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Impact of vermicompost and pea (*Pisum sativum* L.) based intercropping system on soil fertility and quality attributes of pea and garlic

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Abstract
An experiment entitled "Impact of vermicompost on growth and production potential of pea-based intercropping system (*Pisum sativam* L.)" was conducted at the vegetable farm, Department of Vegetable Science, College of Horticulture and Forestry, Jhalrapatan City, Jhalawar during rabi season 2022-23. The variety used in experiment was Pea- AP 1 (Azad Pea 1) and Garlic G282. The experiment consisted of fifteen treatment combinations having three levels each of vermicompost (0, 2.5, and 5 ton/ha) and five levels of different intercropping system (Sole Pea, Sole Garlic, Pea + Garlic 1:1, 2:1, 2:2) in Factorial Randomized Block Design with three replications. The interaction effect of Vermicompost and intercropping V_2I_1 (Vermicompost@5ton/ha + Sole Pea) system on pea was found significant on maximum total soluble solids (19.93) in pea, Ascorbic acid (26.21 mg /100 gm) and Crude protein (24.13%) as compared to other treatment, respectively. However, the interaction impact of vermicompost and intercropping system V_2I_2 (Vermicompost@5ton/ha + Sole Garlic) was found suitable for growth, yield, and quality attributes of garlic. The maximum TSS (35.97 °Brix), ascorbic acid (12.86 mg/100 g) and crude protein (8.44%) as compared to other treatment. The interaction effect of vermicompost and intercropping system on soil after harvest had non-significant effect on the soil pH, electrical conductivity, organic carbon, soil P and K after harvesting respectively. The interaction effect of vermicompost and intercropping system on soil after harvest increases significant affected the soil maximum N (341.44 kg ha^{-1}) with treatment V_2I_1 (Vermicompost @5ton/ha + Sole Pea) as compared to V_0I_2 (Vermicompost @0ton/ha+Sole Garlic), respectively.

Keywords: Crude protein, electrical conductivity, intercropping, organic carbon, vermicompost

Introduction
Pea (*Pisum sativum* L.) is a member of the Legume family. This herbaceous annual plant can grow up to 20 cm in dwarf size and up to 1.25 meters in height. It is a crop that self-pollinates and produces pods, or edible fruit. Peas are a major crop that is cultivated all over the world.

As a member of the Alliaceae family, garlic (*Allium sativum* L) is one of the most aromatic herbaceous annual spices. With a distinct strong aroma, it is the second most extensively grown spice crop among allium crops after onion. Originating in central Asia, garlic was later brought to the Mediterranean region during prehistoric times (Thompson and Kelly, 1957) [1].

Vermicompost is a amazing natural fertilizer that contains growth regulators and hormones that boost plant output. It also makes a substantial contribution to the enhancement of soil structure and is a rich source of minerals, such as potassium, phosphate, and nitrogen that are essential for plant growth (Mona *et al*. 2011) [2]. The best way to stabilize crop production is by intercropping, particularly when it comes to vegetable production. Farmers use intercropping because it lowers the incidence of pests and diseases, helps enhance total crop production per unit area, and offers insurance against crop failure (Lyocks *et al*. 2013) [3].

Growing two or more crops concurrently on the same field for a duration long enough to encompass the vegetative stage is known as intercropping (Gomez and Gomez, 1983) [4]. Among the top 10 vegetable crops in the world, peas (*Pisum sativum* L.) are in the top 10. Peas are used in human diets all over the world and are high in the amino acids tryptophan and lysin, as well as rich in carbs, vitamin A and C, calcium, phosphorus, and protein (21-25%) (Bhat *et al*. 2013) [5].

In India and Rajasthan, garlic (*Allium sativum* L.) and peas (*Pisum sativum* L.) are two of the most significant vegetable crops. They are grown as garlic bulbs, dry seeds, or pea green pods for both domestic and international markets. Small farmers are the ones who use intercropping systems the most since they maximize unit production and are widely used in third-world nations. Intercropping with legume crops is also a great way to reduce soil erosion and maintain crop productivity. The current study, "Impact of Vermicompost and Pea (*Pisum Sativum* L.) Based Intercropping System on Soil Fertility and Quality Attributes of Pea and Garlic" was conducted in light of the previously mentioned facts and in recognition of the significance of vermicompost and intercropping systems.

