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RESEARCH

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Intercropping young almond trees with snap bean under Nubaria region conditions

Mahmoud Sami Abourayya[1], Nabila Elbadawy Kaseem[1], Thanaa Shaban Mohamed Mahmoud[1], Neama Mohamed Marzouk[2] and Amal Masoad Rakha[1*]

Abstract

Background: Intercropping systems play an effective role in increasing the efficiency of land usage and improving the economic return. During the seasons of 2018 and 2019, the field experiment was conducted to evaluate the effects of snap bean intercropping on the growth and nutritional status of young almond trees. Examine the impact on snap bean plant growth, green and dry yields, and quality. In addition, evaluate the impact of snap bean incorporation in the soil on soil chemical characteristics. The snap bean Bronco cv. was planted in two rows between rows of 5 × 5 m almond trees, and after harvest, snap bean plants were incorporated (20 cm deep) into the soil and the chemical characteristics of the soil were examined after 60 days.

Results: The growth characteristics and leaf chemical constituents of almond young trees were significantly increased under the intercropping with snap bean plants. The highest growth, yield and pods quality of snap bean were recorded by intercropping with almond trees compared to the sole plants. Incorporation of the snap bean in the soil after harvest promoted a difference in pH and organic carbon content and increases the available contents of N, P and exchangeable elements of K, Ca and Mg in soil after 60 days incorporation compared with soil without incorporation.

Conclusions: Intercropping the snap bean Bronco cv. between the almond trees and incorporate it into the soil after harvesting to maximise the use of the land area and obtain the highest profit.

Keywords: Almond, Snap bean, Intercropping system, Incorporation, Profitability, Soil fertility

Background

In recent years, lowering soil erosion and water losses, restoring environmental balance, enhancing land-use efficiency and raising economic benefits of land unit area have been widely focused on the profitability and sustainability of production management. Intercropping is one of the main pillars of sustainable agriculture, and it is widely used in many regions of the world due to its numerous benefits, including efficient input utilization, nutrient exchange, weed competition and pathogen reduction (Daizy et al. 2008; Ghosh and Pal 2010), increased soil fertility (Pardon et al. 2017) and higher productivity per unit of land area than the monoculture of either crop (Daizy et al. 2008; Philip et al. 2017; Shampazuraini et al. 2021).

Intercropping cultivation demonstrates every day that it is possible to improve agricultural practices in order to make agricultural investment a sustainable practice, significantly benefiting producers of small farms, where the absolute majority has limited physical area for their crops (Vieira et al. 2014; Brito et al. 2017). Factors such as tolerance to competition for vegetative growth, time of associations, arrangements and management used and, finally, the quantity and value of the product harvested will influence the financial results of intercropped crops (Brito et al. 2018). Cropping in the orchard's interspaces

*Correspondence: aaaam_am@yahoo.com
[1] Department of Horticultural Crops Technology, Agricultural and Biological Research Institute, National Research Centre, 33 El Bohouth St. (Former El-Tahrir St.), Dokki, Giza P.O. 12622, Egypt
Full list of author information is available at the end of the article

not only creates extra income, but it also helps to prevent soil erosion by providing ground cover and improves the physicochemical condition of the soil (Gajbhiye et al. 2020; Kumar 2020).

Almond (*Prunus amygdalus B*) trees begin to bear fruit three years after they are planted in the orchard. Because almond trees are often planted at 5×5 m spacing, there is more than enough space for producing vegetable crops in the early years, especially from the start of the growing season until the trees become dormant. It is necessary to have a good capacity for interspecific combination when choosing the species to be intercropped, as this will result in higher output and agroeconomic efficiency in intercropped systems (Camili et al. 2013). The higher gross income has been recorded from the various intercrops under the intercropping system in papaya (Gadre 1997) and in guava with vegetable crops as compared to guava grown as a sole crop (Singh et al. 2015). Gajbhiye et al. (2020) had further reported that the highest net profit from the cashew-based intercropping system with Yardlong bean.

