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Intercropping of Cauliflower with Lettuce Is More Effective for Sustainable Fertilizer Management and Minimizing Environmental Risks

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Abstract: Intercropping systems are one of the sustainable agricultural models as they play an important role in protecting soil fertility, efficient use of resources, maintaining stable yields, and reducing the effectiveness of diseases and pests. The aim of this study was to investigate the effects of intercropping (IC) cauliflower (*Brassica oleracea* L. var. botrytis) with leaf lettuce (*Lactuca sativa* L. var. crispa) on the yield and quality parameters of cauliflower and to evaluate the overall productivity of the system under different nitrogen fertilization rates (160, 200, and 240 kg N ha^{-1}). Our results showed that the leaf chlorophyll value (SPAD), plant weight, leaf weight, head diameter, head height, head weight, and total yield of cauliflower were found to increase as the nitrogen dose increased in both the monocropping (MC) and IC systems. The most efficient nitrogen fertilizer doses for cauliflower were 234.7 kg ha^{-1} for MC and 176.6 kg ha^{-1} for IC, respectively. When the intercropping system was used the total yield (cauliflower and lettuce) was higher than the yield of cauliflower (MC) for the same total area and fertilizer amount. The land equivalent ratio (LER) values were greater than 1 in the intercropping system at all fertilization rates, which indicated that the IC system was more productive than the MC system for the same unit of land. Our findings also showed that intercropping was an effective method to increase fertilizer use efficiency and the soil organic matter, nitrogen content, plant available P, K, Mg, Zn, Fe, Mn, and Cu. In conclusion, while intercropping cauliflower with lettuce did not adversely affect the yield of cauliflower, it enabled harvesting more plants (cauliflower and lettuce) from the same land area by using the same amount of fertilizer, which makes intercropping a sustainable, economical, and ecological model that increases the land-use and fertilizer-use efficiencies.

Keywords: intercropping; nitrogen fertilization; cauliflower; leaf lettuce; sustainability

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1. Introduction

The amount of arable land all over the world is constantly decreasing due to increasing population and industrialization [1]. Approximately 70% more food is needed to feed the overpopulation [2]. Especially in Asia and Africa, where producers own small lands, agricultural lands are under pressure to produce for human nutrition [3]. As global food demand increases, stricter environmental protection regulations and sustainability rules are put forward to prevent agricultural expansion and deforestation [4]. Today, there is no opportunity to increase the agricultural areas, and the per capita agricultural area is decreasing due to the increase in human population.

To date, many methods such as increasing the yield with breeding techniques, using genetically modified organisms, and application of chemical fertilizers and pesticides are used in order to provide the food needed for the increasing world population. While each method has its own advantages and disadvantages, there is still a need for production techniques that are not harmful for ecology and comply with the principles of sustainable agriculture. One of the most effective methods to increase the productivity and use of labor in an area is to use the soil intensively by obtaining more than one product per year, especially in places where the climate is suitable. This can be achieved by cultivation of several annual crops that mature in a short time together or in succession [5].

Agricultural diversity and its effective management are also of great importance for sustainable agriculture [6]. Sustainable agriculture aims to use nature as a model for designing agricultural systems. Intercropping is a diversified farming practice included in sustainable farming techniques [7] and is a method to increase the diversity in the agro-ecosystem [8]. Intercropping refers to the cultivation of two or more plants together in the same place and at the same time [9,10]. Intercropping has many benefits such as increasing the use of environmental resources, obtaining more efficiency compared to sole cropping, providing disease, pest and weed control, protecting soil fertility that improves product quality, preventing erosion, increasing land use efficiency in low-input agricultural systems. It can also reduce the risk factor for farmers since it provides more stable yields [10–12]. The species to be grown with intercropping should not adversely affect the growth of the main crop, should not compete with the main crop, and should be a species that provides an advantage in the cultivation of the main crop and generates more income with the main crop from the unit area than the monoculture [8].

Cauliflower (*Brassica oleraceae* var. botrytis) belongs to the Brassicaceae family, and is a good source of minerals, vitamins, phytochemicals, and carbohydrates. Similarly, leaf lettuce (*Lactuca sativa* L. var. crispa) also contains necessary elements for human nutrition. Both cauliflower and lettuce are cool climate vegetables and are grown widely in Turkey with a total annual production of 235,000 tons (9100 ha) and 234,000 tons (9600 ha), respectively. It is necessary to increase the yield to be obtained from the unit area due to the limited or even decrease in the possibilities of expanding the agricultural lands. Therefore, when considering the increase or diversification of the yield to be obtained from the unit area, cultivation methods such as intercropping come to the fore.

Nitrogen fertilization is indispensable for plants since it improves the vegetative growth, leaf area index, number of leaves, chlorophyll content of leaves, and photosynthesis in plants. Parallel to the increase in photosynthesis, it has a positive effect on yield and quality [13]. For cauliflower, nitrogen fertilization is very crucial for the development of well, tight, and white heads [14]. While low levels of nitrogen results in insufficient leaf and small head formation, in the cases where nitrogen is high, browning of the head color, whipping in the cauliflower leaves, forming a leafy and loose head and hole stem occur [15]. Insufficient or excessive fertilizer applications will cause economic losses in agricultural production, and especially excessive nitrogen application causes serious environmental problems over time [13]. There are many studies examining the effects of nitrogen fertilization [16,17] and intercropping practices [18] on the yield and quality of cauliflower. However, studies on the effect of nitrogen fertilization and intercropping together in cauliflower are limited. The aim of this study is to increase agricultural profitability and sustainability by increasing the crop production obtained from the unit area by using the same field and the same inputs. Therefore, this study was carried out to determine the yield and land use efficiency in cauliflower+leaf lettuce intercropping systems.

2. Materials and Methods

2.1. Plant Materials

Cauliflower (*Brassica oleracea* L. var. botrytis cv. Barcelona F1) and leaf lettuce (*Lactuca sativa* L. var. crispa cv. Funly F1) were used as plant materials.

2.2. Experimental Site

The plants were grown in two growing seasons (2014 and 2015) in the 'Research Field' of Atatürk University, Erzurum, Turkey, which is located at 39.933 N, 41.236 E with an altitude of 1850 m above sea level. Weather data (precipitation, mean temperature and mean humidity) were obtained from the Erzurum Meteorological Station, which is five kilometers away from the experimental site. The meteorological data recorded over the two growing seasons (2014 and 2015) are shown in Figure 1. The following properties of the soil in the experimental area were determined: soil texture (clay loam), pH (7.5), EC (0.015 dS cm^{-1}), total N (0.0091%), exchangeable Ca (1062.50 mg kg^{-1}), Mg (42.64 mg kg^{-1}), K (205.20 mg kg^{-1}), Na (10.10 mg kg^{-1}), plant-available P (16.56 mg kg^{-1}), available Fe (4.13 mg kg^{-1}), Mn (4.56 mg kg^{-1}), Zn (3.45 mg kg^{-1}), Cu (7.86 mg kg^{-1}), and B (0.48 mg kg^{-1}).

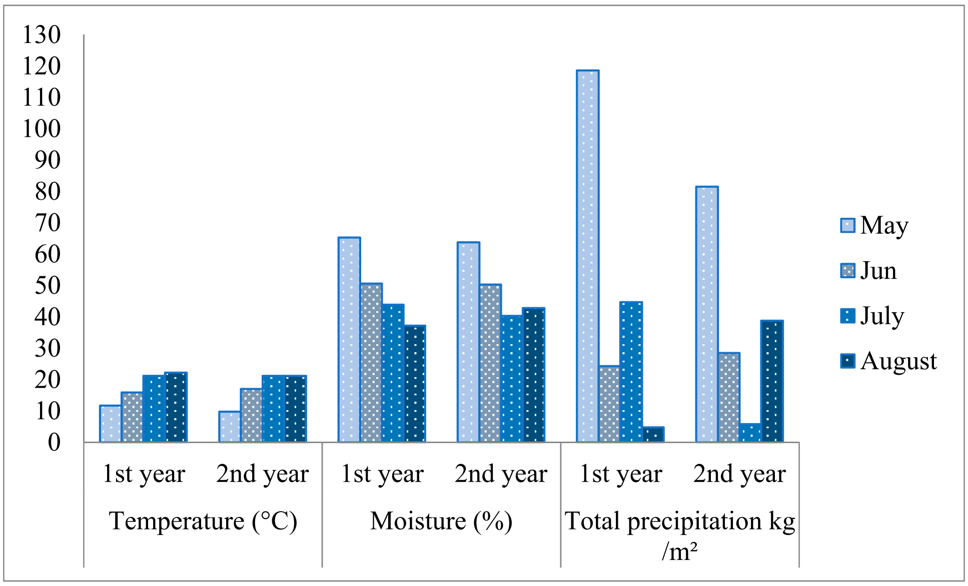

Figure 1. The meteorological data recorded over the two growing seasons (2014 and 2015).

