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Effect of Direction and Distance of *Moringa oleifera* on Growth and Yield of Cabbage (*Brassica oleracea*)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

A field experiment was conducted at the moringa-based experimental farm of the Department of Agroforestry and Environment, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur from November 2020 to September 2021. The aim of the study was to assess how well cabbage performed and adapted to various orientations and distances from the moringa tree. The experiment was carried out in a Randomized Complete Block Design (RCBD) with three replications. Four different directions along with one control plot were used as factor A and different distances from tree base was treated as factor B. The data of some ecophysiological parameters like maximum light intensity and soil temperature were noticed in south direction and the widest distance from tree base. The highest soil moisture was found at north direction. Most of the growth parameters showed better performance in open field compared to shade condition. In the case of interaction effect, the south direction and the widest distance (180 cm) from moringa tree base showed the highest number of outer leaves, head length, width, head diameter, head length, and head weight compared to other directions and distances. Concurrently, the maximum total yield and marketable yield were recorded from 180 cm in south direction whereas the lowest yield was found at the closest distance (80 cm) and east direction. The marketable yield of south, west, north, and east directions were reduced by 8.43, 14.87, 23.86 and 31.52% as compared to open field. At 130

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cm and 80 cm distance the yield was reduced by 16.42 and 32.26% as compared to 180 cm distance from tree base. The current findings suggested that cabbage may be grown in partial shade in moringa-based agroforestry production systems without enduring significant yield losses.

Keywords: Agroforestry system; cabbage; moringa; orientation; yield.

1. INTRODUCTION

Cropland agroforestry is considered as a production technique where agricultural crops are grown in combination with tree species on the same piece of land to maximize the utilization of natural resources like land, sunlight, water owing to get more profit. This farming technique has been expanded in a large scale to meet the food demand of Bangladesh [1]. Crop land agroforestry includes various multipurpose tree species which are grown along with various annual crops like, rice, wheat, and other seasonal vegetables in farmer’s land. The system provides food, fuel, timber, construction materials, raw materials etc. Soil conservation and improvement have been one of the another most important functions of this system [2].

Correspondingly, human nutrition is crucial for the overall development of a country. Vegetables could be really important in this regard. Vegetables are often abundant in vitamins, minerals and vital amino acids. According to Food and Agriculture Organization, the average recommended per capita vegetable consumption is 250 g whereas Bangladesh only consumes 75 g of vegetables on average per person, including sweet potatoes [3,4]. It would take more than 10 million tons of vegetables to meet the minimum daily requirement of 250 g of vegetables per person per day. Although, the area and production of vegetable have expanded over the past few years, yet the supply and demand still vary considerably. Farming systems face a number of difficulties, including changing weather patterns, poor management, a shortage of good planting materials, and others. So, to produce vegetables along with fruit and/or forest trees is the best alternative to meet the entire requirement. However, the agroforestry production system is complex and is affected by many factors. Plant ecophysiology should be understood to know how plant adopt themselves under different environmental stress like shade, extreme high or low temperature, drought or waterlogging stress.

Moringa oleifera (Drumstick) is an important vegetable in many tropical and sub-tropical countries including Bangladesh. It is highly drought-tolerant and due to its medicinal and nutritional qualities; it is one of the most adaptable and valuable multifunctional trees in the world. Consequently, it has been referred to as a "miracle tree" and "mother's best friend tree" globally [5]. Its leaves and roots are sufficiently high in protein, fiber, calcium, phosphorus, potassium, sulfur, iron, ascorbic acid, carotene, choline, thiamine, riboflavin, and nicotinic acid [6]. In Bangladesh, moringa is an important homestead species that is irregularly planted beside roads across the country. Intriguingly, moringa trees can able to penetrate a substantial amount of the light accessibility and nutrient dynamics also improved by leaf litter to understory vegetables like cabbage because of their deciduous and light crown nature [7]. The cropland agroforestry system could incorporate this species as a key multifunctional tree.

Likewise, Moringa, cabbage (*Brassica oleracea*) is a commercially important vegetable crops in Bangladesh and it contains a considerable amount of vitamins and minerals. It is reported that consumption of cabbage downregulate the risk of diabetics, obesity, heart disease, and overall mortality [8]. Though, some sporadic field research has been done on moringa based agroforestry system; but no systematic and long-term field researches were done due to lack of permanent structures. Nevertheless, the planting directions and distance from the tree base have the greatest impact on the yield of agricultural crops in agroforestry systems. In an agroforestry system, crops are grown in the appropriate directions which will increase crop productivity through harvesting maximum solar radiation and reduce the shade effect. Additionally, crop yields are higher at larger distances from tree bases compared to those at closer distances. As distance increases from the tree base, Photo-synthetic Active Radiation (PAR) availability also increases whereas below-ground resources competition is reduced [9]. Therefore, a study was undertaken to estimate the yield and yield attributes of cabbage considering different directions and also find out the optimum distance from the tree base for having a better yield of cabbage under moringa based agroforestry systems.

2. MATERIALS AND METHODS

2.1 Experimental Site and Climatic Condition

The field experiment was conducted at the moringa based research farm of the Department of Agroforestry and Environment, BSMRAU, Gazipur, Bangladesh during the period from November 2020 to September 2021.The experimental location is 8.2 meters above sea level and is situated in the center of Madhupur Tract's (24°29' N latitude, 90°26' E longitude). The experimental location is situated in a sub-tropical climate with abundant rainfall from April to September and little else during the rest of the year. The soil is silty-clay loam in texture which belongs to Salna series of Shallow Red-Brown Terrace soil. The average relative humidity in both case (morning and noon) were fluctuated. However, Average relative humidity at morning was always higher than noon.

