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Full Length Article

Pepper-Garlic Intercropping System Improves Soil Biology and Nutrient Status in Plastic Tunnel

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Abstract

A two year (2009-2011) experiment was conducted to investigate effect of pepper-garlic intercropping system on soil biology and nutrient profile in plastic tunnel to overcome continuous monocropping obstacles. During first year's trial, garlic cloves of four cultivars (G026, G025, and G087 for the harvest of bulbs) were intercropped between two rows of pepper seedlings (cv. Golden Pepper) on each bed. Similarly, garlic bulb (cv G064 for the harvest of green seedlings) was sandwiched between two rows of pepper seedlings. During 2nd year, the pepper crop was transplanted on the same beds already having garlic in the field of previous crop, following the same geometry. Sole pepper was grown as control. Both crops received uniform fertilization and irrigation as per requirements of pepper. Results revealed that concentration of soil bacteria and actinomycetes was higher respectively after one month of garlic intercropping during both the years of study as compared to the sole pepper; however, fungal population exhibited a diminishing trend. Soil protective enzyme activity (invertase, urease, and alkaline phosphatase) also showed dynamic changes after the intercropping of garlic. The principal soil nutrients (NPK) attained higher levels in pepper-garlic co-growth treatments as compared to the sole pepper The intercropping with green garlic (cv. G064) resulted highest nutrient levels suggesting that the effect might be cultivar specific. It was concluded that the intercropping of pepper with garlic enhances the soil fertility by changing nutrient levels, enzymatic activity and the soil microbial population. Overall, the pepper-garlic intercropping model provides a cost effective and eco-friendly organic farming system for vegetable growers.

Keywords: Intercropping systems; Pepper; Garlic; Allelopathy; Soil microbial activity; Soil enzymes; Soil nutrition

Introduction

Pepper (*Capsicum annum* L.) is an important and highly profitable vegetable across the world with good nutritional value having significant amount of vitamin A and C. Amongst other biological activities, it is an excellent source of compounds with considerable antioxidant and anti-cancer activity, stimulates immune system, prevents cardiovascular diseases and delays the aging process (Podsedek, 2007; Chuah *et al.*, 2008).

The continuous pepper monocropping often results in various cultivation obstacles like deterioration of soil physio-chemical properties, accumulation of toxic compounds and increase of pathogen populations in soil. Due to monocropping sometime require the replanting of entire pepper crop posing additional expenses along with labor. To overcome these problems, pepper-garlic intercropping model was investigated in plastic tunnel environment and found that intercropping can maximize the relative yield of each companion crop in protected structures (Li *et al.*, 1999).

In China, one third of the cultivated area is under multiple cropping systems and contributing to the half of the total grain yield (Tang, 1994). Most of the studies on intercropping have been focused on the legume-cereal intercropping, however a very few reports have been published on intercropping of vegetable crops especially interspecific below ground interactions between intercropping species (Zhang and Li, 2003). According to Sullivan (2001) intercropping is practiced with the objective of maximizing plant cooperation rather than plant competition for maximum crop yields and similar results were revealed in coffee-banana intercropping system (Van-Asten *et al.*, 2010).

In response to biotic and a-biotic stresses, all roots have significant ability to secrete both low and high molecular weight molecules into the rhizosphere. The amount of root exudates depends on the plant species, age, stress factors and cultivars. Root exudation served as an important energy and carbon source for microorganism in soil (Quian *et al.*, 1997). Root exudates have low molecular weight compounds such as sugars, amino acids, organic acids and phenolic compounds. These compounds (especially phenolic compounds) affect the growth and development of plants and microorganism. Root exudates also contain higher molecular weight compounds such as

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flavonoids, fatty acids, steroids, tannins, vitamins, alkaloids, enzymes and growth regulators, involved in primary and secondary plant metabolic processes (Fan *et al.*, 1997; Uren, 2000). Therefore, root exudates play a key role in resource competition by soil metabolic process, microbial population and altering soil chemistry. Intercropping revealed characteristic differences in the microbial community composition and activities in the rhizosphere compared to monoculture (Wu *et al.*, 2013). Garlic root exudates promoted the nutrition absorption in different receiver vegetables like lettuce, pepper, cucumber, Chinese cabbage and radish and also showed positive effects on the growth of tomato and hot pepper (Zhou *et al.*, 2007). Likewise, the application of three different allelochemicals showed the increased absorption of nutrition (N, P and K) in tomato roots (Geng *et al.*, 2009).

All over the world, especially in China, the application of high level of chemical fertilizers and over irrigation to get the higher yields contributes adversely to environmental problems like greenhouse effect, soil degradation and desertification. It is dire need to develop the ecologically-based and sustainable farming system (Rains *et al.*, 2011). Considering the sustainability, nutritional diversity and income security, the monocropping system has to be substituted with intercropping systems as an alternate sustainable agriculture with lower input and stabilized yields. Intercropping, as one the multiple cropping systems, has been practiced by farmers for many years in various ways playing important role in China. Most studies on intercropping have been focused on the legume-cereal intercropping; however, very little research has been published on intercropping of vegetable crops especially interspecific below ground interactions between intercropping species (Zhang and Li, 2003).

Garlic is an important allelopathic and antimicrobial crop and many researchers have focused on the garlic extracts (Cheng *et al.*, 2011; Wei *et al.*, 2011); however a few reports found on garlic root exudates for the suppression of different vegetables diseases and their effects on the soil fertility. Some researchers worked on the garlic-cucumber intercropping system and their effect on soil microbial and enzymatic activity (Ren *et al.*, 2008; Xuemei *et al.*, 2012); however, research work on pepper garlic intercropping system is scarce. In our previous studies we identified that garlic root exudates have strong inhibition effects against various diseases of pepper (Khan and Cheng, 2010; Khan *et al.*, 2011) but it is difficult to apply garlic root exudates to soil. However by intercropping of garlic with pepper we can focus on the change in soil rhizosphere. Some plant species have allelopathic potential by releasing allelochemicals into the rhizosphere. These allelochemicals affect plant metabolism such as photosynthesis, respiration and ion uptake. Their role in ion uptake is particularly important, since the root is the first organ to come in contact with the allelochemicals of the rhizosphere. Plant root exudates contain simple carbon substrates, including primary metabolites such as sugars, amino acids and organic acids in addition to a diverse array of secondary metabolites that are released into the rhizosphere and surrounding soil (John and Mini, 2005).