2.3. Experimental Set-Up

Cauliflower and leaf lettuce seedlings were grown separately in the greenhouse of Atatürk University. Cauliflower seeds and lettuce seeds were sown in 216-celled seedling growing trays (peat–perlite (2:1, v/v)). Cauliflower was intercropped with leaf lettuce in the field after 3–4 true leaves stage was reached (Table 1; Figure 1). Cauliflower seedlings were planted in 0.60 × 0.50 m in sole and intercropping cropping systems. In intercropping treatments, one row of leaf lettuce (within-row plant spacing 0.30 m) was planted between cauliflower rows simultaneously in separate plots. In sole planting, leaf lettuce spacing was 0.30 × 0.20 m (Figure 2). Drought stress was avoided by irrigation. Hoeing was done 3 times for weed control. There was no pesticide or herbicide application.

Table 1. Sowing–planting times and distances of the crops used in the field trial.

Crop	Sowing Time		Planting Time		Planting Distance	
	1st year	2nd year	1st year	2nd year	Sole	Intercropping
Cauliflower	24 April	23 April	5 June	7 June	60 × 50 (cm)	60 × 50 (cm)
Leaf lettuce	24 April	23 April	5 June	7 June	30 × 20 (cm)	60 × 20 (cm)

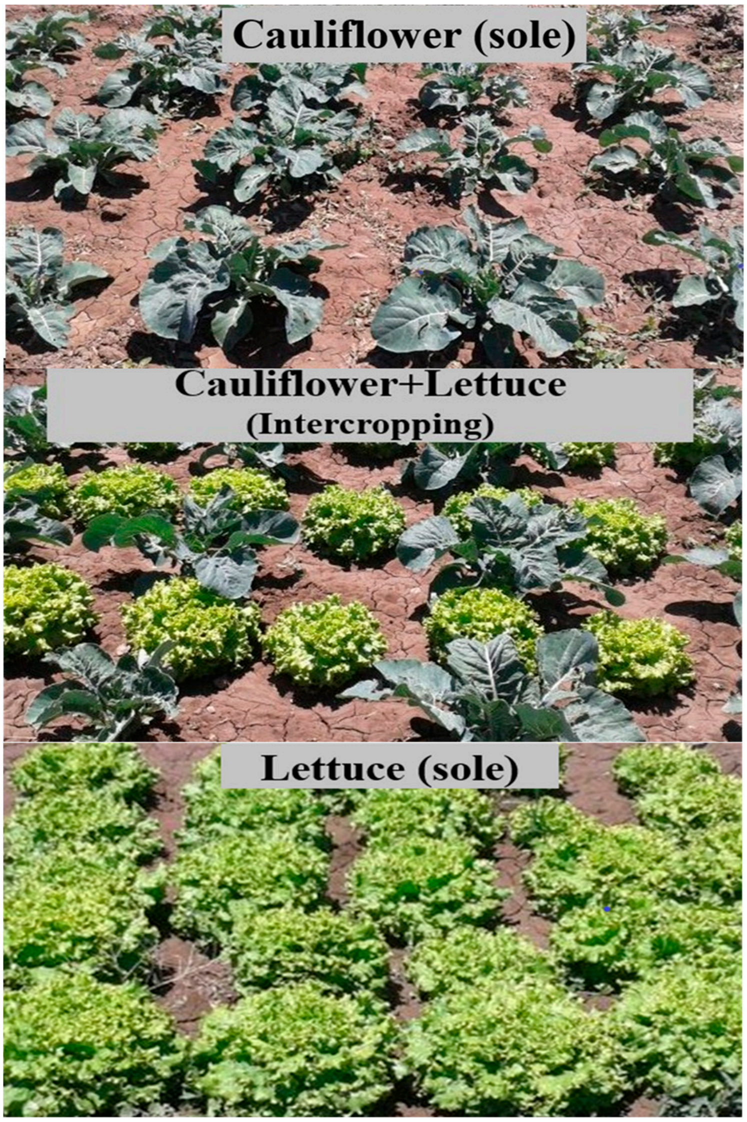

Figure 2. Cropping treatments in the experiment plots.

The experiment was conducted in randomized complete block design with two factors (cropping systems and nitrogen levels) with four replicates (25 plants per replicate). Two treatment effects were studied in this research: cropping system (monocropping and intercropping) and nitrogen doses (160, 200 and 240 kg N ha^{-1}). Basal fertilizer application was 200 P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1} for cauliflower + lettuce intercropping, and nitrogen doses were 160, 200, and 240 kg N ha^{-1}. For leaf lettuce alone, basal fertilizer application was 100 kg N ha^{-1}, 80 P_2O_5 ha^{-1}, and 120 kg K_2O ha^{-1} [19]. There were seven treatments: cauliflower sole (160, 200, and 240 kg N ha^{-1}), cauliflower + leaf lettuce (160, 200, and 240 kg N ha^{-1}), and leaf lettuce alone. Treatments were tested with 28 plots in total.

The cauliflower plants were harvested when they reached marketable size in early August. The inner rows were used for sampling and harvest. The plants were cut at ground level to determine the yield, the head weight, the plant weight, the leaf number, the leaf weight, the stem diameter, the head diameter, and the head dry matter ratio. The plant materials were kept in an incubator at 68 °C for two days to determine dry weights. The leaf lettuce plants were harvested to determine the yield, the stem diameter, and the plant weight 30 days after transplanting.

2.3.1. Chlorophyll Reading Values (SPAD)

A chlorophyll meter (SPAD-502, Konica Minolta Sensing, Inc., Sakai, Japan) was used to determine the chlorophyll content in the leaves of cauliflower and leaf lettuce.

2.3.2. Nitrate Analysis

The method by Cataldo et al. [20] was used for nitrate analysis.

2.3.3. Extraction and Quantification of Vitamin C

High performance liquid chromatography (HPLC) was used for Vitamin C analysis [21].

2.3.4. Soil and Plant Analyses

Soil samples were air dried, crushed, and passed through a 2-mm sieve before physical and chemical analysis. The Kjeldahl method [22] was used to determine organic N while plant-available P was determined by using the sodium bicarbonate method of Olsen et al. [23]. Electrical conductivity (EC) was measured in saturation extracts according to Rhoades [24]. Soil pH was determined in 1:2 extracts, and calcium carbonate concentrations were determined according to McLean [25]. Soil organic matter (OM) was determined using the Smith–Weldon method according to Nelson and Sommers [26]. Ammonium acetate buffered at pH 7 [27] was used to determine exchangeable cations. Microelements in the soils were determined by diethylenetriaminepentaacetic acid (DTPA) extraction methods [28].

Leaf tissue sub-samples taken during head formation (five youngest leaves) were oven dried at 68 °C for 48 h, ground and passed through 1 mm sieve size. Total N was determined by Kjeldahl method using a Kjeldahl distillation unit (Vapodest 10 Rapid, Gerhardt, Konigswinter, Germany). Macro- (P, K, Ca Mg and Na) and micro-elements (Fe, Mn, Zn, Cu, and B) were determined after wet digestion (HNO_3–H_2O_2 acid mixture, 2:3 *v*/*v*) of dried and ground sub-samples in a microwave digestion equipment (Berghof Speedwave MWS-2, Eningen unter Achalm, Germany), by using an inductively couple plasma spectrophotometer (Optima 2100 DV, ICP/OES, Perkin-Elmer, Shelton, CT, USA) [29].