2.2 Experimental Design and Layout

The experiment was carried out in a two factor Randomized Complete Block Design (RCBD) with three replications. The experiment was followed in concentrated ring method (Fig. 1). The treatments are as follows:

Factor A: Four directions of the tree i.e. North, East, South and West; Factor B: Distance of cabbage from the tree base (80 cm, 130 cm and 180 cm). An individual moringa tree was considered as a single replication. There was a control plot of cabbage that received full sunlight without tree species.

2.3 Moringa Orchad Establishment

The field was cleared and prepared during the second week of June 2015. The 12 m × 8 m block/plot for each tree was marked by measuring tape having five-meter distance from the plot. Twenty pits were prepared in each block 60 cm × 60 cm × 60 cm in size. Moringa stem-cuttings were collected from different districts of Bangladesh. The collected stem-cuttings were transplanted in pits during first week of July 2015. The spacing of all trees was 4 m × 4 m.

2.4 Planting Materials and Seedling Establishment

The cabbage (Atlas-70) seeds were sown in bed on 24th October 2020. The soil of the bed was prepared finely for smooth seed germination Thirty-two (32) days old, healthy, uniform seedlings were transplanted on 26th November 2020, maintaining row to row and plant to plant spacing of 70 cm × 60 cm, respectively. Post transplanting irrigation was given for successful seedling establishment. Dead and weak plants were uprooted and gaps were filled with healthy seedlings of same age preserved in seedbed.

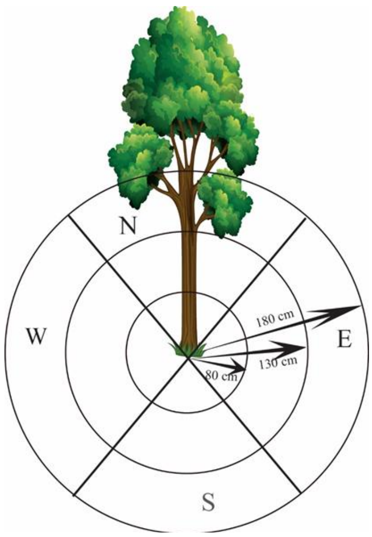

Fig. 1. Layout of the study area

2.5 Data Collection

Twenty plants were selected from each plot for data collection. Data of light intensity, soil moisture and soil temperature were taken at field conditions. The observed plant parameters were number a of outer leaves (plant^{-1}), fresh weight of outer leaves (g plant^{-1}), dry weight of outer leaves (g plant^{-1}), Outer leaf length (cm plant^{-1}), outer leaf width (cm plant^{-1}), head length (cm plant^{-1}), head diameter (cm plant^{-1}), head weight (kg plant^{-1}), head dry weight (kg plant^{-1}), total weight (t ha^{-1}), marketable yield (t ha^{-1}). Harvesting was done by treatment wise after judging the compactness of cabbage head. Harvesting was stared from February to March 2021. The soil moisture was taken by using soil moisture meter-DSMM 500. The soil temperature was taken by using a thermometer. Light intensity data was measured from canopy area of moringa plant by using a TES 1335 light meter.

2.6 Statistical Analysis

All data were subjected to analyses of variance (ANOVA) using STATISTIX 10 Software. The comparisons of treatment means were made using Least Significant Difference (LSD) at 5 % level of probability (p = 0.05).

3. RESULTS AND DISCUSSION

3.1 Light Availability, Soil Moisture and Soil Temperature at Different Directions and Distances

The light intensity was found to vary noticeably on an open field and at various directions. Light availability in an agroforestry system was significantly lower than in an open field at all measurement dates. At 30 days after planting (DAP), the highest light was available in open field followed by south, west, north and east directions. Most of the light was observed at south direction at 60 DAP among the various directions. In case of 70 DAP, the maximum light was observed in the south direction (1024 lux), which was substantially compared to the north direction (Fig. 2a).

Additionally, the light intensity varied significantly depending on the distance from the tree base. At 30, 40, 50, 60 and 70 DAP, the maximum light was available at 180 cm distance from tree base followed by 130 cm, 80 cm distance. At 70 DAP, relatively better light (1447.33 lux) intensity was obtained at 180 cm distance from tree base than other level of distances (Fig. 2b).

As shown in Fig. 2c, at all the measurement dates (20, 30, 40, 50, 60, 70 DAP), soil moisture content was higher in agroforestry system than open field condition, although there was some variation among the directions. The highest soil moisture (32%) was noted at north direction followed by west, east and south directions at 60 DAP. At 70 DAP the maximum soil moisture (22.11 %) was recorded at north direction and lowest in south direction (21.26 %) (Fig. 2c). The north direction recorded the most soil moisture on maximum days, whereas the south direction recorded the lowest soil moisture. The soil moisture was high in different directions compared to open field due to shade condition which reduce the evaporation and preserve the soil moisture [10].

In most of the case soil moisture was decreased with increasing the distance from tree base, having a bit inconsistency. At 70 DAP, the maximum soil moisture was found at 80 cm (22.25%) and minimum 180 cm (21.18%) from tree base which was statistically different to each other (Fig. 2d). In maximum case the soil moisture was the highest at 130 cm that is medium distance from tree base and lowest at 180 cm from tree base.

In general, soil temperature was relatively higher in open field than agroforestry fields regardless of directions. At 50 DAP, the maximum soil temperature was noted in open field followed by south, north and west directions that were insignificant to each other (Fig. 2e). Among the different directions, the maximum soil temperature was found in south direction (27.64°C) and minimum in east direction (23.37°C) at 70 DAP (Fig. 2e).