The main objective of the current research was to overcome the soil deterioration obstacles imposed by successive pepper cultivation by controlling nutrient imbalance, soil physico-chemical characteristics, to focus the change in microbial communities of pepper rhizosphere intercropped with garlic and to index the spectrum of protective enzymes.

Materials and Methods

The experiment was conducted in plastic tunnel soil at the vegetable research station, College of Horticulture, Northwest A&F University (N 34° 16', E 108° 4') Yangling, Shaanxi province, the People's Republic of China.

Experimental Design

This field experiment was carried out for two successive years (2009–2010 and 2010–2011), during the first year two models of intercropping namely normal garlic (sowing cloves for harvest of scapes and/or bulbs) and green garlic (sowing bulbs cv. G064 for harvest of green seedlings more than once) were used for intercropping with pepper, and three garlic cultivars namely G026, G025, and G087 were used to screen suitable cultivar for normal garlic intercropping. The pepper (cv. Golden Pepper) was transplanted on 21st of April, 2009 in two rows on each bed. Later on, garlic was intercropped in between two rows of pepper on 31st of august 2009 and sole pepper (mono-crop) was taken as control (Fig. 1A).

For the second year of experiment (2010–2011), the pepper crop was transplanted on 19th March 2010 on the same beds having garlic in the field that was grown previous year during the month of August. During the 2nd year of experiment, two intercropping models namely normal garlic and green garlic were again intercropped with pepper but based upon better performance, only garlic cultivar G026 was used for normal garlic intercropping. Same numbers of pepper plants were maintained on each bed and equal level of nutrition and same numbers of irrigations were provided to all the treatments (Fig. 1B). In two year experiment, during the co-growth period of pepper and garlic, the crops were fertilized and irrigated based on the requirements of pepper while only irrigation but no top dressing were supplied during the sole growth period of garlic.

Soil Sampling

Soil samples were collected from pepper plant's rhizospheres at 20 days intervals during intercropping period and at 30 days interval when sole crop in the field started from pre-transplanting. The soil samples were used for testing microorganisms' immediately after collection and then were air dried ground and sieved by using the 1 mm mesh for subsequent enzyme and soil nutritional analysis.

Soil Microorganism Analysis

Soil microorganisms (bacteria, fungi and actinomycetes) were counted using the standard dilution plate methods according to colony forming units (CFUs) as described by Fan and Li (1982). Ten percent soil solution with distilled water (18 Mega ohms) centrifuged for 20 min and used for fungal count whereas, 0.1% and 0.001% soil solution was utilized for estimation of actinomycete and bacterial populations, respectively. The fungi, bacteria and actinomycetes were incubated with beef broth peptone substrate, Gause No.1 substrate and potato dextrose agar (PDA), respectively. To control the growth of bacteria, the fungi substrate was added with 3 mL lactic acid per liter of growth medium while the actinomycetes substrate was added with 1 mL potassium dichromate per liter of culture medium. For each treatment three replications were prepared and 1 µmL solution was used for each replication.

Soil Enzymes Activity Analysis

Four kinds of soil enzymes (sucrase, urease, alkaline phosphatase and catalase) were measured by the procedures as described by the different scientists (Guan and Shen, 1984; Guan, 1986; 1989). (1) H_2O_2 as the medium and a 0.1 mol $KMnO_4$ titration method for catalase. (2) Na_2RPO_4 (R indicates benzene material) as the medium and measuring releasing content using the color comparison method (P_2O_5 mg/100 g, 37°C, 2 h) for Alkaline phosphatase. (3) Measuring NH_3-N content (NH_3-N $mg{\cdot}g^{-1}$, 37°C, 24 h) by the color comparison method, with urea as medium for urease. (4) Measuring glucose content (glucose $mg{\cdot}g^{-1}$, 37°C, 24 h) by the color comparison, glucose as the medium for sucrose by using Photo-spectrometer (Guan, 1986).

Soil Nutrient Content Analysis

All soil samples were air-dried and sieved through 2 mm mesh and then used to determine the nitrogen (N), potassium (K), phosphorus (P) and Soil organic matter (SOM). The total quantification of N, P, K and SOM was done before intercropping and at the time of uprooting of pepper crop. However, their available amount to the plants was measured at each 20 days interval during entire intercropping period and 30 days interval during sole crop in the field. Total nitrogen was determined by using Gunning and Hibbards method of sulphuric acid digestion and distillation with macro Kjeldahl apparatus (Jackson, 1962); and available N was calculated as the sum of ammonium N (NH_4-N) and nitrate N (NO_3-N). Available phosphorus (AP) was calculated as previously described by Watanabe and Olsen (1965) and available K (AK) was determined by Gallenkamp Flame Analyzer (Method 18) (Black, 1965). The total P and K (TP and TK) were calculated by first digesting the soil using the H_2SO_4-$HClO_4$ method and then measuring the level as described for AP and AK. For organic matter the same method was followed as given by Magdoff *et al.* (1996).

Statistical Analysis

The experiment was designed in RCBD with three replications. All data were assessed by analysis of variance using the statistical analysis software STATISTIX-8.1 and least significant difference test at $\alpha = 0.05$ was used for multiple comparisons.

Results

Impact on Soil Microbial Quantity

Bacteria: Prior to garlic intercropping (August 31, 2009), the soil was analyzed for micro-organisms and the concentration of bacteria was 8.6×10^6cfu/g. After the intercropping, all the garlic treatments showed gradually increasing trend and attained maximum levels during October 2009, as compared to the control treatment (2.60×10^6cfu/g). The higher number of soil bacteria was observed on October 10, 2009 in the field intercropped with normal garlic cv. G087 (10.88×10^6cfu/g), however higher number was found in the field intercropped with normal garlic cv. G026 (10.90×10^6cfu/g) and green garlic cv.G064 (10.70×10^6 cfu/g) at the end of October (October 31, 2009). A descending trend was observed in the bacterial concentration in all the treatments at the time of uprooting of pepper crop. In March 2010, when only garlic was in the field, the concentration of bacteria was recorded higher in the control as compared to other intercropped treatments. In April 2010, after the transplanting of pepper, the concentration of bacteria was higher in the field intercropped with green garlic cv.G064 (9.06×10^6cfu/g) as compared to the control. However, no significant difference was recorded in bacterial concentration during the time when only pepper was in the field before next intercropping of garlic (from April to August, 2010) as described in Fig. 2A.