2.3.5. Yield

The yield of cauliflower (ton ha^{-1}) was calculated by multiplying the head weight (g $plant^{-1}$) by the number of plants in 1 ha (33,333 plants).

The yield of lettuce (ton ha^{-1}) was calculated by multiplying plant weight (g $plant^{-1}$) by the number of plants in 1 ha (166,666 plants for sole, 83,333 plants for intercropping).

2.3.6. Land Equivalent Ratio (LER)

The LER values were calculated as follows: LER = LA + LB = AI/AS + BI/BS, where LA and LB are the individual LERs of two crops A and B; AI is the yield of crop A in intercropping, AS is the yield of crop A in sole cropping, and LA is the ratio of AI to AS; BI is the yield of crop B in intercropping, BS is the yield of crop B in sole cropping, and LB is the ratio of BI to BS.

2.3.7. Statistical Analysis

The experimental design was hierarchical with respect to two factors arranged in a randomized complete block design with four replications per treatment. The first factor (main factor-cropping systems) had two levels (monocropping and intercropping), and the second one (subfactor-nitrogen levels) had three levels (160, 200 and 240 kg N ha^{-1}). Before the ANOVA test, the normality test was performed. Data was subjected to analysis of variance (two-way ANOVA) to compare the effects of cropping systems, nitrogen level treatments, and interactions. Means were separated by Duncan's multiple range tests (DMRT) ($p < 0.05$).

3. Results

Growth and yield parameters of cauliflower were found to be significantly affected by nitrogen fertilization, while cropping treatments had no significant effect ($p > 0.05$) on these parameters (Tables 2 and 3). Nitrogen application very significantly affect the plant weight ($p < 0.001$) and the highest plant weight was achieved when 240 kg ha^{-1} nitrogen was applied in both monocropping (MC) and intercropping (IC) systems in both years. Nitrogen $\times$ cropping system interaction was found to be not significant for plant weight. When 240 kg ha^{-1} nitrogen was applied, two-year average plant weight values of the cauliflower for the MC and IC treatments were 1127.01 g plant^{-1} and 11,120.19 g plant^{-1}, respectively. Although plant weight slightly decreased in the IC system (by 0.61%) compared to MC for cauliflower, the IC system may still be considered more productive since the total aboveground biomass was higher in IC (1599.35 g plant^{-1}: cauliflower (1120.19 g plant^{-1}) and lettuce (389.16 g plant^{-1})) than in the MC cauliflower (1127.07 g plant^{-1}) and MC lettuce (440.14 g plant^{-1}) for the same total area and fertilizer amount.

Table 2. Plant weight, leaf number, leaf weight, stem diameter, and chlorophyll reading value of cauliflower in monocropping (MC) and in intercropping (IC) at different nitrogen fertilizer rates.

	Nitrogen (kg ha^{-1})	Plant Weight § (g plant^{-1})		Leaf Number Per Plant §		Leaf Weight § (g plant^{-1})		Stem Diameter § (mm)		Chlorophyll Reading Value § (SPAD)	
		1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
MC	160	1008.35 c	1009.38 d	20.40 c	23.85 ns	455.38 c	391.25 c	37.99 b	39.15 ns	54.30 c	61.65 b
	200	1047.75 b	1085.00 c	21.45 bc	23.80	496.25 b	431.25 b	40.93 a	51.43	61.33 b	67.65 a
	240	1086.65 a	1167.50 a	22.48 a	25.88	529.08 a	492.50 a	41.36 a	51.25	62.30 b	70.05 a
IC	160	1009.35 c	1012.25 d	20.76 c	24.50	453.93 c	370.50 c	36.58 b	48.61	56.28 c	60.83 b
	200	1052.90 b	1120.00 bc	20.98 c	26.20	496.48 b	426.25 b	39.79 a	51.50	62.40 b	66.35 a
	240	1082.55 a	1157.83 ab	22.60 a	24.75	520.05 a	476.25 a	39.96 a	50.87	66.25 a	67.65 a
Nitrogen		***	***	***	ns	***	***	***	***	**	**
Cropping		ns	ns	ns	ns	ns	ns	ns	ns	*	ns
N × C		ns	ns	ns	ns	ns	ns	ns	ns	**	ns

§ The mean values with the same letter within the same column are not significantly different ($p > 0.05$). ns: $p > 0.05$, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

Table 3. Head diameter, head height, head weight, head dry matter, and vitamin C of cauliflower in monocropping (MC) and in intercropping (IC) at different nitrogen fertilizer rates.

	Nitrogen (kg ha^{-1})	Head Diameter § (cm)		Head Height § (cm)		Head Weight § (g plant^{-1})		Head Dry Matter Ratio § (%)		Vitamin C § (mg 100 g^{-1})	
		1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
MC	160	11.35 c	15.05 d	8.96 c	8.43 b	434.03 e	523.75 c	11.96 a	6.68 ns	99.50 b	94.50 b
	200	12.38 b	16.00 b	9.30 b	9.15 a	496.00 c	536.68 b	11.59 a	6.87	109.50 a	111.00 a
	240	12.95 a	17.53 a	9.59 a	9.28 a	544.35 a	566.25 a	12.21 a	6.72	90.25 c	58.50 d
IC	160	11.40 c	14.83 d	8.83 c	8.51 b	410.20 f	506.25 d	11.53 a	6.10	94.25 bc	68.50 c
	200	12.45 b	15.50 b	9.01 b	9.39 a	455.38 d	537.50 b	10.37 b	6.74	98.75 b	90.25 b
	240	13.13 a	15.83 bc	9.38 ab	9.32 a	525.43 b	566.75 a	11.38 b	6.20	80.00 d	64.50 c
Nitrogen		***	***	***	**	***	***	***	ns	**	**
Cropping		ns	*	ns	ns	ns	ns	**	ns	*	*
N × C		ns	**	ns	ns	ns	ns	**	ns	ns	**

§ The mean values with the same letter within the same column are not significantly different ($p > 0.05$). ns: $p > 0.05$, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