Taking into accounts the soil moisture, at different DAP, relatively higher soil temperature was recorded at 180cm distance from tree base than the other levels of distance at different time of observations (Fig. 2f). However, the highest soil temperature (26.40°C) was found at 180 cm and the lowest (23.75°C) was at 80 cm distance from tree base at 70 DAP. The present results are consistent with those documented in hedgerow-tomato intercropping [10], bale-based agroforestry system [11].

3.2 The Effect of Different Directions and Distances on Leaf Characteristics of Cabbage

3.2.1 Number of outer leaves per plant

Number of outer leaves per plant of cabbage at different directions under moringa based agroforestry systems and open condition showed considerable variation at harvesting dates. Among different directions the east (12.67) direction showed better performance which is significantly similar with south (12.64) and north (12.08) directions except west (11.17) direction (Fig. 3a). Nevertheless, open field produced the highest number of outer leaves per plant than shade condition. It might be due to maximum photosynthesis in open condition, which influenced production of more outer leaf. It has been reported that shading reduced leaf number and leaf thickness of okra [12].

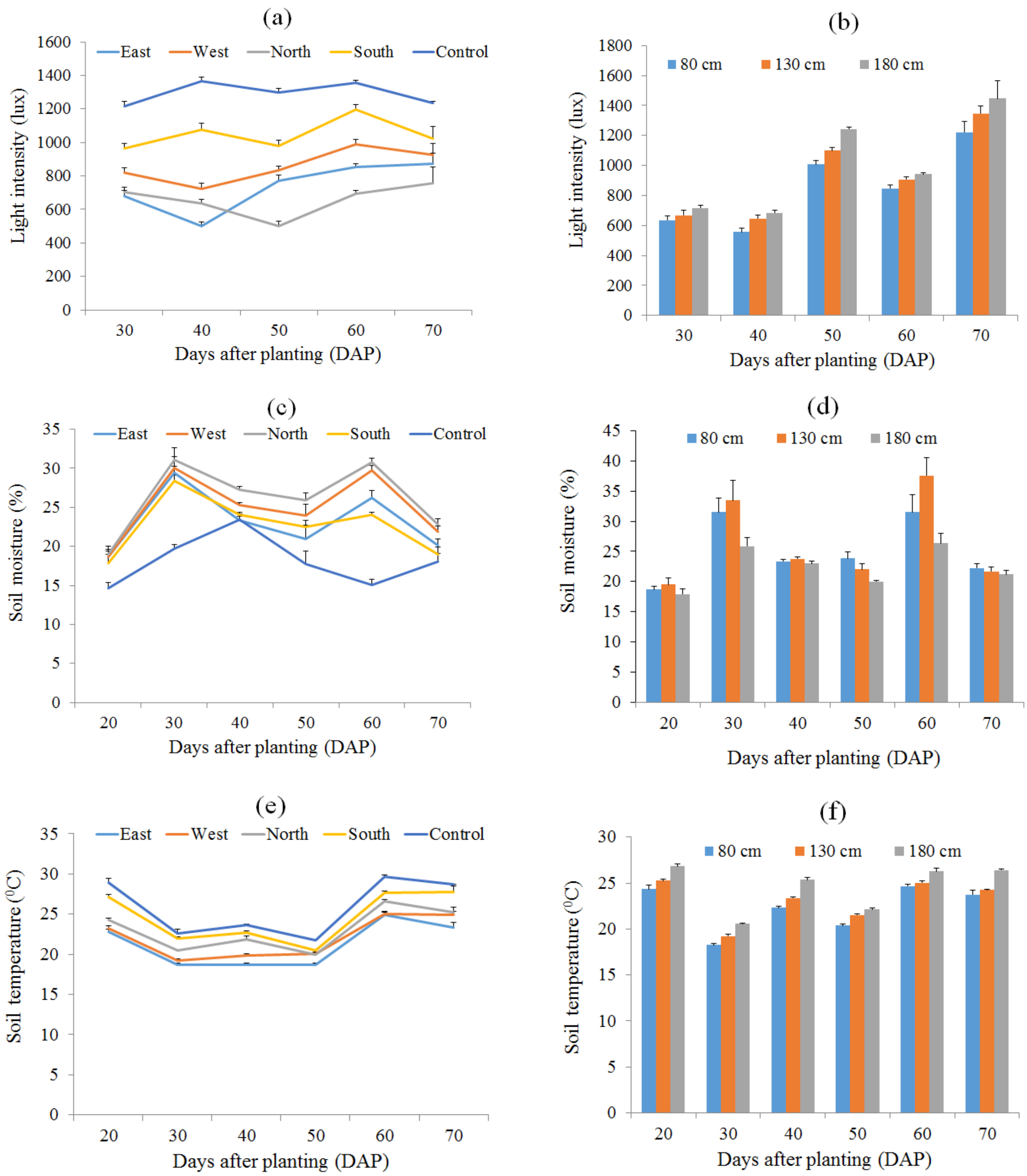

Fig. 2. Light intensity, soil moisture content and soil temperature at different directions and open condition i.e. control (a) and different distance from tree base (b). Data represents mean ± SE of 3 independent replicates and means followed by uncommon letter(s) differ significantly by LSD at 5% level

As the distance from the tree base increased, the number of outer leaves gradually increased. At harvesting time, the highest number of outer leaves per plant (14.36) and the lowest (9.82) were found at the far (180 cm) and closest (80 cm) distance from tree base, respectively (Fig 3b). This might be due to corresponding increase of light level. The reduced synthesis of photosynthates under low light conditions may be the cause of the lower number of outer leaves per plant under the lowered light conditions for a longer period [13]. It can be also explained that competition between trees and crops for natural resources (such water and nutrients) in the areas closest to the moringa tree's base might be another reason for lower number of outer leaves [14,15].