For the next growing season the garlic was intercropped on 15th September, 2010 there was increasing trend in bacterial population in the entire field intercropped with garlic as compared to the control (Table 1).

Fungi: In this experiment, data regarding general concentration of soil fungi was recorded without detailed fungal identification. Before intercropping the soil fungi concentration was 1.65×10^3cfu/g, but after the intercropping no significant difference was observed in fungi concentration between the intercropped and control fields. After pepper harvesting, the highest level of fungi concentration (5.37×10^3cfu/g) was recorded in the plot intercropped with green garlic cv.G064 while the lowest was observed in the control during April, 2010.

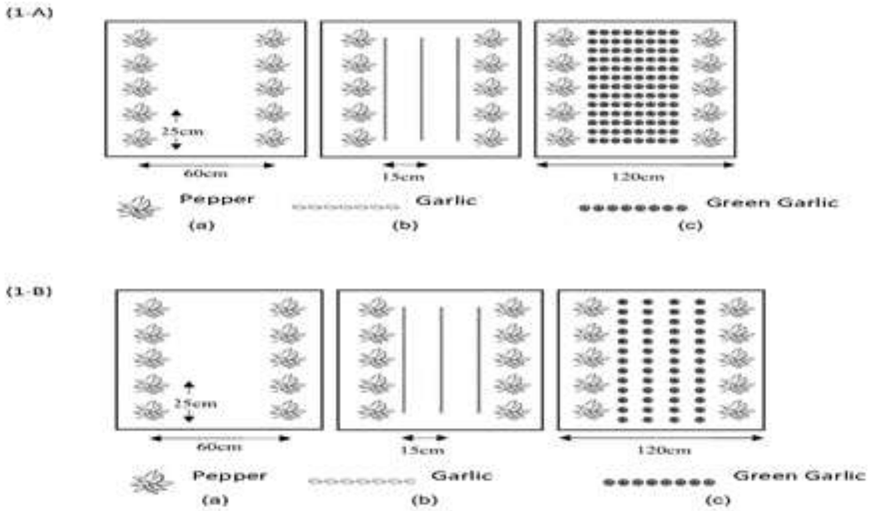

Fig. 1: Experiment layout, (1-A) design used for first year and (1-B) is used for 2nd year experiment. Pepper ( ), Garlic cloves ( ), Green garlic ( ) in the plastic tunnel experiment: (a) Pepper monoculture (b) Pepper/garlic intercropping (c) Pepper/green garlic intercropping

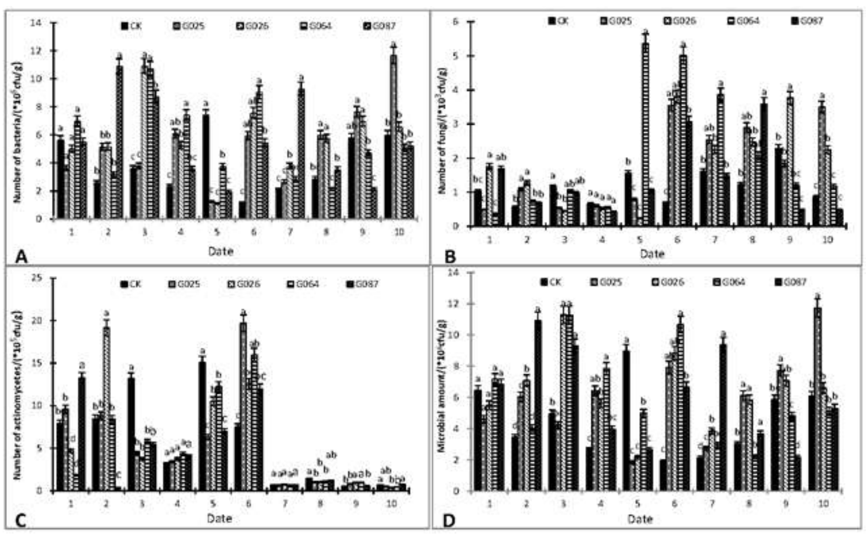

Fig. 2: Effect of Intercropping of Garlic and Green garlic with pepper on Soil Microbial Activity during first year of intercropping

However, after the harvest of garlic bulbs from April 2010 to August 2010, when only pepper crop was in the field, little higher concentration was observed in the garlic intercropped field as compared to the control (sole pepper crop) as reflected in the Fig. 2B.

Dynamic change in the number of fungi was observed during the next growing season in the month of September, 2010 when garlic was intercropped again. It was observed that after the intercropping of garlic, fungi concentration showed increasing trend and highest level (3.873×10^3cfu/g) was observed in the treatment of green garlic (cv.G064) intercropped during the month of October 2010 (Table 1), while the lowest level was observed in control. The graph depicted that the control showed constant number of fungi and there was no change during October and November 2010.

Actinomycetes: The concentration of actinomycetes was recorded 17.067×10^5cfu/g before intercropping of garlic in August 2009. After the intercropping of garlic, increasing trend of actinomycetes concentration was observed. However, the concentration of actinomycetes was recorded higher in garlic intercropped treatments during March and April 2010, when only garlic was in the field. The highest concentration of actinomycetes was recorded in G025 (19.68×10^5cfu/g) as shown in Fig. 2C.