Materials and Methods

Experimental site

The field experiment was carried out at Vegetable farm of Department of Vegetable Science, College of Horticulture & Forestry, Jhalrapatan City, Jhalawar. The district is situated between 23˚45″ and 24˚52″ North latitudes and 75˚27″ and 76˚56″. East longitudes at 131.14 m above mean sea level.

Experimental details

Treatments were arranged in Factorial Randomized Block Design with three replications. The experiment was carried out in Total of 45 plots and area of each plot was 12 m^2 (3 m × 4 m). The experiment consisted of two factors and with 3 level of each factors Vermicompost 3 level (0, 2.5, 5 t/ha) and factors two Intercropping system 5 level (Sole Pea, Sole Garlic, Pea+ Garlic 1:1, 2:1, 2:2) with a total of 15 number of treatments. The spacing followed in the pea and garlic R×P (3 m × 4 m).

Method analysis

pH

Using a glass electrode pH metre and 1:2 soil water suspensions, the pH of the soil was measured. (Jackson, 1973) [6].

Electrical conductivity (dS m^{-1})

Electrical conductivity of soil water suspensions (1:2.5) calculated using EC meter (Model Elico CL 180) as elaborated by Jackson (1973) [6].

Organic carbon (%)

The chromic acid wet oxidation method developed by Walkley and Black (1934) [7] serves as the foundation for the calculation of soil organic carbon.

$$\text{Organic carbon (\%)} = \frac{10(B - T) \times 0.003 \times 100}{B \times \text{Weight of soil (g)}}$$

Where,

B = Volume (ml) of ferrous ammonium sulphate solution required for blank titration.

T = Volume of ferrous ammonium sulphate solution needed for titration of soil sample.

Available Nitrogen (kg ha^{-1})

Utilising the alkaline potassium permanganate method as recommended by Subbiah and Asija (1956) [8], available nitrogen was ascertained.

Available N (kg/ha) = R × 31.36

Where,

R = Volume of 0.02 N H_2SO_4 required for titration

Available Phosphorus in soil (kg ha^{-1})

Available phosphorus was determined with extraction by 0.5 M $NaHCO_3$ solution adjusted at pH 8.5 as suggested by Olsen *et al.* (1954) [9].

$$\text{Available P (kg ha}^{-1}) = \frac{R \times \text{Volume of extract} \times 2.24 \times 10^6}{\text{Volume of aliquot} \times \text{Weight of soil} \times 10^6}$$

Where,

R= ppm P in the aliquot = $\frac{R\times 100}{5} \times \frac{2.24}{5}$

(Obtained from standard curve) = (ppm P) R × 8.96 × 2.29

Available Potassium (kg ha^{-1})

Available potassium was determined by extracting the soil by shaking with 1 N neutral ammonium acetate solution by flame photometer as suggested by Metson (1956) [10].

$$\text{Available K (kg ha}^{-1}) = \frac{R \times \text{Volume of extract} \times 2.24 \times 10^6}{\text{Weight of soil taken} \times 10^6}$$

Where,

R = ppm of K in the extract (obtained from the standard curve)

Total soluble solids (^{0}Brix)

The total soluble solids (TSS) content was determined with the help of ' Zeiss ' Hand Refractometer at the time of harvesting of Bulb.

Ascorbic acid content (mg/100 g)

Ascorbic acid determined by volumetric method by using 2, 6- dicholorophenol- indophenols dye (Ranganna, 1999) [11].

Crude protein content (%)

Estimation of nitrogen was done by colorimetric method as suggested by Snell and Snell (1949) [12] using the Spectronic-20 (MSLP UV-1200). The formula used for calculating the protein is as.

Protein % = Nitrogen % × 6.25*

Statistical Analysis

The appropriate standard error (S.Em. ±) was calculated in each case and critical difference (CD) at 5 percent level of probability was operated to compare the treatment means, where the treatment effects were significant (Panse and Sukhatme, 1967) [13].

