funds and “Soil Resource Development Institute (SRDI)” located in the Sylhet region of Bangladesh for assisting in soil nutrient analysis.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/111225