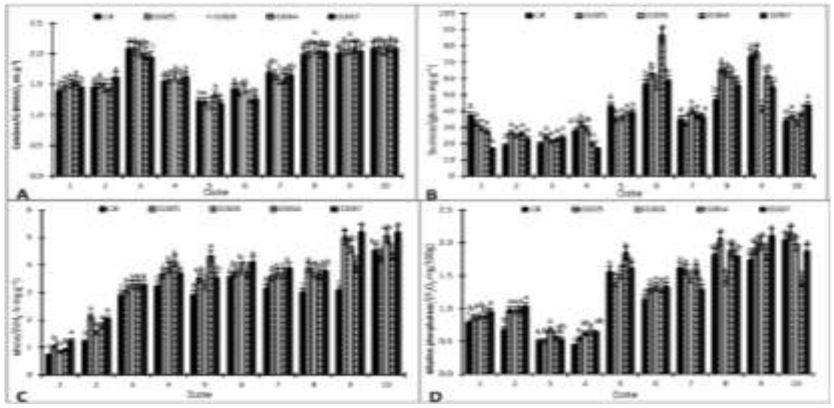

Fig. 3: Effect of Intercropping of garlic and green garlic with pepper on soil enzymatic activity during first year of intercropping

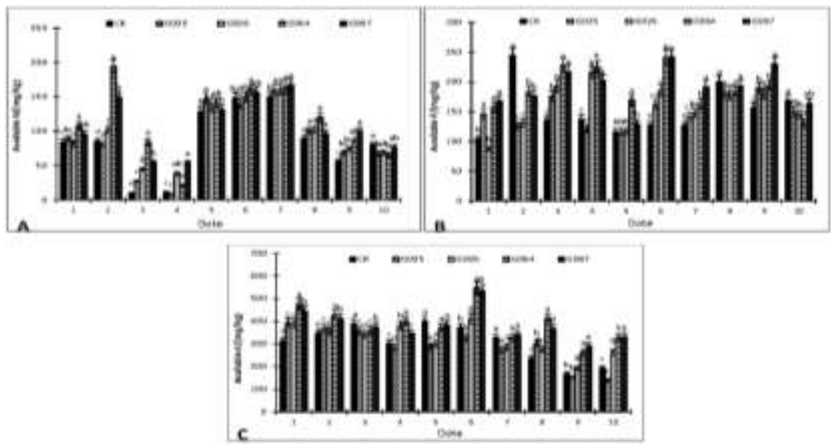

Fig. 4: Effect of intercropping of garlic and green garlic with pepper on soil available nutrients (NPK) during first year of intercropping

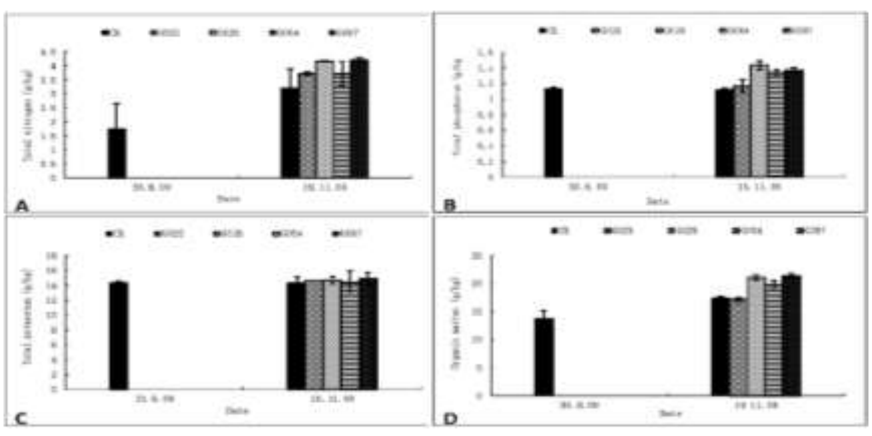

Fig. 5: Effect of Intercropping of garlic and green garlic with pepper on soil total nutrients and soil organic matter during first year of intercropping

The concentration of actinomycetes was higher in treatment intercropped with green garlic (cv.G064) during month of October (2010.10.25) as compared to normal garlic cv.G026 and the control during the next growing season when garlic was intercropped in September 2010 (Table 1).

Table 1: Effect of intercropping on Soil microbial Concentration during 2nd year; Soil microbial population including bacteria, fungi, actinomycetes and total microbes during 2nd year. Ck is for control (monoculture of pepper crop), G026 is intercropped with garlic cv.G026 and G064 is treatment intercropped with garlic cv. G064. LSD, Least Significant Difference; *p values ≤ 0.05 by LSD

	Bacteria/(*10^6cfu/g)				Fungi/(*10^3cfu/g)				Actinomycetes / (*10^5cfu/g)				Total microbe. /(*10^6cfu/g)			
Treatment	15.9.10	5.10.10	25.10.10	15.11.10	15.9.10	5.10.10	25.10.10	15.11.10	15.9.10	5.10.10	25.10.10	15.11.10	15.9.10	5.10.10	25.10.10	15.11.10
Ck	6.71 ±.91a	7.65 ±0.81b	5.36 ±1.79a	17.35 ±2.8a	1.73 ±0.4a	2.82 ±.33b	2.23 ±.38a	2.29 ±.36b	1.34 ±0.17b	1.21 ±.21a	1.01 ±.22a	1.16 ±.24ab	9.77 ±1.57a	11.68 ±1.36b	8.61 ±2.4a	20.80 ±3.49a
G026	5.39 ±2.64a	9.98 ±1.01a	7.31 ±.39a	9.92 ±1.01b	2.06 ±.49a	1.86 ±.12b	1.79 ±.49a	5.04 ±.24a	2.25 ±0.30a	1.22 ±.21a	1.37 ±.16a	0.87 ±.14b	9.61 ±3.44a	13.06 ±1.34b	10.48 ±1.05a	15.83 ±1.48b
G064	7.76 ±1.3a	8.99 ±1.44ab	7.49 ±1.03a	16.12 ±4.1a	2.31 ±.37a	3.88 ±.59a	1.57 ±.82a	4.19 ±.51a	1.23 ±0.17b	0.96 ±.05a	1.44 ±.03a	1.48 ±.14a	11.29 ±1.86a	13.83 ±2.08a	10.51 ±1.89a	21.80 ±4.79a

Data in a column followed by the same letter are not significantly different at p=0.05

Table 2: Effect of Intercropping on Soil enzymatic activity during 2nd year; Soil Enzymatic activity i.e. Catalase, Sucrase, Urase and alkaline Phosphatase for 2nd year. Ck is for control (monoculture of pepper crop), G026 is intercropped with garlic cv. G026 and G064 is treatment intercropped with garlic cv. G064. LSD, Least Significant Difference; *p values≤0.05 by LSD