Results and Discussion

Effect of vermicompost on quality attributes of Pea

The result of present investigation reveals that total soluble solid (^{0}Brix) in pea, Ascorbic acid (mg /100 gm), Crude protein (%) significantly increased with increasing levels of vermicompost as compared to control. The highest dose of vermicompost i.e., V_2 (Vermicompost @5ton/ha) recorded maximum TSS (19.08 ^{0}Brix), ascorbic acid (25.36 mg/100 g) and crude protein (23.35%) respectively, in pea pod as compared to lowest qualitative value that total soluble solids (17.32 ˚Brix) in pea, Ascorbic acid (23.08 mg /100 gm) and

Crude protein (21.67%) in treatment V_2 (Vermicompost@0ton/ha). Increase in ascorbic acid might be due to the availability of nitrogen leading to balanced C: N ratio enhancing the vegetative growth resulting in high photosynthetic activity (Gayathri and Krishnaveni, 2015) [14]. The vermicompost play a crucial role in protein synthesis by improving the availability of N and S through mineralization which helps in formation of sulphur containing amino acids and maximum total soluble solids may be due to attributed to greater movement and availability of essential nutrients that might have accelerated the breakdown of complex polysaccharides into simple sugars and directs their accumulation in developing heads (Mal *et al*. 2014) [15].

Effect of Intercropping on quality attributes of Pea

The result of present investigation revealed that total soluble solid (^{0}Brix) in pea, ascorbic acid (mg /100 g) and crude protein (%) significantly increased with increasing different intercropping system. The maximum qualitative attributes were recorded under treatment I_1 (sole Pea) i.e., TSS (18.63), ascorbic acid (24.72 mg/100 g) and crude protein (23.01%) as compared minimum qualitative attributes were recorded under treatment I_4 (Pea +Garlic 2:1) i.e., TSS (17.87 ^{0}Brix), crude protein (22.10%) and ascorbic acid (23.98 mg/100 g). However, the treatment I_3 (Pea + Garlic 1:1) was found at par with I_1 (Sole Pea) under TSS. While the treatment (Pea + Garlic 1:1) and I_5 (Pea + Garlic 2:2) was found at par with I_1 (Sole Pea) under crude protein. The possible reason for significant higher value may be due to its reason that pea is a leguminous crop that reflected its benefits on garlic yield *via* absorption of more nitrogen from the soil by the pea nodules as compared to sole crop (Adhikary *et al*. 2015) [16].

Interaction effect of vermicompost and intercropping system on pea qualitative attributes

The maximum qualitative attributes were recorded under treatment V_2I_1 (Vermicompost@5ton/ha+ Sole Pea) i.e., TSS (19.93 ^{0}Brix), ascorbic acid (26.21 mg/100 g), crude protein (24.13%). The minimum qualitative attribute was recorded under treatment V_0I_1 (Vermicompost @0ton/ha+ Sole Pea) i.e., TSS (16.77 ^{0}Brix), ascorbic acid (22.29 mg/100 g), crude protein (21.30%), was found in treatment (Vermicompost @0ton/ha+ Sole Garlic). It might be due to varying competition between intercrops for light, moisture, nutrient and space with increasing in plant density more reduction in yield attributes of pea were found when it was intercropped with garlic (Patil and Padmani, 2007) [17].

Effect of vermicompost on quality Attributes of Garlic

The result of present study clearly shows that the TSS, ascorbic acid, crude protein increased significantly due to application of different levels of vermicompost as compared to control.

In qualitative attributes the highest dose of vermicompost i.e. V_2 (Vermicompost@5ton/ha) recorded maximum TSS (34.89%), ascorbic acid (11.91 mg/100 g), crude protein (7.46%) as compared to minimum TSS (30.50%), ascorbic acid (10.77 mg/100 g), crude protein (5.99%) respectively, However, the highest dose (Vermicompost @5ton/ha) was found statistically superior as compared to control V_0 (vermicompost @0ton/ha). Application of vermicompost helped in vigorous vegetative growth and imparted deep green colour to the foliage which favoured photo synthesis activity of the plants, so there was greater accumulation of carbohydrates in bulb and due to this, there was more synthesis of TSS content. (Surindra, 2009) [18].

Effect of intercropping on quality attributes of Garlic

The maximum TSS (33.58 ^{0}Brix), ascorbic acid content in garlic (11.52 mg/100 g) and crude protein (7.08%) were recorded in treatment I_2 (Sole Garlic) as compared to minimum TSS (32.43 ^{0}Brix) under treatment I_3, (Pea + Garlic 1:1) and minimum ascorbic acid content in garlic (11.05 mg/100 g) and crude protein (6.42%) were recorded in treatment I_5 (Pea + Garlic 2:2). However, the treatment I_4 (Pea+ Garlic 2:1) and I_5 (Pea + Garlic 2:2) was found at par with I_2 (Sole Garlic). In sole garlic the higher quality attributes was obtained due to increased availability of nutrients in the soil that might lead to synthesis and accumulation of more photosynthates (Sharma *et al*. 2009) [19].