The open field had significantly the longest outer leaf length per plant (33.66 cm), while the east direction had the shortest (23.55 cm), which was followed by the south, west, and north directions, respectively (Fig. 3c). In general, outer leaf length per plant was decreased with increasing distance from tree base. At harvesting time, significantly maximum (27.65 cm) and minimum (23.67 cm) outer leaf length per plant was found at the far (180 cm) and closest (80 cm) distance from tree base, respectively (Fig. 3d).

The west direction showed significantly the highest outer leaf width per plant (25.65 cm), while the east direction had the lowest outer leaves width per plant (22.78 cm), which was identical to the north and south directions, respectively (Fig. 3e). The open field i.e. control, exhibited the utmost value (33.33 cm) for the width of the outer leaves per plant of cabbage. Closest distance from tree base showed negative effect on outer leaf width per plant in cabbage. At harvesting time, significantly the highest outer leaf width per plant (25.33 cm) and the lowest (22.58 cm) was found at the far (180cm) and closest (80 cm) distance from tree base that was insignificant to each other, respectively (Fig. 3f). Under shaded conditions, there may be a downregulation of cell division and growth [16].

3.2.2 Fresh and dry weight of outer leaves per plant

Fresh and dry weight of outer leaf of cabbage per plant were affected at different directions under moringa based agroforestry systems and open condition (Fig. 4). In case of different directions, the highest fresh weight of outer leaves per plant (0.604 g) were noted in south direction followed by north (0.578g), east (0.542 g) and west (0.537 g) directions (Fig 4a). Similarly, the highest (0.155 g) dry weight of outer leaves per plant were observed in open field which was identical with south direction (Fig. 4b). The south directions outperformed every other directions in terms of the fresh and dry weights of the outer leaves per plant. These could be explained that, south direction reduces the influence of shade and provides adequate light, which helps to boost crop productivity [17]. The results of the current investigation were also supported by Meer et al*.,* (2021) [10] in tomato.

At harvesting time, the maximum (180 cm) distance yielded considerably greater fresh weight (0.7731 g), but the closest (80 cm) distance from the tree base produced less (0.5210 g) outer leaves per plant (Fig. 4c). Likewise, significantly the highest dry weight of outer leaves per plant (0.127g) was noticed at longest distan ce (180cm) and lowest (0.092 g) at closest (80 cm) distance from tree base, respectively (Fig. 4d). This finding aligned with the research findings of Sayed et al., (2009) [18] and Khatun et al., (2009) [19] in Telsur (*Hopea odorata*) and Civit (*Swinfonia floribunda*).

3.3 Combined Effect of Direction and Distance on Leaf Characteristics of Cabbage

The variation in number of outer leaf, fresh and dry weight of outer leaf, outer leaf length and width per plant of cabbage due to the combined effects of different directions and distances from the tree base has been presented in Table 1.

The highest number of outer leaves per plant of cabbage i.e. 16, 15.33, 14.67 were recorded at control, 180 cm in south and north directions, respectively which were significantly similar to each other. But the lowest number of outer leaves (9) was noted 80 cm in west direction which was insignificant with 80cm in the north direction.

Considering the interaction effect of directions and distances, the maximum fresh (1.037 g) and dry (0.114 g) weight of outer leaves per plant of cabbage were recorded at open field condition i.e. control. In case of combined effect of directions and distances, the fresh weight was higher (0.782 g) at 180 cm in south which was identical with 180 cm west (0.718), 130 cm south (0.709) directions under moringa based agroforestry system, respectively. However, dry weight of outer leaves per plant was found to be highest at 180 cm in south (0.099 g) and west (0.091 g) and 130 cm in south (0.88 g) directions whereas lowest was noticed at 80 cm in east (0.048 g) and north (0.051 g) directions, respectively (Table 1).

In case of outer leaf length per plant of cabbage, the maximum length was recorded in control (36 cm). The second highest value were obtained at 180 cm in south and west directions. The lowest outer leaf length (20.10 cm) per plant of cabbage was noted at 80cm distance in east direction regardless of measurement dates (Table 1).