	Catalase (0.1KMnO$_4$ mL·g^{-1})				Sucrase (glucose mg·g^{-1})				Urase(NH$_3$-N mg·g^{-1})				Alkaline Phosphatase (P$_2$O$_5$ mg/100 g)			
Treatment	15.9.10	5.10.10	25.10.10	15.11.10	15.9.10	5.10.10	25.10.10	15.11.10	15.9.10	5.10.10	25.10.10	15.11.10	15.9.10	5.10.10	25.10.10	15.11.10
Ck	2.19 ±.01a	2.08 ±.03a	2.09 ±.03a	1.81 ±.12a	77.46 ±9.48a	63.31 ±4.29b	55.71 ±6.27a	44.46 ±6.58a	3.47 ±.24b	3.70 ±.12c	3.21 ±0.57b	3.44 ±0.59b	2.04 ±.34a	1.99 ±.23a	0.98 ±.13a	1.05 ±.11a
G026	2.22 ±.01a	2.12 ±.11a	1.98 ±.03b	1.91 ±.03a	57.05 ±2.02b	54.22 ±2.97c	59.66 ±11.8a	50.87 ±8.47a	4.67 ±.04ab	4.65 ±.11a	4.59 ±0.41a	4.83 ±0.43a	2.06 ±.28a	2 ±.24a	1.13 ±.16a	1.11 ±.27a
G064	2.20 ±.035a	2.15 ±.01a	2.15 ±.04a	1.91 ±.07a	60.70 ±4.83b	72.32 ±3.18a	60.78 ±5.08a	47.74 ±10.3a	5.13 ±.98a	4.12 ±.14b	4.28 ±0.53ab	4.34 ±0.09ab	2.05 ±.18a	2.14 ±.42a	1.19 ±.02a	1.15 ±.15a

Data in a column followed by the same letter are not significantly different at p=0.05

Total microbial activity: Total microbial activity can be seen from the Fig. 1D. It was observed that total microbial activity showed the same trend as in case of bacteria because number of bacteria is the most effective factor to change the soil microbial activity. In the whole experiment, the microorganisms showed moderately increasing trends from September 2009 to November 2009 in the intercropped treatments with garlic.

We observed that during 2nd year of experiment total microbial activity in the plots intercropped with green garlic cv.G064 showing increasing trend as compared to normal garlic treatments and control (Table 1).

Effect on Soil Enzymatic Activities

Catalase: The catalase activity found increased in the treatments during October and November 2009. However, after the harvest of pepper crop, the activity of catalase showed decreasing trend in all the treatments (Fig. 3A); however, an increasing trend was observed in all the treatments during April 2010 after the transplantation of pepper crop, which remained same during June, July and August 2010.

During the 2nd year of experiment, the catalase activity showed decreasing trend with the passage of time. The data revealed that treatment intercropped with green garlic (cv.G064) showed higher activity of enzyme followed by normal garlic cv.G026 treatment and the control respectively (Table 2).

Invertase/Sucrase: The dynamic change in invertase activity can be observed in the F 3-B, which was derived from the trend line (y=0.246x-0.027, R^2=0.990). Before the intercropping of garlic (2009.8.31) the invertase activity was recorded 8.216 glucose mg·g^{-1}. It can be clearly observed from the results that the enzymatic activity increased in all the intercropping treatments as compared to control during October 2009 (2009.10.10 and 31). Symbiotic soil microorganism activity increased with the increase in metabolism of symbiotic roots. With the increase of root exudation, microbes can release substances into soil such as humus. Soil degradation, improves the soil enzymatic activity of soil microorganisms in the soil ecosystem. Increase in the number of microbes and enhanced microbial activity improve the soil. With the decrease of temperature, soil microbial activity also decreased that leads to limitise the soil enzymatic activity. After the winter season, in April when pepper was transplanted again in the standing garlic crop, the symbiotic activity increased and green garlic intercropped showed higher concentration of invertase (87 glucose mg·g^{-1}) followed by intercropping normal garlic cvs G025, G087 and G026, however the lowest value was recorded in the control (56.69 glucose mg·g^{-1}). The activity of invertase gradually decreased when alone pepper crop was in the field in all the treatments.

The garlic was intercropped in the standing crop of pepper on 2010.09.15 during 2nd year of experiment and after the intercopping, the dynamic change in invertase

Table 3: Influence of intercropping on soil available nutrition during 2nd year; Soil available nutrients i.e. Available Nitrogen (AN), Available Phosphorus (AP) and available potassium (AK) during 2nd year. Ck is for control (monoculture of pepper crop), G026 is intercropped with garlic cv. G026 and G064 is treatment intercropped with garlic cv. G064. LSD, Least Significant Difference; *p values ≤ 0.05 by LSD

	Available nitrogen (mg/kg)				Available phosphorus(mg/kg)				Available potassium(mg/kg)			
Treatments	15.9.2010	5.10.2010	25.10.2010	15.11.2010	15.9.2010	5.10.2010	25.10.2010	15.11.2010	15.9.2010	5.10.2010	25.10.2010	15.11.2010
Ck	47.85± 15.2a	28.01± 8.08a	80.03± 0.5b	78.51± 1.06b	131.84± 7.6b	141.21± 12.17b	106.62± 6.04a	118.47± 14.17a	71.99± 70.05a	204.23± 23.31a	166.94± 23.79ab	152.89± 0b
G026	60.68± 17.6a	30.35± 14a	89.13± 0.2a	87.15± 1.85a	167.35± 20.03a	146.50± 8.89b	111.88± 18.5a	130.21± 18.22a	246.80± 23.51a	244.85± 23.33a	194.16± 0a	234.27± 0a
G064	73.51± 13.2a	35.01± 14.5a	97.76± 3.5a	91.23± 4.35a	127.50± 13.62b	175.03± 6.23a	113.04± 15.01a	123.92± 6.4a	231.66± 70.08a	217.93± 23.33a	153.40± 0b	193.33± 3.4ab

Data in a column followed by the same letter are not significantly different at p=0.05

Table 4: Influence of Intercropping on Soil total Nutrients during 2nd year: Soil total nutrients, Total nitrogen (TN), total phosphorus (TP), total potassium (TK) and Soil organic matter (SOM) during 2nd year. Ck is for control (monoculture of pepper crop), G026 is intercropped with garlic cv. G026 and G064 is treatment intercropped with garlic cv. G064. LSD, Least Significant Difference; *p values ≤ 0.05 by LSD