Interaction effect of vermicompost and intercropping system on qualitative attributes of garlic

The maximum TSS (35.97 ^{0}Brix), ascorbic acid content in garlic (12.86 mg/100 g), crude protein (5.11%) were recorded in treatment V_2I_2 (Vermicompost@5ton/ha+Sole Garlic) as compared to minimum TSS (28.89 ^{0}Brix), ascorbic acid content in garlic (9.48 mg/100 g) and crude protein (5.11%) were recorded in treatment V_0I_2 (Vermicompost@0ton/ha + Sole Garlic). However, the treatment V_1I_2 (Vermicompost@2.5ton/ha+ Sole Garlic), V_2I_3 (Vermicompost@5ton/ha + Pea + Garlic 1:1) and V_2I_4 (Vermicompost@5ton/ha + Pea + Garlic 2:1) was found at par with V_2I_2 (Vermicompost@5ton/ha + Pea + Garlic 2:2) under TSS. The higher content of qualitative attributes of sole garlic but highest at par was found with treatment V_2I_4 with all intercropping system might be due to the garlic crop was grow as intercrop in between two row of pea, as a result more nutrient were available to garlic as more amount of nitrogen was fixed by pea in both the rows (Choudhary and Jana, 2012) [20].

Combined effect of vermicompost and intercropping system on soil attributes

Further, the combined effect of vermicompost and intercropping system was found significant with respect to soil attributes. The minimum soil pH (7.05) and electrical conductivity (ds m-^{1}) was found under treatment V_2 (Vermicompost @5ton/ha), maximum organic carbon (0.53%) was found in treatment V_2 (Vermicompost@5ton/ha). The maximum value of available nitrogen (337.37 kg/ha), phosphorus (26.60 kg/ha) and potassium (218.99 kg/ha) under treatment V_2 (Vermicompost@5ton/ha) as compared to minimum value of available nitrogen (335.06 kg/ha), phosphorus (22.84kg/ha), potassium (216.14 kg/ha) was found V_0 (vermicompost @0ton/ha). Further, the intercropping system effect on pH and electrical conductivity was found non significant, whereas sole crop I_1 (Sole Pea) recorded maximum available nitrogen (339.06 kg/ha), phosphorus (26.22 kg/ha) and potassium (221.18 kg/ha) and minimum value was found in treatment I_2 (Sole garlic) with available nitrogen (333.56 kg/ ha), phosphorus (22.67 kg/ ha) and potassium (213.39 kg/ ha). The interaction effect of vermicompost and intercropping system was found significant on soil attributes. The interaction effect of vermicompost and intercropping system on pH, electrical conductivity (ds m^{-1}) and organic carbon was found non-significant. The interaction effect of vermicompost and intercropping system with maximum available nitrogen (341.44 kg/ha) was obtained under treatment V_2I_1 (Vermicompost @5ton/ha+ Sole Pea), phosphorus, potassium found non-significant effect and minimum value was found in treatment V_0I_2 (Sole garlic) value of available nitrogen (331.38 kg/ ha). The production of $NH4^+$, CO2 and organic acids during microbial metabolism in vermicompost may be contributed to the decrease in soil pH. The increase of the rates of vermicompost also reduced soil bulk density and particle density. The decrease in soil electrical conductivity value under V_2 (VC @ 5 t/ha) treatment could be attributed to vermicompost to soil and proton release thereby resulting in accumulation of organic anions such as malate, citrate and oxalate in plants. The increase in organic carbon content may be attributed to addition of organic materials and better root growth (Sharma *et al*. 2005). The higher residual nitrogen content of soil in sole pea or (Pea + Garlic 1:1) plot is because pea being a legume enrich soil by fixing the atmospheric nitrogen changing it form an inorganic form to forms that are available for uptake by plants and the fixed nitrogen which perhaps became available on the sequential crops after the senescence of the legume and the decomposition of residues. The interaction effect of vermicompost and intercropping system with maximum available nitrogen (341.44 kg/ha) was obtained under treatment V_2I_1 (Vermicompost @5ton/ha+ Sole Pea) and phosphorus, potassium found non-significant effect and minimum value was found in treatment V_0I_2 (Sole garlic) value of available nitrogen (331.38 kg/ ha). It might be due to addition of organic matter through biomass of intercrops, root nodules and huge leaf fall decomposition in the system (Gopinath *et al*. 2011) [21].