Similarly, the highest leaf weight, head diameter, head height and head weight for cauliflower were obtained when 240 N kg ha^{-1} was applied for both MC and IC treatments (Tables 2 and 3). Overall, the highest head weights were obtained from 240 kg N ha^{-1} application dose in both systems and for both years. Nitrogen $\times$ cropping system interaction was found not significant for head weight for both years. The cauliflower head weight was used for the yield calculations and the yield values for both MC and IC treatments are given in Figure 3. For the 1st year, the highest yield (18.1 ton ha^{-1}) was achieved when 240 kg N ha^{-1} was applied in the MC system while the lowest yield (13.7 ton ha^{-1}) for cauliflower was obtained in the IC system with 160 kg N ha^{-1} application. On the other hand, for the 2nd year, the highest yield was achieved when 240 kg N ha^{-1} was applied and there was no significant difference between cropping systems (18.9 ton ha^{-1} for both). When two-year average yield values are considered, the regression analysis shows that when 234.7 kg N ha^{-1} nitrogen is applied a yield of 18.5 ton ha^{-1} can be achieved for the MC system and a nitrogen application of 176.6 kg N ha^{-1} results in a yield value of 18.2 ton ha^{-1} for the IC system (Figure 4). For lettuce the yield was calculated from the plant weight. Nitrogen applications significantly affected the plant weight ($p < 0.001$) of leaf lettuce in intercropping system for both years (Table 4). The highest plant weights for lettuce were obtained from the MC system for both years (542.65 g $plant^{-1}$ in 1st year and 337.63 in 2nd year). Cropping methods did not significantly affect the plant weight, leaf dry matter ratio, and stem diameter. Nitrogen × cropping system interaction was not significant for these parameters. Figure 5 shows that the effect of different nitrogen dose applications and cropping methods on leaf lettuce yield were statistically significant ($p < 0.001$) in both years. Yield of leaf lettuce was the highest in the MC system in both years (90.5 ton ha^{-1} and 56.3 ton ha^{-1}). Although the plant weight was found to be not affected by the cropping system (Table 4), the yield was lower in the case of IC since the number of plants per unit area decreased. However, the IC system is still an economical, ecological, and sustainable model when the total yield is considered. For the same total area and fertilizer amount (240 kg N $ha^{-1)}$, two-year average yield for MC cauliflower was 18.5 ton ha^{-1}; on the other hand, the total yield for the IC system was 50.7 ton ha^{-1} (18.2 ton ha^{-1} (cauliflower) + 32.5 ton ha^{-1} (lettuce)) (Figures 3 and 5). An even higher yield (53.4 ton ha^{-1} (18.2 ton ha^{-1} (cauliflower) + 35.2 ton ha^{-1} (lettuce)) could be achieved if the optimum fertilizer amount for cauliflower (176.6 kg N ha^{-1}) was applied (Figure 4). As seen in the results of the research, only 18.5 tons of cauliflower product is obtained from the area where cauliflower is grown MC, while a total of 50.7 tons of product is obtained for 32.5 tons of lettuce plant in addition to the cauliflower product with the same fertilizer application in IC. When you take into account the nitrogen fertilizer used per hectare, 18.2 tons of product is obtained with 240 kg of nitrogenous fertilizer, while an additional 35.2 tons of product is taken with the same fertilizer without any change in cauliflower yield, the use of nitrogen fertilizer causes about 2.71 times more effective use. Especially considering that nitrogen fertilizer is washed away from the soil, co-sowing and washing loss are reduced, as well as effective use of nitrogen fertilizer, resulting in a reduction in production costs. Considering the two-year soil results, the increase in soil organic matter causes an increase in the bacterial activity of the soil, and this positive effect causes an increase in the usefulness of the nutrients. As seen in the results, we can see that the biodiversity increases and the availability of nutrients (P, K, Mgi Zn, Fe, Mn, Cu) increases as it is directly proportional to the increase in the number of plants per unit area and the total amount of C.

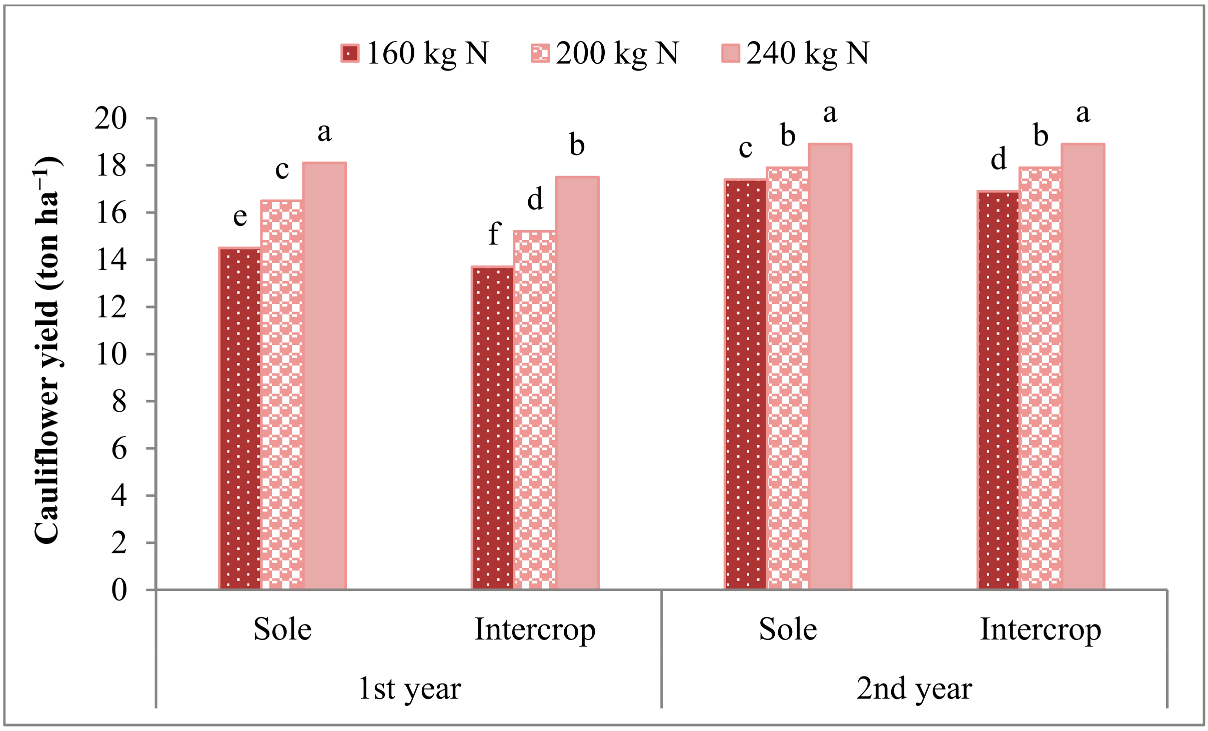

Figure 3. Effects of N fertilizer doses and cropping systems on cauliflower yield. Means with the same letter for each year are not significantly different ($p > 0.05$).

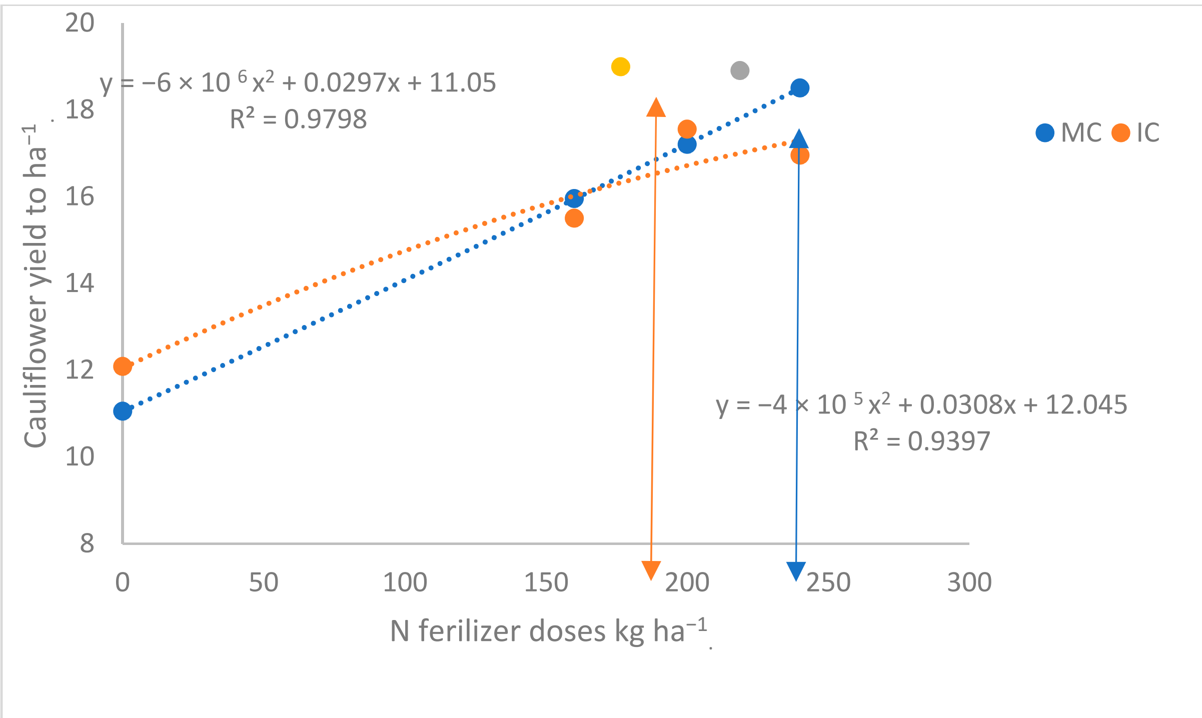

Figure 4. Optimum N fertilizer doses for the MC system (234.7 kg N ha^{-1}) and the IC system (176.6 kg N ha^{-1}).