	Total nitrogen (g/kg)		Total phosphorus(g/kg)		Total potassium(g/kg)		Soil Organic Matter(g/kg)	
Treatments	15.9.2010	15.11.2010	15.9.2010	15.11.2010	15.9.2010	15.11.2010	15.9.2010	15.11.2010
Ck	1.29±0.023b	1.41±0.044ab	1.32±0.023b	1.64±0.051a	13.46±1.826a	13.06±0.175a	15.80±2.66b	19.41±0.66b
G026	1.42±.004a	1.36±0.008b	1.52±0.016a	1.30±.0314b	12.56±0.173a	14.13±0.972a	20.06±1.09a	20.41±1.21ab
G064	1.27±0.056b	1.44±0.007a	1.32±0.031b	1.24±.017b	12.77±.172a	13.72±.799a	17.08±.103ab	22.10±0.26a

Data in a column followed by the same letter are not significantly different at p=0.05

enzyme was observed as shown in the Table-2 derived from the trend line (y=0.179x-0.044, R^2=0.991). The enzymatic hydrolysis of sucrose to glucose and fructose, improved the nutritional status of soil carbon. The results revealed that activity of enzyme showed upward trend in the treatment intercropped with green gralic (cv.G064). It was found that with the passage of time, the invertase activity showed decreasing trend and at the time of harvesting of pepper (2010.11.15) the treatment of normal garlic cv.G026 was at higher side (50.87 glucose $mg \cdot g^{-1}$) and trend was as follows normal garlic cv.G026>green garlic cv.G064>CK.

Urase: The activity of urase derived from trend line (y=0.038x +0.016, R^2 = 0.994) as shown in F 3-C, clearly depicts that with the passge of time, the activity of urease shows increasing trend in all treatments. Before intercropping of garlic on 2009.8.31, the urase activity was recorded 4.04 NH_3-N $mg \cdot g^{-1}$. During October and November 2009, increasing trend was observed in activity in the field intercropped with green garlic (cv.G064) and comparatively lower value was seen in the control. It is clear from the results that intercropping of garlic had great influence on the activity of urease.

During 2nd year of the experiment, the activity of urase enzyme derived from the trend line (y = 0.040 x +0.036, R^2 = 0.991) is shown in the Table 2, depicting that at the time of intercropping garlic in September 2010, green garlic (cv.G064) intercropping showed higher activity of enzyme but after intercropping the treatment of normal garlic cv.G026 showed upward trend and remained same till the harvesting of pepper crop followed by green garlic and the control. The green garlic cv.G064 showed lower activity might be due to half number of bulb (268 bulbs) used this year as compared to the previous year (536 bulbs) per plot.

Alkaline phosphatase: The soil alkaline phosphatase activity was 0.924 P_2O_5 mg/100 g before intercropping the garlic in standing pepper crop on 2009.8.31. The enzyme activity was derived from the trend line (y=0.057x+0.039, R^2=0.991; Fig. 3D) revealed that the activity of enzyme increased after one month of intercrpping during October in all garlic intercropping fields as compared to the control. In March 2010, alkaline Phosphatase activity was recorded at the higest level (1.84 P_2O_5 mg/100 g) in green garlic (cv.G064) intecropped treatment when only garlic was in field. The increase in alkaline Phosphatase activity was recorded in all the treatments from April 2010 (after the transplanting of pepper) to August 2010.

The activity of alkaline phosphatase during 2nd year can be observed from the Table 2 derived from the trend line (y=0.024x+0.007, R^2 = 0.997). The activity directly influenced the decomposition of soil organic phosphorus transformation and bioavailability. The results revealed that at the time intercropping of garlic in September 2010 the enzymes activity was almost same in all the treatments but after the intercropping of garlic first activity of enzyme intercropped with green garlic (cv.G064) showed upward trend followed by normal garlic treatment and the control but with the passage of time the activity showed downward trend. However, the inter-treatment trend was same i.e. green garlic (cv.G064)>normal garlic cv.G026>CK, respectively.

Influence on Soil Nutrients

Nitrogen contents: From the Fig. 4A, it is observed that available nitrogen content showed dynamic change after the intercropping of garlic. Available nitrogen contents was 91.7 mg/kg on 2009.8.30 before intercropping.

After the intercropping, it showed increasing trend and the field intercropped with green garlic (cv.G064) revealed the highest level by attaining 194.6 mg/kg followed by normal garlic cv.G087 and cv.G026 during the month of October (2009.10.10) while the lowest value was recorded in control at the end of October. At the time of uprooting of pepper crop in November 2009, the contents of available nitorgen decreased to the lowest level in all treatments. There was slight increase when pepper was intercropped in the standing garlic during April 2010.Total nitrogen was recored 1.73 g/kg before the intercropping of garlic on 2009.8.31 and at the end of pepper crop during November 2009 the contents of total nitrogen was observed higher in the plot intercropped with normal garlic cv.G087> normal garlic cv.G026>green garlic (cv.G064)> normal garlic cv.G025 as comapred to the control as shown in Fig. 5A.

The available nitrogen contents during 2^{nd} year can be observed from the Table 3. Garlic was intercropped on 2010.09.15. It was observed that available nitrogen contents were decreased in first instant but during the month of October (2010.10.25) the content of nitrogen increased in all treatments and remains the same till the end of pepper crop. The garlic intercropped with green garlic was at higher level followed by normal garlic cv.G026 and the control, respectivly. The total nitrogen was measured before intercropping of garlic and at the end of pepper crop during 2^{nd} year as shown in Table 4. It was observed at the time of intercropping that the treatment intercropped with green garlic showed higher contents of total nitrogen while at the end of pepper crop the treatment intercropped with normal garlic cv.G026 showed higher level (1.43 g/kg).

Phosphorus contents: The change of available phosphorus contents in soil are shown in F 4-B based on the trend line ($y=0.679x-0.000$, $R^2 = 0.997$). Before intercropping garlic in August 2009, the available phosphorus was 137.25 mg/kg. After the intercropping from September to November the field intercropped with green garlic showed upward trend followed by other garlic treatments, however after the intercropping of pepper next year in April 2010, all the treatments showed downward trend, i.e. all the treatment consumed most of availbale phosphorus after the intercropping of pepper in 2010. Total amount of phosphorus was measured before the intercropping of garlic (2009.8.31) and after the end of pepper crop (2009.11.20) derived from the trend line ($y = 0.665x + 0.022$, $R^2 = 0.997$) as showen in Fig. 5B, it was observed that after the intercropping of garlic total phosphorus level was increased in the order of normal garlic cv.G026> normal garlic cv.G087> green garlic (cv.G064)> normal garlic cv.G025 as compared to the control.