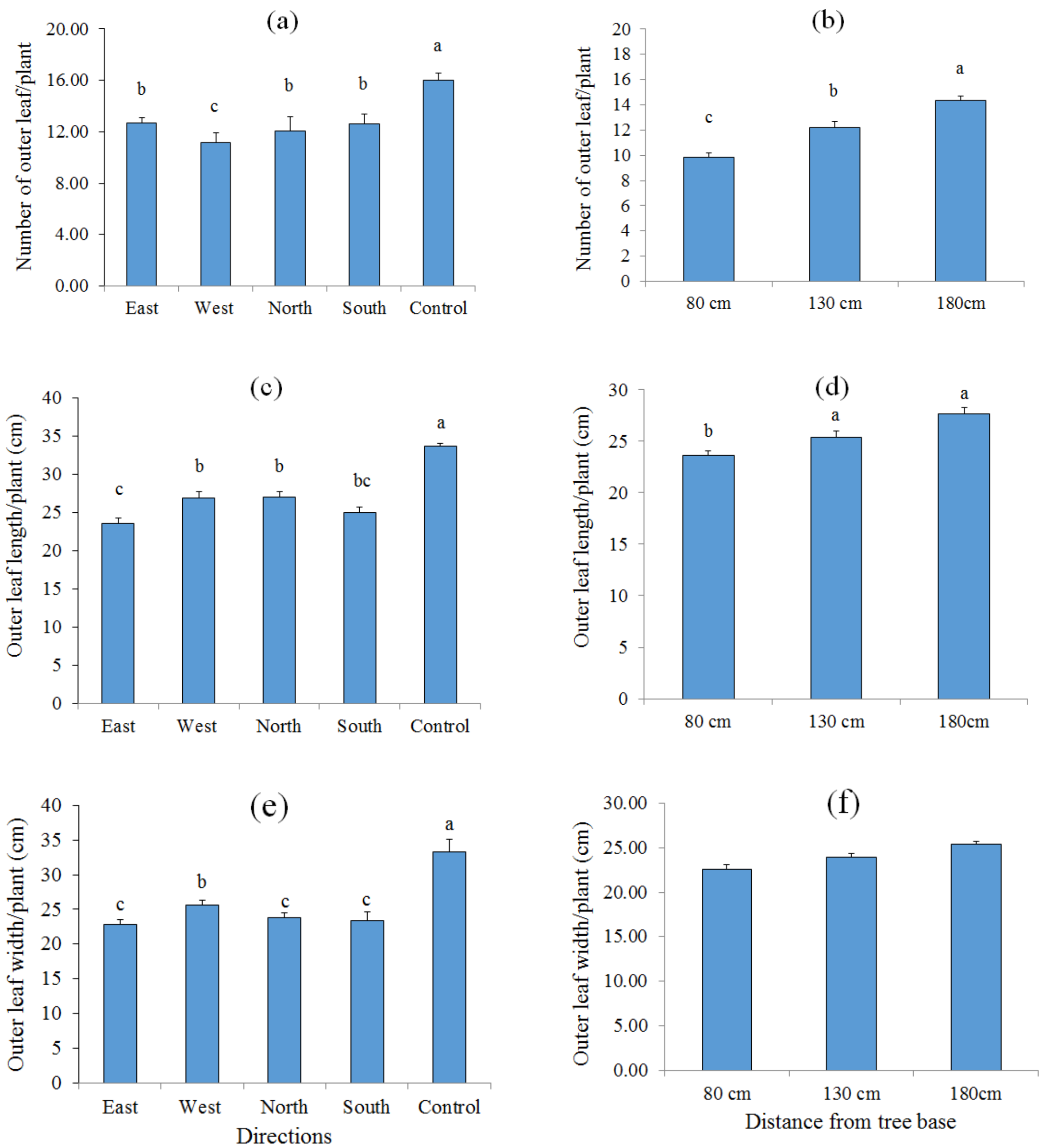

Fig. 3. Effect of different directions and distances from tree base on number of outer leaf (a, b), outer leaf length (c, d) and outer leaf width (e, f) per plant of cabbage. Data represents mean ± SE of 3 independent replicates and means followed by uncommon letter(s) differ significantly by LSD at 5% level

The combined effect of 180 cm in south direction showed the uppermost outer leaf width per plant (27.66 cm) of cabbage that insignificantly followed by 180 cm in west directions under moringa based agroforestry system, respectively. The highest increment of outer leaf width per plant of cabbage were recorded in control (33.33 cm) (Table 1). The increased development of different yield aspects could be attributed to the increased light availability, which promoted photosynthesis and metabolic processes and raised the production of cabbage [11].

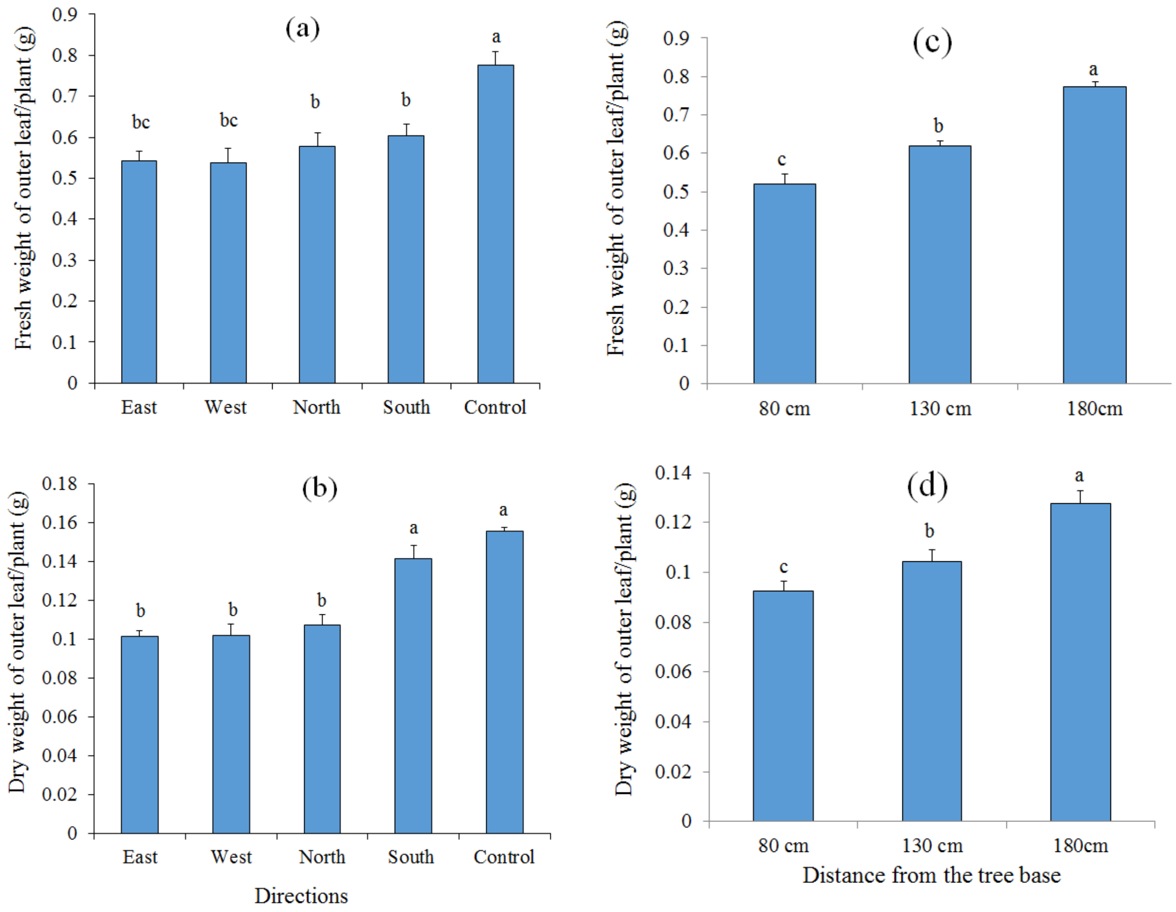

Fig. 4. Effect of different directions and distances from tree base on fresh (a, c) and dry (b, d) weight per plant of cabbage. Data represents mean ± SE of 3 independent replicates and means followed by uncommon letter(s) differ significantly by LSD at 5% level