Table 1: Effect of vermicompost and Pea based intercropping system on quality attributes

		Pea			Garlic		
Treatment notation	**Treatment combination**	**TSS in pod(⁰Brix)**	**Ascorbic in pod acid (mg/100 g)**	**Crude in pod protein (%)**	**TSS in cloves (⁰Brix)**	**Ascorbic in cloves acid (mg/100 g)**	**Crude protein in cloves (%)**
V_0	(Vermicompost @0ton/ha)	17.32	23.08	21.67	30.60	10.77	5.99
V_1	(Vermicompost @2.5ton/ha)	18.66	24.69	22.87	33.78	11.28	6.83
V_2	(Vermicompost @5ton/ha)	19.08	25.36	23.35	34.89	11.91	7.46
Factor (Vermicompost)	SEm ±	0.06	0.00	0.13	0.24	0.09	0.05
	CD at 5%	0.18	0.02	0.39	0.73	0.27	0.15
I_1	Sole Pea	18.63	24.72	23.01	-	-	-
I_2	Sole Garlic	-	-	-	33.58	11.52	7.08
I_3	Pea + Garlic (1:1)	18.52	24.40	22.77	32.43	11.21	6.74
I_4	Pea + Garlic (2:1)	17.87	23.98	22.10	33.38	11.51	6.79
I_5	Pea + Garlic (2:2)	18.39	24.40	22.64	32.83	11.05	6.42
Factor (Intercropping)	SEm ±	0.07	0.01	0.15	0.28	0.10	0.05
	CD at 5%	0.21	0.02	0.45	0.84	0.31	0.17
V_0I_1	Vermicompost @0t/ha+ Sole Pea	16.77	22.29	21.30	-	-	-
V_0I_2	Vermicompost @0t/ha+ Sole Garlic	-	-	-	28.89	9.48	5.11
V_0I_3	Vermicompost @0t/ha + Pea + Garlic (1:1)	17.62	23.39	22.94	30.54	11.22	6.35
V_0I_4	Vermicompost @0t/ha +Pea +Garlic (2:1)	17.34	23.02	21.64	31.81	11.44	6.39
V_0I_5	Vermicompost @0t/ha+ Pea + Garlic (2:2)	17.56	23.64	21.18	30.77	10.96	6.11
V_1I_1	Vermicompost @2.5t/ha +Sole Pea	19.20	25.67	23.60	-	-	-
V_1I_2	Vermicompost @2.5t/ha+ Sole Garlic	-	-	-	35.89	12.22	8.44
V_1I_3	Vermicompost @2.5t/ha + Pea + Garlic (1:1)	18.74	24.40	22.97	31.80	11.02	7.23
V_1I_4	Vermicompost @2.5t/ha +Pea +Garlic (2:1)	17.95	24.33	22.26	33.70	11.20	7.32
V_1I_5	Vermicompost @2.5t/ha+ Pea + Garlic (2:2)	18.76	24.37	22.66	33.76	10.71	6.86
V_2I_1	Vermicompost @5t/ha +Sole Pea	19.93	26.21	24.13	-	-	-
V_2I_2	Vermicompost @5t/ha+ Sole Garlic	-	-	-	35.97	12.86	7.08
V_2I_3	Vermicompost @5t/ha +Pea+ Garlic (1:1)	19.19	25.43	23.43	34.97	11.39	6.74
V_2I_4	Vermicompost @5t/ha +Pea+ Garlic (2:1)	18.34	24.60	22.42	34.65	11.91	6.79
V_2I_5	Vermicompost @5t/ha +Pea+ Garlic (2:2)	18.87	25.20	23.45	33.98	11.49	6.42
Factor (Vx I)	SEm ±	0.12	0.01	0.26	0.49	0.18	0.10
	CD at 5%	0.36	0.05	0.78	1.46	0.55	0.30

Table 2: Effect of vermicompost and Pea based intercropping system on soil attributes