During the 2^{nd} year the available phosphorus based on the trend line ($y = 0.693 x -0.034$, $R^2 = 0.954$; Table 3) showed dynamic change. It was observed that after the intercropping of garlic the contents of available phosphorus suddenly showed increasing trend in treatment intercropped with green garlic (cv.G064) on October 05, 2010. However, later on it showed downward trend like other treatments. At the end of pepper crop on 2010.11.15 the contents of available phosphorus showed trend as normal garlic cv.G026> green garlic (cv.G064)>CK. The total phosphorus contents were measured before intercropping of garlic (2010.09.15) and at the end of pepper crop (2010.11.15) was derived by the trend line ($y = 0.665x +0.022$,$R^2 = 0.997$; Table 4). The results showed that at the time of intercropping of garlic during the month of September the treatment intercropped with garlic bulbs (G064) showed higher level of contents, however at the end of pepper crop the control showed higher level of contents as compared to garlic intercropped treatments that showed that higher consumption of total phosphorus in intercropped treatments as compared to the control.

Potassium contents: The concentration of available potassium (K) during the first year of experiment can be seen from the Fig. 4C based on the trend line ($y=0.064x+0.010$, $R^2 = 0.996$). The available potassium before intercropping on 2009.8.31 was recorded 425.22 mg/kg. It was observed that with the passage of time during October and November, all the treatment showed downward trend. At the time of intercroppig pepper in April 2010, a slight increase in potassium level was observed and later showed downward trend in all treatments. As far as total potassium is concerned, the concentration level was almost same in all the treatments before and after the experiment, there was no significant change observed as shown in Fig. 5C based on the trend line ($y=3.383x+1.609$, $R^2 = 0.995$).

During the 2^{nd} year of experiment the dynamic change in concentration of available potassium can be seen in Table-3 derived from trend line ($y=2.500x+2.275$,$R^2 = 0.997$). It was observed that available potassium contents showed downward trend all over the experiment in control, however higher level was seen in normal garlic cv.G026 intercropping followed by green garlic intercropping. The concentration of total potassium was measured twice in the experiment and derived from the trend line ($y=3.383 x +1.609$, $R^2 = 0.995$). Before intercropping the garlic the contents of total potassium was higher in the control as compared to garlic intercropped treatment, however at the end of pepper crop higher level of total potassium was observed in treatment intercropped with green garlic followed by treatment intercropped with normal garlic cv.G026 and the control as shown in Table 4.

Soil Organic Matter

Organic matter was measured in soil samples before intercropping garlic on August 31, 2009 and at the end of pepper crop on November 19, 2009. The data revealed that organic matter increased with the growth of pepper crop, however reletively less amount was observed in the control (17.37 g/kg) and high level of organic matter was observed in treatment intercropped with garlic showing trend as normal garlic cv.G087> normal garlic cv.G026>green garlic.F 5-D.

During the second year of experiment the change in organic matter can be observed in Table 4. Organic matter was measured before intercropping of garlic (2010.09.15) and at the end of pepper crop (2010.11.15). It was observed that organic matter increased with the growth of pepper and garlic. At the end of pepper crop in the treatment intercropped with normal garlic cv.G026 showed higher level of organic matter, followed by garlic intercropped with green garlic and the control.

Discussion

Intercropping is commonly attributed to the complementarily of resource capture pattern by crops (Rodrigo *et al.*, 2001). It is generally considered that the combination of the two species may improve the efficiency of soil water and nutrient uptake throughout the soil profile.

Soil micro-organisms possess a great importance in energy flow, organic matter turnover, nutrient cycling (Yao *et al.*, 2000; Schutter *et al*., 2001), while their biomass activity can be affected by soil management and cropping systems (Yin *et al.*, 2004). The soil microbial activity is an important factor for soil formulation and nutrient cycling due to their critical involvement in many soil ecosystem processes (Spedding *et al.*, 2004). The current study was planned to assess the effect of garlic-pepper intercropping on soil microbial activity, microbial biomass and soil nutrient. Our results showed increasing trends the concentration of soil micro organisms in all the treatments with garlic intercropped in pepper, especially green garlic (cv.G064) as compared to the control. Higher level of bacteria and other microbes were obsereved when both the crops were in the field but with the uprooting of pepper crop the microbial activity of all three organism showed downward trend in both the years of experiments. It revealed that with the growth of pepper crop, the release of root exudates was more with the passage of time providing more nutrition to promote rapid proliferation of microorganisms so that concentration of microbes increased. Our results were in close hormony to the findings of Xu and Wang (2003), Li *et al.* (2005), Hu *et al.* (2006) and Xie *et al.* (2007) reporting that continuous monocropping may reduces the species and quantity of soil bacteria as well as lowers the number of fungi species. Ren *et al.* (2008) also found that the densities of bacteria, acitinomyectes and total microbes in rhizosphere of soil were significantly higher under intercopping of arobic rice with watermelon as compared with monocropping. The lower activity of micro-organism in pepper sole crop may be the cause of soil to be more favourbale to the deleterious micro-organisms or decrease nutrient availibility to crops.

Garlic is an important intercropping crop because at early growth stage it possess high number of root hairs resulting in increased production of root exudates. There are many evidences to suggest that root secretes compounds, such as catechin, influence microbial communities in the the rhizosphere of plants resulting with competitive outcomes between this plant and its neighbours (Weir, 2007).