Table 4. Plant weight, leaf dry matter, stem diameter, vitamin C, and chlorophyll reading value of leaf lettuce in monocropping (MC) and in intercropping (IC) at different nitrogen fertilizer rates.

	Nitrogen (kg ha^{-1})	Plant Weight § (g plant^{-1})		Leaf Dry Matter Ratio § (%)		Stem Diameter § (mm)		Vitamin C § (mg 100 g^{-1})		Chlorophyll Reading Value § (SPAD)	
		1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
MC		542.65 a	337.63 a	4.92 a	6.17 a	27.80 ns	28.88 a	62.50	71.00 b	49.90 bc	44.40 c
IC	160	529.00 ab	329.43 ab	5.08 a	4.38 b	28.30	28.91 a	74.33 a	79.75 a	49.05 c	46.50 c
	200	507.95 b	318.15 b	3.89 b	5.17 ab	30.01	26.26 b	60.00 b	65.25 b	53.23 a	52.53 b
	240	479.83 c	298.50 c	4.49 ab	4.30 b	29.58	26.79 b	38.67 c	54.25 c	52.01 ab	55.55 a
Nitrogen		***	***	***	***	ns	***	***	***	**	**
Cropping		ns	ns	ns	ns	ns	ns	ns	**	*	ns
N × C		ns	ns	ns	ns	ns	ns	ns	**	**	ns

§ The mean values with the same letter within the same column are not significantly different ($p > 0.05$). ns: $p > 0.05$, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

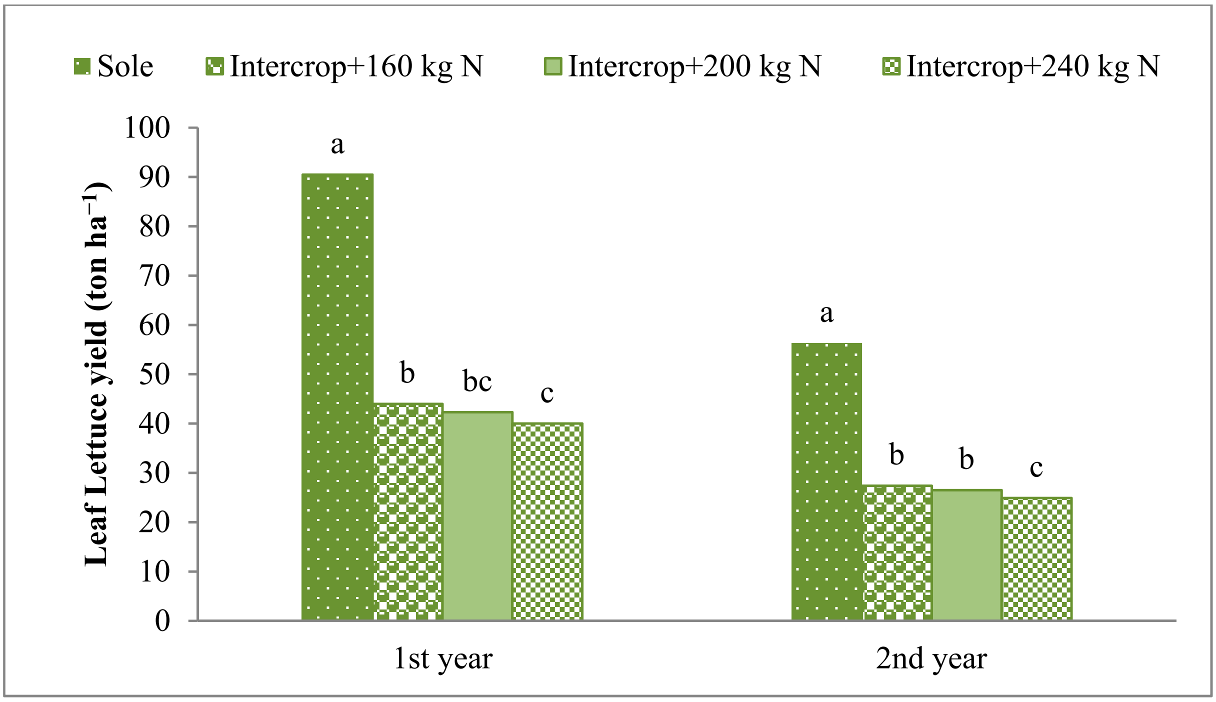

Figure 5. Effects of N fertilizer doses and cropping systems on leaf lettuce yield. Means with the same letter for each year are not significantly different ($p > 0.05$).

Table 2 shows that chlorophyll reading value of cauliflower was significantly affected by the dose of nitrogen in both IC and MC. When 240 kg ha^{-1} nitrogen was applied two-year average chlorophyll values of cauliflower were 66.17 and 66.95 for MC and IC treatments, respectively. On the other hand, no significant difference was observed in the head dry matter ratio of cauliflower when different nitrogen doses or cropping system was applied (Table 3). Vitamin C content of cauliflower significantly differed between treatments (Table 3). In both MC and IC systems, the highest vitamin C amount was obtained when 200 kg N ha^{-1} was applied. Two-year average vitamin C contents were 110.25 mg 100 g^{-1} and 94.5 mg 100 g^{-1} when 200 kg N ha^{-1} nitrogen was applied in MC and IC systems, respectively.

The leaf dry matter ratio of lettuce was significantly ($p < 0.001$) affected by nitrogen fertilization in both years whereas the effect of cropping system was not significant (Table 4). The highest two-year average leaf dry matter ratio (5.55%) and the lowest two-year average leaf dry matter ratio (4.40%) were obtained in the MC system and the 200 kg N ha^{-1}

nitrogen-applied IC system, respectively. The highest amounts of vitamin C in leaf lettuce (74.33 mg 100 g^{-1} and 79.75 mg 100 g^{-1}) were found in the IC system when 160 kg N ha^{-1} nitrogen fertilizer was applied for both years (Table 4). Vitamin C content decreased with the increased nitrogen doses in the IC system. Nitrogen × cropping system interaction was not significant. Increasing nitrogen dose significantly increased the chlorophyll reading value of leaf lettuce. Among all treatments, the highest two-year average SPAD value (53.78) was obtained when 240 kg N ha^{-1} fertilizer was applied (Table 4).

Tables 5–7 show the micro- and macro- element content of cauliflower. Our findings show that both nitrogen doses and cropping systems significantly ($p < 0.001$) affected the N, NO_3, P, K, and Ca contents of cauliflower. NO_3, N, P, K, Ca, Mg, Mn, and B contents of cauliflower leaves increased with increasing nitrogen doses in both cropping systems. However, intercropping decreased the content of NO_3, N, Ca, Mg, and Mn content of cauliflower leaves. P, K, Fe, Cu, and B content of cauliflower leaves changed based on years. The highest NO_3, N, and Ca contents were obtained when 234.7 kg N ha^{-1} nitrogen was applied in MC according to regression analysis.

Table 5. N, NO_3, P, and K content of cauliflower in MC and in IC at different nitrogen fertilizer rates.

	Nitrogen (kg ha^{-1})	**N § (%)**		**NO_3 § (mg kg^{-1})**		**P § (mg kg^{-1})**		**K § (mg kg^{-1})**	
		1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
MC	160	2.55 e	2.66 e	1510.78 c	1220.50 d	1459.09 c	1652.47 b	25,855.88 d	29,930.61 b
	200	3.02 c	3.11 c	1651.82 b	1446.75 b	1523.86 ab	1646.22 b	29,590.06 a	31,744.41 a
	240	3.75 a	3.84 a	1907.34 a	1672.25 a	1559.21 a	1634.69 b	27,944.14 b	32,352.15 a
IC	160	2.42 f	2.46 f	1366.95 d	1182.25 d	1339.38 d	1455.46 c	23,686.85 e	26,986.72 c
	200	2.85 d	2.90 d	1535.23 c	1360.75 c	1515.30 b	1628.21 b	25,346.18 d	31,904.08 a
	240	3.16 b	3.24 b	1653.89 b	1454.00 b	1541.59 ab	1715.00 a	26,949.27 c	31,561.97 a
Nitrogen		***	***	***	***	***	***	***	***
Cropping		***	***	***	***	***	**	***	**
N × C		***	***	***	***	***	***	***	***

§ The mean values with the same letter within the same column are not significantly different ($p > 0.05$). **: $p < 0.01$, ***: $p < 0.001$.