Treatment notation	Treatment combination	Soil P^H after harvest	EC (dSm^{-1}) after harvest	organic carbon (%) after harvest	Available N (kg ha^{-1}) after harvest	Available $P_2 0_5$ (kg ha^{-1}) after harvest	Available $K_2 0$ (kg ha^{-1}) after harvest
V_0	(Vermicompost @0ton/ha)	7.60	0.66	0.47	335.06	22.84	216.14
V_1	(Vermicompost @2.5ton/ha)	7.19	0.62	0.51	337.09	24.20	217.33
V_2	(Vermicompost @5ton/ha)	7.05	0.61	0.53	337.37	26.60	218.99
Factor (Vermicompost)	SEm ±	0.04	0.00	0.003	0.296	0.186	0.401
	CD at 5%	0.13	0.01	0.009	0.862	0.540	1.168
I_1	Sole Pea	7.22	0.62	0.51	339.06	26.22	221.18
I_2	Sole Garlic	7.37	0.64	0.49	333.56	22.67	213.39
I_3	Pea + Garlic (1:1)	7.30	0.63	0.51	336.89	25.00	218.36
I_4	Pea + Garlic (2:1)	7.22	0.63	0.51	336.18	23.95	216.34
I_5	Pea + Garlic (2:2)	7.30	063	0.50	336.84	24.88	217.55
Factor (Intercropping)	SEm ±	0.05	0.00	0.004	0.382	0.240	0.518
	CD at 5%	N/S	N/S	0.012	1.113	0.698	1.508
V_0I_1	Vermicompost @0t/ha+ Sole Pea	7.54	0.65	0.48	336.27	24.21	219.35
V_0I_2	Vermicompost @0t/ha+ Sole Garlic	7.67	0.67	0.45	331.38	21.31	211.85
V_0I_3	Vermicompost @0t/ha + Pea + Garlic (1:1)	7.65	0.67	0.47	336.29	23.25	217.37
V_0I_4	Vermicompost @0t/ha +Pea +Garlic (2:1)	7.57	0.66	0.47	335.19	22.27	215.39
V_0I_5	Vermicompost @0t/ha+ Pea + Garlic (2:2)	7.60	0.67	0.46	336.20	23.15	216.74
V_1I_1	Vermicompost @2.5t/ha +Sole Pea	7.15	0.62	0.52	339.49	26.21	221.85
V_1I_2	Vermicompost @2.5t/ha+ Sole Garlic	7.25	0.63	0.50	334.93	22.45	213.51
V_1I_3	Vermicompost @2.5t/ha + Pea + Garlic (1:1)	7.20	0.62	0.51	336.84	24.56	217.78
V_1I_4	Vermicompost @2.5t/ha +Pea +Garlic (2:1)	7.12	0.62	0.52	337.08	23.44	216.25
V_1I_5	Vermicompost @2.5t/ha+ Pea + Garlic (2:2)	7.22	0.63	0.50	337.10	24.34	217.25
V_2I_1	Vermicompost @5t/ha +Sole Pea	6.97	0.60	0.54	341.44	28.25	224.19
V_2I_2	Vermicompost @5t/ha+ Sole Garlic	7.21	0.63	0.51	334.37	24.26	214.81
V_2I_3	Vermicompost @5t/ha +Pea+ Garlic (1:1)	7.05	0.61	0.54	337.55	27.21	219.92
V_2I_4	Vermicompost @5t/ha +Pea+ Garlic (2:1)	6.97	0.60	0.54	336.28	26.15	217.39
V_2I_5	Vermicompost @5t/ha +Pea+ Garlic (2:2)	7.07	0.61	0.53	337.21	27.16	218.65
Factor (Vx I)	SEm ±	0.10	0.00	0.007	0.661	0.415	0.897
	CD at 5%	N/S	N/S	N/S	1.927	N/S	N/S

Conclusion

The experiment demonstrated that applying 5 ton/ha of vermicompost significantly enhanced the quality of both pea and garlic crops when used in the appropriate intercropping systems. For peas, the best results were achieved with Sole Pea (V_2I_1), showing higher total soluble solids, ascorbic acid, and crude protein. For garlic, the optimal conditions were found with Sole Garlic (V_2I_2), resulting in superior total soluble solids, ascorbic acid, and crude protein. Although soil pH, electrical conductivity, organic carbon, phosphorus, and potassium remained unaffected, soil nitrogen levels significantly increased under the V_2I_1 treatment.

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