Table 1. Combined effect of different direction and distance from tree base on leaf characteristics of cabbage in association with moringa tree

Interaction	NOL	FWOL(g)	DWOL(g)	OLL(cm)	OLW(cm)
80 cm × East	11.06efg	0.402ef	0.048ef	20.10e	21.33f
80cm × West	9.00 g	0.451de	0.060de	24.66cde	21.05f
80cm × North	9.06 g	0.405ef	0.051def	21.00e	23.00cde
80 cm × South	10.16 fg	0.474de	0.059de	23.00de	20.66f
130 cm × East	12.96 cde	0.512d	0.069cd	23.33de	22.33def
130cm × West	11.00 efg	0.623cd	0.076c	25.81cd	26.00bc
130 cm × North	11.83 def	0.555d	0.071cd	25.00cd	25.33c
130 cm × South	13.10 cde	0.709bc	0.088b	24.66cde	25.50c
180 cm × East	13.96 bcd	0.527d	0.072cd	25.33cd	23.66cd
180 cm × West	13.50 bcd	0.718b	0.091b	29.00b	26.00bc
180 cm × North	14.67 ab	0.687c	0.077c	25.00cd	23.00cde
180 cm × South	15.33 a	0.782b	0.099b	29.33b	27.66b
Control	16.00 a	1.037a	0.114a	36.00a	33.33a
CV (%)	5.29	6.91	4.44	6.79	4.47

Values are means ± standard errors (n = 3). Different alphabetical letters with the same column indicates significant differences among various treatments according to a least significant difference test (LSD) (P < 0.05). NOL- Number of Outer Leaves, FWOL- Fresh Weight of Outer Leaf, DWOL- Dry Weight of Outer Leaf, OLL- Outer Leaf Length, OLW- Outer Leaf Width

3.4 The Effect of Different Direction and Open Field on Head Characteristics per Plant

3.4.1 Head length per plant

Head length is one of the important yield contributing attributes of cabbage. Head length per plant at different directions under moringa based agroforestry system and open condition showed drastic variation during harvesting. In case of different directions, significantly the highest (15.38 cm) and the lowest (11.35 cm) head length per plant were noted in south and east directions, respectively. But open field showed the maximum head length (17 cm) of cabbage under moringa based agroforestry systems (Fig. 5a). The varying shade levels have a substantial impact on head length.

Mostly, the important yield attributes of cabbage was decreased with increasing distance from tree base. It was observed that the uppermost head length per plant (12.92cm) was obtained at 180cm distance from tree base. But, the lowermost (10.50cm) was observed at 80cm distance from tree base (Fig. 5b). This might be due to corresponding increase of light level. Similar to our findings, Kittur et al., (2016) [20] discovered that the maximum turmeric yield was noticed at widely spaced bamboo trees, while the closet spacing recorded the minimum yield.

3.4.2 Head diameter per plant

Head diameter of each plant varied significantly depending on its direction under moringa based agroforestry system and open condition. The average head diameter per plant was 19.50 cm for the south direction, followed by west (18.61 cm), north (18.36 cm) and east (17.53 cm) directions, respectively (Fig. 5c). Remarkably, it was noticed that all three distances from the tree base (180 cm, 130 cm, and 80 cm) had nearly identical head diameters per plant, measuring 20.01 cm, 18.44 cm, and 17.95 cm, respectively (Fig. 5d).

3.4.3 Head weight per plant

The head weight per plant, which is the most desired yield-contributing trait of cabbage, was the highest (2.18 kg) and the lowest (1.6 kg) in south and east directions, respectively. However, reduction was noticed at all directions when compared with control plants (Fig. 5e). Similar results were also observed in Lohakat (*Zyliadolabi formis*) tree in association with winter vegetables [21].

The head weight of cabbage substantially changed as the distance from the tree base increased. The most desirable characteristic of cabbage that contributed to production i.e. head weight per plant, was 2.16 kg and 1.78 kg, respectively, at 180 cm and 130 cm from the tree base, which were noticeably different from each other (Fig. 5f). Like our results Yogeshwari et al*.,* (2019) [22] found that plant at closer distance from tree base has severely affected by the competition of tree root. Due to completion for growth resources in nearest region of tree base this yield reduction may be occurred.

3.4.4 Marketable yield (t ha^{-1})

The marketable yield of cabbage heads under the moringa-based agroforestry system and in the open field showed noticeable differences as a result of different directions. The maximum marketable yield (98.08t ha^{-1}) was recorded in control, but it was statistically similar (89.81t ha^{-1}) to south direction (Fig. 6a). On the other hand, the minimum marketable yield (67.16t ha^{-1}) of cabbage were noted in east direction that was identical with north direction. The cabbage was grown in winter season (November-March) when the canopy volume of moringa trees was minimum to interrupt the light availability to understory crops, which also reflects in the findings on understory cabbage yields [5].