Table 6. Ca, Mg, Na, and Fe content of cauliflower in monocropping (MC) and in intercropping (IC) at different nitrogen fertilizer rates.

	Nitrogen § (kg ha^{-1})	**Ca § (mg kg^{-1})**		**Mg § (mg kg^{-1})**		**Na § (mg kg^{-1})**		**Fe § (mg kg^{-1})**	
		1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
MC	160	19,752.54 c	21,449.54 c	6574.78 a	6205.77 a	246.45 ns	274.05 ns	407.74 a	434.79 ab
	200	23,321.02 b	24,679.43 ab	6633.92 a	6172.19 a	226.85	256.65	409.52 a	444.69 a
	240	24,318.00 a	25,661.21 a	6399.08 b	5875.21 b	212.20	222.50	426.50 a	415.85 bc
IC	160	18,924.26 d	19,932.76 d	6181.03 c	5648.63 c	248.95	281.01	356.11 b	399.98 c
	200	23,432.68 b	24,320.20 b	6185.82 c	6250.31 a	191.93	216.41	367.60 b	433.93 ab
	240	23,640.10 b	23,861.90 b	6451.01 b	6147.33 a	219.54	251.87	358.70 b	431.20 ab
Nitrogen		***	***	***	***	*	ns	ns	*
Cropping		**	***	ns	ns	ns	ns	***	ns
N × C		***	***	ns	ns	ns	ns	ns	ns

§ The mean values with the same letter within the same column are not significantly different ($p > 0.05$). ns: $p > 0.05$, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

Table 7. Cu, Mn, Zn, and B content of cauliflower in monocropping (MC) and in intercropping (IC) at different nitrogen fertilizer rates.

	Nitrogen (kg ha^{-1})	Cu § (mg kg^{-1})		Mn § (mg kg^{-1})		Zn § (mg kg^{-1})		B § (mg kg^{-1})	
		1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
MC	160	37.42 ab	36.29 a	46.20 b	45.59 c	43.94 ab	44.41 ns	28.77 d	31.86 c
	200	37.37 ab	32.87 c	55.58 a	56.48 a	41.53 c	43.80	31.24 c	34.33 b
	240	36.72 b	34.59 abc	55.12 a	54.73 a	43.70 ab	44.47	36.98 a	41.10 a
IC	160	33.89 c	29.63 d	54.37 a	50.19 b	44.81 a	44.57	25.45 e	29.25 d
	200	36.49 b	33.57 bc	43.49 c	48.90 b	42.49 bc	42.33	35.65 ab	33.37 bc
	240	38.83 a	35.47 ab	44.85 bc	49.03 b	42.50 bc	44.96	34.62 b	33.81 bc
Nitrogen		**	*	ns	***	**	ns	***	***
Cropping		ns	*	***	***	ns	ns	ns	***
N × C		ns	*	ns	***	ns	ns	ns	***

§ The mean values with the same letter within the same column are not significantly different ($p > 0.05$). ns: $p > 0.05$, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

Soil parameters were analyzed and presented in Table 8. The effect of different nitrogen doses and cropping methods on soil macro and micronutrients were found statistically ($p < 0.001$) significant for both years. According to two-year average values, organic matter, N, P, K, Ca, Mg, Zn, Fe, Mn, Cu, and B of cauliflower growing soil were the highest in IC growing medium when 176.6 kg N ha^{-1} was applied. Our findings showed that intercropping was an efficient method to increase the soil quality index (organic matter, N, P, K, Ca, Mg, Zn, Fe, Mn, Cu, and B contents).

Table 8. Two-year average soil parameters (0–30 cm depth) (MC: cauliflower monocropping, IC: cauliflower intercropping with lettuce).

Growth Medium * (*w*/*w*)	pH §	EC § dS cm^{-1}	OM § (%)	N § (%)	P § (mg kg^{-1})	K § (mg kg^{-1})	Ca § (mg kg^{-1})
Initial	7.50 b	0.015 b	0.33 c	0.0091 c	16.56 c	205.20 c	1062.50 c
MC	7.88 a	0.067 a	0.46 b	0.008 b	25.00 b	330.67 b	2460.77 b
IC	7.05 c	0.02 b	1.05 a	0.093 a	88.55 a	435.30 a	3680.44 a
	Mg § (mg kg^{-1})	**Zn § (mg kg^{-1})**	**Fe § (mg kg^{-1})**	**Mn § (mg kg^{-1})**	**Cu § (mg kg^{-1})**	**B § (mg kg^{-1})**	**Na § (mg kg^{-1})**
Initial	42.64 c	0.22 c	4.13 c	4.56 c	7.86 c	0.48 c	10.10 b
MC	83.60 b	0.59 b	5.10 b	6.30 b	12.44 b	0.65 b	14.00 a
IC	116.50 a	1.40 a	8.60 a	12.80 a	23.78 a	0.80 a	14.70 a

§ The mean values with the same letter within the same column are not significantly different ($p > 0.001$). * MC: monocropping (cauliflower), IC: intercropping (cauliflower and lettuce).

Land equivalent ratios (LER) were found higher than 1 in intercropping system at all nitrogen fertilizer rates (Figure 6).

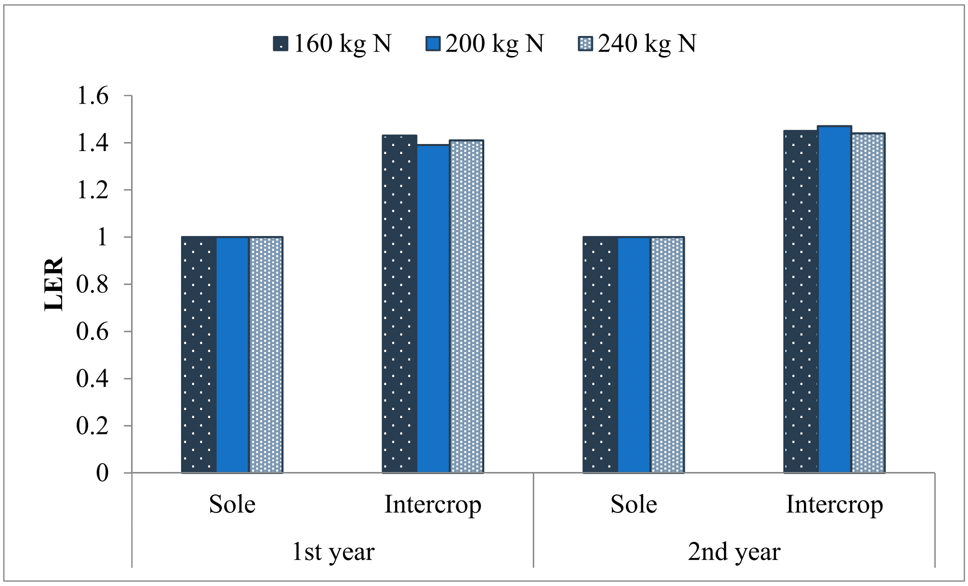

Figure 6. Land equivalent ratio (LER) using the sole crop yield of cauliflower from the corresponding N levels as control.