Many researchers described that the soil enzymes activity can be used as sensitive indicator of changes in soil biological activity and fertility in response to various soil management practices (Gajda *et al.*, 2000; Martyniuk *et al*., 2001). Soil enzymes play important role in the phenomenon of soil that effects the soil fertility and soil metabolism. Plant root exuadates generates about 90% of the soil metabolic activity affecting the contents of soil enzymes directly or indirectly. Plant roots secretes extracellular enzymes and stimulats the soil microbial activity. According to Shun and Tong (2001), soil enzymatic activities are relative to trend and strength of biochemical process, which directly affect the soil productivity, ecosystem performance and economy. Urase showed close relationship with urea hydrolyzation and increase the utilization rate of nitrogen fertilizer (Cookson and Lepiece, 1996; Klose and Tabatabai, 1999). Alkaline Phosphatase deal with phosphorus decomposition and improve soil phosphorus validity (Pascual *et al*., 2002).

During the first year of experiment (2009–2010) we found that two enzymes (urase and catalase) showed upregulatory trend after one month of intercropping of garlic in pepper crop and later on declined. However, two enzymes (alkaline phosphatase and invertase) showed first decending and later on asending tendency. Highest level of concentration was observed in green garlic treatment and lowest was in the control (sole pepper crop). After the 2nd time transplanting of pepper crop in April 2010, all the four enzymes showed upward trend with the growth stages of pepper crop and the same trend was observed in the case of micro organisms. These results are supported by different scientist (He and Zhu, 1997; Hu and Zhang, 2001) stating that microbe activity had a strong effect on soil enzymes. Wan and Ping (2003) concluded from their experiment that intercropping can increase the contents of organic matter and also improve the soil enzymatic activities and fertility.

During the 2nd year of experiment after the 2nd time intercropping of garlic during month of september, there was no significant changes observed in the concentration of enzyems. Activity of all the enzymes showed either downward trend or remained the same. However, normal garlic cv.G026 intercropping was relatively higher than green garlic treatment and the control. It is because the soil was not ploughed since last year and was untouched, the organic fertilizer was low and such soil remitted the soil enzyme activities and these results were supported by Huang (1981). It can be observed that with the deduction of number of bulbs as compared to previous year the activity of soil enzymes was also decreased and normal garlic cv.G026 intercropping showed higher concentration during 2nd year. The results revealed that the coexistance of bothe the crops supports the increased concentration of all the enzymes, which decreased with the uprooting of pepper crop.

According to Peries and Fernando (1983) nitrogen is a vitally important plant nutrient which is a constituent of many organic compounds likely protein, amino acids, chlorophyll, alkaloids and others. Phosphorus is an important nutrient of plant and is a component of nucleo-proteins, enzymes and lecythine. It performs an essential role in respiration, photosynthesis and in the formation of reproductive organs such as fruits and seeds. Its major role is physiological process, i.e. transfer of energy in the plant body (Jalil, 1988). Potassium is definitely an essential element for plant life. It is considered to be necessary for carbohydrate, protein and oil synthesis in plants. It is elusive in the soil with respect to plant availability. Potassium availability to plants varies with different factors among which are clay contents (texture) and clay composition (mineralogy) of soils.

Munna and Singh (2001) stated that with the intensive cultivation of vegetable in orchard fields supported continuous recycling of plant residues and improved microbiological transformations of nutrients into an available form. The experiment showed that intercropping revealed possitive effects on soil nutrition. During the first year of our experiment (2009–2010), the available nitrogent (N) and phosphorus (P) contents showed upward trends after intercropping and at the time of maturity of pepper crop during the month of november the level of nitrogent move to the lower side, however at the time of 2nd transplanting of pepper crop during month of April 2010 the concentration of nitrogen in soil showed upward trend. It was oberved that the treatment of intercropping with garlic especially intercropped with bulbs showed higher level as compared to contol (sole pepper crop). During the 2nd year of experiment (2010–2011), after intercropping garlic, the nitrogen contents first showed decending then acending trend in all treatments but treatments with garlic was higher side as compare to sole crop.

During the second year of experiment it was observed that after the intercropping of garlic, the contents of available phosphorus (P) suddenly showed upward trend in treatment intercropped with green garlic (cv.G064 bulbs) on october 05, 2010. However later on it showed downward trend like other treatments. At the end of pepper crop on 2010.11.15, the contents of available phosphorus showed the trend normal garlic cv.G026>green garlic >CK.

As for as contents of available potassium were concerned during first year, all the treatment showed downward trend, i.e. more amount of potassium was used during intercropped period. At the time of intercroppig pepper in April 2010, little increase in potassium level was observed which latter on showed downward trend in all treatments. It was observed in 2nd year of experiment that available phosphorus contents showed downward trend in control. However higher level was observed in normal garlic cv.G026 intercropped followed by intercropped with green garlic. Our results are supported by Soon and Arshad (1996) who stated that the effects of cropping systems on C, N, P and K are influenced by crop type, cropping and tillage frequencies. Likewise, Dahmardeh *et al.* (2010) reported that the contents of nitrogen, phosphorus and potassium of soil following intercrops were improved as compared to sole maize crop. Intercropping can increase nutrient elements of soil compared to sole maize and improve conservation of soil fertility.

The organic matter (C) of soil is the most important factor which differentiate the microbial communities and activities in the different farming systems (Gunapala and Scow, 1998). According to Hu and Cao (2007), the microbial metabolic quotient, size and activity of micrbial biomass and soil enzymatic activity predict condition of soil fertility and should be considered as important indicator of changes in soil quality. If the level of organic matter decreases, it becomes very difficult to grow plants in soil because of lowered soil fertility, increased deletarious microbes, erosion, compaction and water availibility problems. Organic matter was measured before intercropping of garlic and at the time of uprooting of paper during both the years. It was observed that the level of organic matter in soil increased with the growth of pepper crop, however, at the end of pepper crop, the concentration of organic matter was recorded. The amount of organic matter was higher in garlic intercropped treatments as compared to control during both the years. These results are supported by different findings (Wan and Ping, 2003; Dogliotti *et al.*, 2004) that intercropping and crop rotation can inrease the contents of organic matter and also improve soil enzymatic activities and fertility.

Conclusion

Based on the results of our experiment, it is concluded that intercropping of pepper with garlic is much better than sole pepper crop in green house/plastic tunnel with respect to soil microbes, enzymatic activities and nutrition. Pepper intercropping with green garlic is the best intercropping system for soil health to overcome the monocropping soil obstacles. This research offered an orientation towards pepper-garlic inter-planting model with regard to its evaluation and implication dimensions. In future we will focus on the effects of intercropping on fruit quality of vegetable crops.

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