The marketable yield of cabbage also varied significantly due to increasing distance from tree base. The highest distance (180 cm) from the tree base showed the maximum marketable yield (87.54t ha^{-1}) and minimum (59.30t ha-1) was found at closest (80cm) distance from tree base (Fig. 6b).

3.4.5 Combined effect of yield contributing characters of cabbage

In the current study, the major yield-contributing characteristics of cabbage were significantly impacted by the interaction of different directions and distance from tree base (Table 2). The largest cabbage head length per plant were recorded at control (17 cm) which was identical to that of 180 cm distance in south (15.47cm) and 130 cm in south (15.43 cm) directions. The lowest head length was found at 80cm distance in east direction (10.20 cm).

The diameter of the cabbage head varied substantially depending on the tree's direction and distance from the base. Over the direction and distance from the tree base, maximum head diameter (22.70 cm) was recorded in open field condition which was statically different to the other combined effect of different directions and distance from tree base (Table 2). However, the minimum head diameter per plant of cabbage i.e. 15.10 cm was recorded at 80 cm distance in east direction.

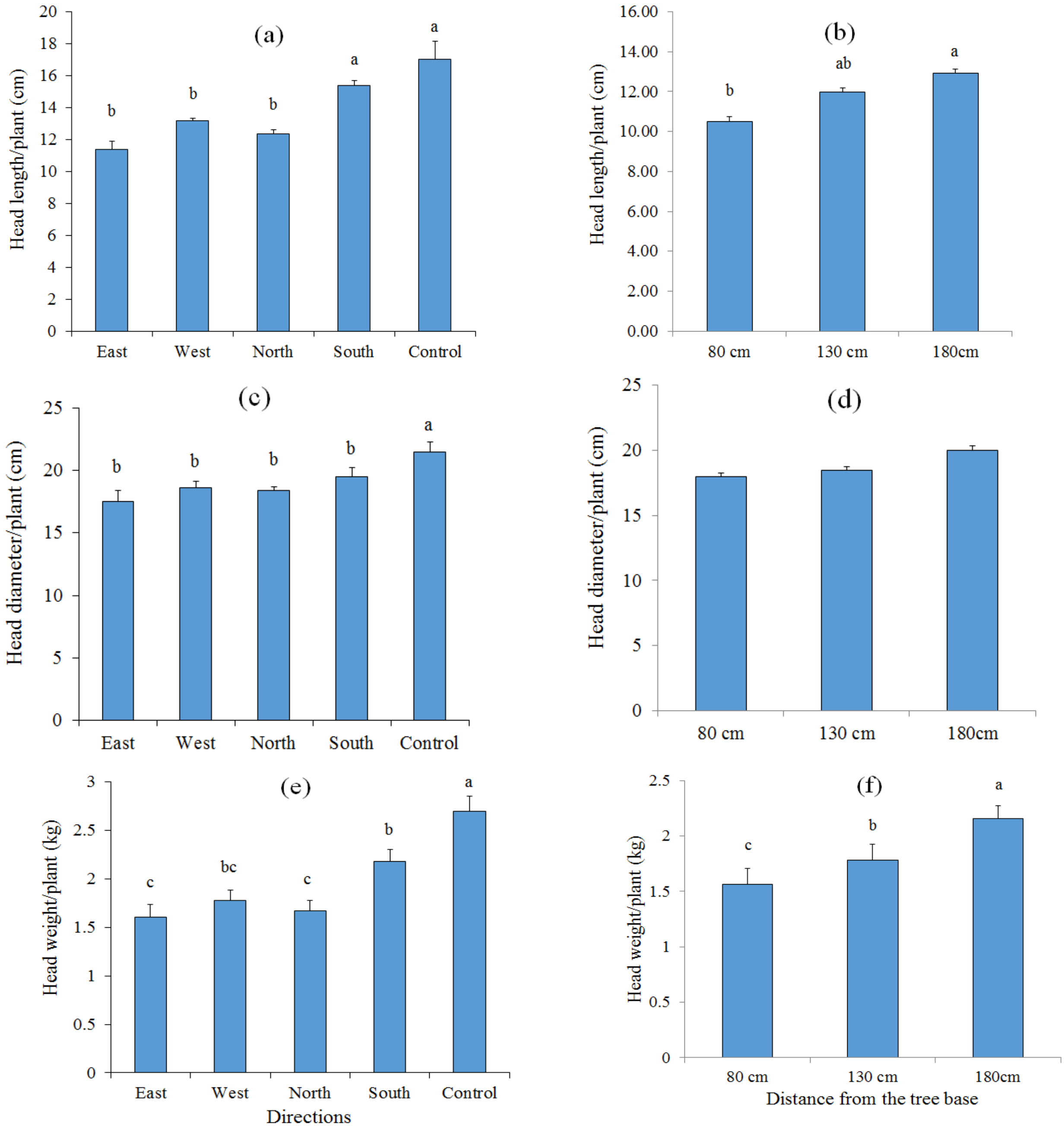

Fig. 5. Effect of different directions and distances from tree base on head length (a, b), head diameter (c, d) and head weight (e, f) per plant of cabbage. Data represents mean ± SE of 3 independent replicates and means followed by uncommon letter(s) differ significantly by LSD at 5% level