4. Discussion

We have investigated the effects of nitrogen fertilization doses and cropping systems on the yield and yield parameters of cauliflower. The leaf chlorophyll value (SPAD), plant weight, leaf weight, head diameter, head height, head weight, and total yield of cauliflower were found to increase as the nitrogen dose increased in both MC and IC systems. Moreover, when intercropping system was used the total yield (cauliflower and lettuce) was higher than the yield of cauliflower (MC) for the same total area and fertilizer amount (Figures 3 and 5). Nitrogen fertilization has an important role in increasing the yield and growth parameters of cauliflower, as in other Cruciferous vegetable species. Similar to our findings, earlier studies have also reported that nitrogen fertilization significantly increased the plant growth and chlorophyll content in cauliflower [17,30–32] since nitrogen plays important roles in the meristematic development, chlorophyll formation, and photosynthesis [30]. On the other hand, increasing N doses lowered the vitamin C content of cauliflower heads. The vitamin C content of plants is affected by many pre-harvest factors such as genotype, fertilization, and irrigation [33]. Since excess use of nitrogen fertilizers increases the nitrate concentration in plants, the vitamin C content decreases. A similar study conducted by Chinese cabbage [34] also reported that the lowest amount of vitamin C in cabbage heads was found when the highest dose of nitrogen was applied. Our results showed that the most efficient nitrogen fertilizer doses for cauliflower were 234.7 kg ha^{-1} for MC and 176.6 kg ha^{-1} for IC, respectively (Figure 4). Although the yield of cauliflower increases with the increase in N fertilization dose, it is crucial to find the optimum dose for the growth since high doses of nitrogen activate some physiological and pathological disorders. Our findings showed that the yield of cauliflower was not affected significantly by intercropping. Similarly, Yildirim and Güvenç [18] reported that intercropping cauliflower with vegetables such as onions, lettuce and beans did not adversely affect the yield. Other studies also stated that intercropping late maturing species with early harvesting species does not have a negative effect on the yield of either species [8,10] since the species with short vegetation are harvested before competition for resources such as light, water, and nutrients begins [35,36]. While intercropping cauliflower with lettuce did not adversely affect the yield of cauliflower, it enabled harvesting more plants (cauliflower and lettuce) from the same land area by using same amount of fertilizer, which makes intercropping a sustainable, economical, and ecological model that increases the land-use and fertilizer-use efficiencies. Nitrogen fertilization had a positive effect on micro- and macronutrient content of cauliflower (Tables 5–7). The NO_3, N, P, K, Ca, Mg, Fe, Mn, and B content of cauliflower leaves generally increased with the increasing fertilization dose. Similarly, earlier studies reported that nitrogen fertilization improved plant and root growth enhancing the plant nutrient uptake [16,17]. On the other hand, intercropping decreased NO_3, N, Ca, Mg, and Mn contents of cauliflower leaves and the highest amounts were achieved when 240 kg N ha^{-1} fertilizer was used for both years. However, since the amount of decrease in plant nutrients in cauliflower leaves did not adversely affect the growth parameters, most importantly the head weight, the yield of cauliflower was not significantly affected from intercropping (Table 3 and Figure 3).

The nitrogen rate and cropping system also had significant effect on the growth and yield parameters of leaf lettuce such as plant weight, stem diameter, vitamin C content, chlorophyll reading value, and dry matter ratio (Table 4). In intercropping systems, high nitrogen fertilization treatments negatively affected plant weight, leaf dry matter ratio, and stem diameter of leaf lettuce (Table 4). This may be due to the fact that cauliflower was more competitive than leaf lettuce at high nitrogen doses [1]. Although the plant weight of leaf lettuce was not significantly affected from intercropping, the yield of leaf lettuce was significantly reduced in intercropping system compared to sole cropping (Figure 5), since the number of lettuce in the intercropping system (83,333 plants) was half of the sole cropping system (166,666 plants).

The land equivalent ratio (LER) values were greater than 1 in the intercropping system at all fertilization rates (Figure 6). A LER > 1 indicates that the intercropping (IC) system is more productive than the monocropping (MC) system for the same unit of land, whereas LER < 1 indicates a non-profitable intercropping system supporting a high level of interspecific competition [37–39]. In previous studies, it was stated that intercropping might provide productivity and profitability by high total yields obtained per unit area under field and greenhouse conditions [8,18,40]. This can be explained by the more efficient use of available resources per unit area for different crops [41]. More efficient crop production in limited areas also increases the income of farmers [40,42,43].

5. Conclusions

Improving vegetable production through suitable intercrop combinations and nitrogen fertilization has not been fully explored yet. The aim of this study was to investigate the effects of intercropping cauliflower with lettuce on the yield and quality parameters of cauliflower and to evaluate the overall productivity of the system under different nitrogen fertilization rates.

The yield and growth parameters were positively affected by the increase in nitrogen doses. Our results showed that the most efficient nitrogen fertilizer rates for cauliflower were 234.7 kg ha^{-1} for MC and 176.6 kg ha^{-1} for IC, respectively. When the IC system was used, the total aboveground biomass was higher compared to the MC cauliflower system for the same total area and fertilizer amount. The land equivalent ratio (LER) values were greater than 1 in the intercropping system at all fertilization rates which indicates that the IC system was more productive than the MC system for the same unit of land.

In conclusion, while intercropping cauliflower with lettuce did not adversely affect the yield of cauliflower, it enabled harvesting more plants (cauliflower and lettuce) from the same land area by using the same amount of fertilizer, which makes intercropping a sustainable, economical, and ecological model that increases the land-use and fertilizer-use efficiencies. Intercropping methods, which are among the sustainable agricultural methods, are diversified farming methods using natural resources more effectively, thus minimizing environmental risks and improving livelihood of farmers.

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References

1. Yildirim, E.; Ekinci, M. Intercropping systems in sustainable agriculture. *Süleyman Demirel Univ. J. Fac. Agric.* **2017**, *12*, 100–110.
2. Singh, R.; Srivastava, P.; Singh, P.; Upadhyay, S.; Raghubanshi, A.S. Human overpopulation and food security: Challenges for the agriculture sustainability. In *Urban Agriculture and Food Systems: Breakthroughs in Research and Practice*; IGI Global: Hershey, PA, USA, 2019; pp. 439–467.
3. Awal, M.A.; Pramanik, M.H.R.; Hossen, M.A. Interspecies competition, growth and yield in barley-peanut intercropping. *Asian J. Plant Sci.* **2007**, *6*, 577–584.
4. Crusciol, C.A.C.; Nascenteb, A.S.; Mateusc, G.P.; Parizd, C.M.; Martinsa, P.O.; Borghi, E. Intercropping soybean and palisade grass for enhanced land use efficiency and revenue in a no till system. *Eur. J. Agron.* **2014**, *58*, 53–62. [CrossRef]
5. Thayamini, H.S.; Brintha, I. Review on Maize based intercropping. *J. Agron.* **2010**, *9*, 135–145.
6. Shaker-Koohi, S.; Nasrollahzadeh, S.; Raei, Y. Evaluation of chlorophyll value, protein content and yield of sorghum (*Sorghum bicolor* L.)/mungbean (*Vigna radiate* L.) intercropping. *Int. J. Biosci.* **2014**, *4*, 136–143.
7. Belel, M.D.; Halim, R.A.; Rafii, M.Y.; Saud, H.M. Intercropping of corn with some selected legumes for improved forage production: A review. *J. Agric. Sci.* **2014**, *6*, 48. [CrossRef]
8. Francis, C.A. Intercropping-competition and yield advantage. In *World Soybean Research Conference III: Proceedings*; CRC Press: Boca Raton, FL, USA, 2022; pp. 1017–1024.
9. Yildirim, E.; Turan, M. Growth, yield and mineral content of broccoli intercropped with lettuce. *J. Anim. Plant Sci.* **2013**, *23*, 919–922.
10. Gaba, S.; Lescourret, F.; Boudsocq, S.; Enjalbert, J.; Hinsinger, P.; Journet, E.P.; Navas, M.L.; Wery, J.; Louarn, G.; Malézieux, E.; et al. Multiple cropping systems as drivers for providing multiple ecosystem services: From concepts to design. *Agron. Sustain. Dev.* **2015**, *35*, 607–623. [CrossRef]
11. Güvenç, I.; Yildirim, E. increasing productivity with intercropping systems in cabbage production. *J. Sustain. Agric.* **2006**, *28*, 29–44. [CrossRef]
12. Yildirim, E.; Cil, B.; Ekinci, M.; Turan, M.; Dursun, A.; Gunes, A.; Kul, R.; Kitir, N. Effects of intercropping system and nitrogen fertilization on land equivalent ratio, yield and mineral content of broccoli. *Acta Sci. Pol. Hortorum Cultus* **2020**, *19*, 101–109. [CrossRef]
13. Moniruzzaman, M.; Rahman, M.M.; Hossain, M.M.; Karim, A.J.M.S.; Khaliq, Q.A. Response of coriander foliage to different rates and methods of nitrogen application. *Bangladesh J. Agril. Res.* **2014**, *39*, 359–371. [CrossRef]
14. Kodithuwakku, D.P.; Kirthisinghe, J.P. The Effect of different rates of nitrogen fertilizer application on the growth, yield and postharvest life of cauliflower. *Trop. Agric. Res.* **2009**, *21*, 110–114. [CrossRef]
15. de Camargo, S.M.; da Costa, M.S. Nitrogen and Boron Interactions on Hollow Stem Disorder in Cauliflower under Tropical Conditions: Effect of Boron, Nitrogen and Soil. UC Davis: Department of Plant Sciences. 2009. Available online: https://escholarship.org/uc/item/11z7w7v1 (accessed on 1 January 2022).
16. Islam, M.; Hoque, T.S.; Khan, R.N.A.; Farzana, S.; Ahmed, M.; Khodabakhshloo, N. Influence of different integrated nutrient management strategies on growth, yield and nutritional qualities of cauliflower. *Agric. Res.* **2021**, *10*, 656–664. [CrossRef]
17. Al-lamy, H.A.H.; ALMharib, M.Z.K. The response of cauliflower growth and yield to organic and chemical fertilizers application and spraying with salicylic acid. *Ann. Rom. Soc. Cell Biol.* **2021**, *25*, 9483–9491.
18. Yildirim, E.; Güvenç, I. Intercropping based on cauliflower: More productive, profitable and highly sustainable. *Eur. J. Agron.* **2005**, *22*, 11–18. [CrossRef]
19. Vural, H.; Esiyok, D.; Duman, I. *Vegetable Crops*; Ege University Press: İzmir, Turkey, 2000; p. 440. ISBN 975-97190-0-2.
20. Cataldo, D.A.; Maroon, M.; Schrader, L.E.; Youngs, V.L. Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. *Commun. Soil Sci. Plant Anal.* **1975**, *6*, 71–80. [CrossRef]
21. Romeu-Nadal, M.; Morera-Pons, S.; Castellote, A.I.; Lopez-Sabater, M.C. Rapid high-performance liquid chromatographic method for vitamin C determination in human milk versus an enzymatic method. *J. Chromatogr. B* **2006**, *830*, 41–46. [CrossRef] [PubMed]
22. Bremner, J.M. Nitrogen-total. In *Methods of Soil Analysis Part III*; Bartels, J.M., Bigham, J.M., Eds.; ASA SSSA Publisher Agronomy: Madison, WI, USA, 1996.
23. Olsen, S.R.; Cole, C.V.; Watanabe, F.S.; Dean, L.A. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate*; USDA: Washington, DC, USA, 1954; Circ 939.
24. Rhoades, J.D. Salinity: Electrical Conductivity and Total Dissolved Solids. In *Chemical Methods*, 2nd ed.; Bartels, J.M., Bigham, J.M., Eds.; Methods of Soil Analysis; ASA SSSA Publisher Agronomy: Madison, WI, USA, 1996; Volume 3, pp. 417–436.
25. McLean, E.O. Soil pH and lime requirement. In *Methods of Soil Analysis*, 2nd ed.; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; Chemical and Microbiological Properties; ASA SSSA Publisher: Madison, WI, USA, 1982; Volume 2, pp. 199–224.
26. Nelson, D.W.; Sommers, L.E. Organic matter. In *Methods of Soil Analysis*, 2nd ed.; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; Chemical and Microbiological Properties; ASA SSSA Publisher: Madison, WI, USA, 1982; Volume 2, pp. 574–579.

27. Thomas, G.W. Exchangeable Cations. In *Methods of Soil Analysis*, 2nd ed.; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; Chemical and Microbiological Properties; ASA SSSA Publisher: Madison, WI, USA, 1982; Volume 2, pp. 159–164.
28. Lindsay, W.L.; Norvell, W.A. Development of DTPA Soil Test for Zinc, İron, Manganese and Copper. *Soil Sci. Soc. Am. J.* **1978**, *42*, 421–428. [CrossRef]
29. Mertens, D. AOAC official method 922.02: Plant preparation of laboratory sample. In *Official Methods of Analysis*, 18th ed.; Horwitz, W., Latimer, G.W., Eds.; AOAC: Gaitherburg, MD, USA, 2005; Chapters 3; pp. 1–2.
30. Ali, M.A.M.; Yousef, E.A.A.; Nasef, I.N. Cauliflower growth, yield and quality response to nitrogen fertilization and micronutrients foliar application in newly reclaimed areas. *J. Plant Prod. Mansoura Univ.* **2019**, *10*, 317–325. [CrossRef]
31. Belbase, P.; Bc, L. Effects of different fertilizers on yield and vitamin c content of cauliflower (*Brassica oleracea* var. botrytis)—A Review. *Asian J. Agric. Hortic. Res.* **2020**, *6*, 37–46. [CrossRef]
32. El-Saady, W.A.; Genesia, F.O. Effect of some Inorganic NPK Fertilization Treatments on Cauliflower. *J. Plant Prod. Mansoura Univ.* **2018**, *9*, 1215–1222. [CrossRef]
33. Hancock, R.D.; Viola, R. Biosynthesis and catabolism of L-ascorbic acid in plants. *Crit. Rev. Plant Sci.* **2005**, *24*, 167–188. [CrossRef]
34. Staugaitis, G.; Viskelis, P.; Venskutonis, P.R. Optimization of application of nitrogen fertilizers to increase the yield and improve the quality of Chinese cabbage heads. *Acta Agric. Scand. B Soil. Plant Sci.* **2008**, *58*, 176–181. [CrossRef]
35. Splitstoesser, W.E. *Vegetable Growing Handbook*; Von Nostrand Reinhold: New York, NY, USA, 1990; p. 362.
36. Santos, R.H.S.; Gliessman, S.R.; Cecon, P.R. Crop interactions in broccoli intercropping. *Biol. Agric. Hortic.* **2002**, *20*, 51–75. [CrossRef]
37. Gliessman, S.R. *Agro-Ecological Processes in Sustainable Agriculture*; Slepping Bear Press: Chelsea, MI, USA, 1998.
38. Martin-Guay, M.O.; Paquette, A.; Dupras, J.; Rivest, D. The new green revolution: Sustainable intensification of agriculture by intercropping. *Sci. Total Environ.* **2018**, *615*, 767–772. [CrossRef] [PubMed]
39. Xu, Z.; Li, C.; Zhang, C.; Yu, Y.; van der Werf, W.; Zhang, F. Intercropping maize and soybean increases efficiency of land and fertilizer nitrogen use; A meta-analysis. *Field Crops Res.* **2020**, *246*, 107661. [CrossRef]
40. Chapagain, T.; Pudasaini, R.; Ghimire, B.; Gurung, K.; Choi, K.; Rai, L.; Magar, S.; Bishnu, B.K.; Raizada, M.N. Intercropping of maize, millet, mustard, wheat and ginger increased land productivity and potential economic returns for smallholder terrace farmers in Nepal. *Field Crops Res.* **2018**, *227*, 91–101. [CrossRef]
41. Feng, C.; Sun, Z.; Zhang, L.; Feng, L.; Zheng, J.; Bai, W.; Gu, C.; Wang, Q.; Zhu, Z.; van der Werf, W. Maize/peanut intercropping increases land productivity: A meta-analysis. *Field Crops Res.* **2021**, *270*, 108208. [CrossRef]
42. Mahant, H.D.; Patil, S.J.; Bhalerao, P.P.; Gaikwad, S.S.; Kotadia, H.R. Economics and land equivalent ratio of different intercrops in banana (*Musa paradisiacal* L.) cv. grand naine under drip irrigation. *Asian J. Hortic.* **2012**, *7*, 330–332.
43. Fukai, S.; Trenbath, B.R. Processes determining intercrop productivity and yields of component crops. *Field Crops Res.* **1993**, *34*, 247–271. [CrossRef]