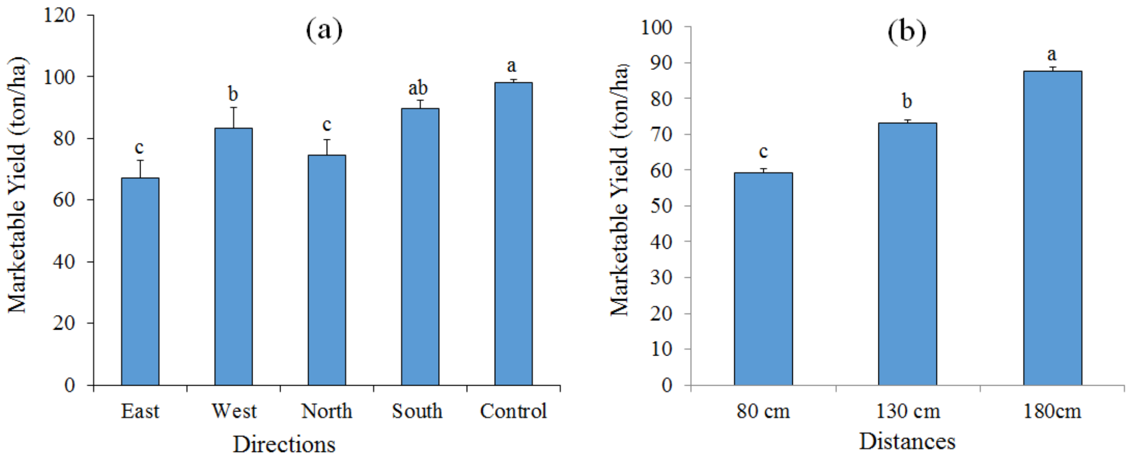

Fig. 6. Marketable yield per plant of cabbage influenced by different directions (a) and open condition i.e. control and different distances from tree base (b). Data represents mean ± SE of 3 independent replicates and means followed by uncommon letter(s) differ significantly by LSD at 5% level

Table 2. Combined effect of different direction and distance from tree base on head characteristics of cabbage in association with moringa tree

Interaction	Head Length (cm)	Head diameter (cm)	Head weight (kg)	Head dry Weight (g)	Total yield (t ha^{-1})	Marketable yield (t ha^{-1})
80 cm × East	10.20e	15.10f	1.065f	0.273g	55.72f	43.97g
80 cm × West	13.13cd	16.77de	1.533de	0.425ef	65.60de	51.74efg
80 cm × North	11.73de	16.33de	1.445ef	0.399fg	62.81de	54.65ef
80 cm × South	13.26cd	17.16cd	1.580de	0.470de	67.28de	59.84ef
130 cm × East	10.46e	16.00de	1.715cde	0.463de	77.75cd	69.91de
130 cm × West	13.56bcd	18.00cd	1.809c	0.645c	80.17cd	77.01cd
130 cm × North	12.40de	17.43cd	1.763cd	0.533cd	79.66cd	72.09cde
130 cm × South	15.43ab	19.00b	1.907bc	0.706b	95.97b	79.94c
180 cm × East	13.40bcd	18.05cd	1.783cd	0.592cd	84.83c	72.46cde
180 cm × West	12.83d	19.06b	1.903bc	0.691b	95.79b	82.55b
180 cm × North	12.97d	18.33cd	1.712cde	0.462de	87.54c	76.73cd
180 cm × South	15.47ab	19.73b	2.089b	0.716b	98.15b	84.03b
Control	17.00a	22.70a	2.702a	0.840a	110.07a	92.05a
CV (%)	6.35	4.81	7.01	5.54	6.01	5.63

Values are means ± standard errors (n = 3). Different alphabetical letters with the same column indicates significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.05$)

The highest head weight of cabbage i.e. 2.089 kg were recorded at 180 cm in south direction whereas the lowest head weight of cabbage i.e. 1.065 kg was observed at 80 cm distance in east direction (Table 2). Moreover, the interaction between different directions and distance from the tree base had an impact on the head dry weight per plant of cabbage. The control showed the uppermost head dry weight per plant (0.840 g) that was statistically significant to all other combinations under moringa based agroforestry systems, respectively. The lowest head dry weight (0.273 g) per plant was recorded at 80cm in east direction (Table 2).

The maximum total yield (98.15t ha^{-1}) was recorded for the 180 cm in south direction whereas the lowest (55.72 t ha^{-1}) for the closest distance (80 cm) and east direction. This result demonstrated that the overall yield increased with the distance increased (Table 2), owing to the availability of adequate light and nutrients to promote the best possible vegetative growth and production. The open field showed the maximum total yield (110.07t ha^{-1}). It can be explained that, the availability of Photosynthetic Active Radiation (PAR) under a tree canopy varies depending on the type of tree, which has an impact on the productivity and growth of understory crops [17]. The yield of the crop adjacent to the tree line has reduced as a result of the tree's shade and the crop's root competition [23]. Also, crop plants were unable to grow properly due to the tree canopy's shade and insufficient sunshine [24].

Regarding the marketable yield, statistically significant changes were seen as a result of the interaction effects between direction and distance from the tree base. The maximum marketable yield (92.05t ha^{-1}) in open field that was statistically significant to the widest distance (180 cm) and south (84.03t ha^{-1}), west direction (82.55 t ha^{-1}). However, the lowest marketable yield (43.97t ha^{-1}) was obtained from 80 cm in east direction (Table 2). The results of the current investigation were also corroborated by Dilla et al*.,* (2019) reports [25].

4. CONCLUSION

The present study concludes that south direction and the widest distance (180 cm) from moringa tree base performed better for obtaining the highest yield and yield contributing characters of cabbage compared to other directions and distances. In comparison to an open field, the marketable yield of south, west, north, and east directions was decreased by 8.43, 14.87, 23.86, and 31.52%, respectively. When compared to 180 cm from the tree base, the yield was decreased by 16.42 and 32.26% at 130 cm and 80 cm, respectively. As we noticed reduced yield under the tree canopy or close to the tree base, which could be attributed by limitations with light transmission or by nutrient and light competition. These two factors might reduce the production of cabbage. Further studies are needed with various aged and spacing of moringa trees and their association under belowground interaction to develop a suitable agroforestry production technology for farmers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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