Snap bean (*Phaseolus vulgaris L.*) is one of the world's most important fresh market vegetable crops. For millions of individuals in countries all over the world, it is a vital source of dietary fibers, calories, protein, carbohydrates, vitamins and minerals (Shehata et al. 2011). The snap bean plant is one of Egypt's most important vegetable crops, grown for both domestic consumption and export. Bean plants are grown on a total of 60,000 feddans, yielding roughly 28,530 tonnes of beans every year (FAO 2010). Thus, intercropping snap bean cv. Bronco with young almond trees cv. Nonpareil offers another option for making almond cultivation sustainable, promoting the generation of an additional source of income and optimizing land-use efficiency, as well as providing nutrients to the intercropped young almond trees through biological nitrogen fixation (Toamia 2006). The goal of this experiment was to determine the effects of snap bean intercropping on growth and nutritional status of young almond trees. Also, investigate this effect on snap bean plant development, green and dry yields and quality, as well as the impact of snap bean incorporation on soil chemical characteristics.

Methods

A field experiment was conducted during two successive seasons of 2018 and 2019 on three years old of almond cv. Nonpareil (*Prunus amygdalus* B.) trees budded on bitter almond rootstock uniform in vigor, with planting space 5×5 m grown under drip irrigation system at Experimental Research Station of National Research Centre at Nubaria, El Behera governorate, Egypt. The soil of the experimental site, as average of the two seasons, was sandy in texture with pH of 7.88 and contained 1.7% HCo3, 2.84% organic matter and 0.99% total nitrogen. The experimental area was arranged in a completely randomized design with three replicates with four trees per replicate.

Intercropping materials

Snap bean (*Phaseolus vulgaris L*) Bronco cultivar seeds were planted on two sides of soil beds, 40 cm width at 10 cm apart within the plant rows on the 1 April in the two seasons of the study and harvested on the 30th of July. All other agricultural practices for snap bean cultivation followed the Egyptian Ministry of Agriculture's standard recommendations for commercial producers. After snap bean harvest, all plants inside the rows were incorporated into the soil (20 cm). After 60 days, five soil samples (30 cm) were randomly collected from the intercropping usage area and pooled to generate a homogenous mixture of samples for examination.

Measurements

Almond trees

Growth parameters Stem length (cm) and diameter (mm), number of branches/tree, number of leaves/tree, leaf fresh weight (g) (average of 25 leaves) and leaf dry weight (g) were measured in mid-August of both seasons. The Cl-202 portable laser leaf area meter was used to measure the leaf area (cm^2). The following equation was used to calculate the specific leaf dry weight SLDW (mg/cm^2):

$$\text{Specific leaf dry weight} = \frac{\text{Leaf dryweight (g)}}{\text{Leaf area}(\text{cm}^2)} \times 1000$$

Leaf chemical constituents Leaf samples were taken from the middle of the current season's growth, washed and dried at 70 °C until a consistent weight was reached for determining the percentages of nitrogen, phosphorus and potassium (% as dry weight) according to AOAC (1985).

Total chlorophyll Total chlorophyll (SPAD unit) was directly measured using a SPAD-502 chlorophyll meter.

Snap bean plants

Plant growth measurements After 45 days of sowing (flowering stage), a representative sample of 6 plants was randomly selected from each experimental plot to measure the following growth characteristics: plant height (cm), number of leaves and branches per plant, total fresh weight and plant dry weight [determined at 65 °C for 72 h using standard methods as illustrated by AOAC (1985)].

Total chlorophyll Total chlorophyll content of the sixth mature leaves was directly measured using a SPAD-502 chlorophyll meter.

Green pods yield and its attributes: Green pods were collected during the harvesting season (40 days) at the harvest stage and the following data were recorded: total green pod yield per feddan (g) fresh and dried weight pods.

Quality of green pods Samples of 100 random green pods were taken at second picking, and the average pod length and diameter were recorded.

Nutritive value

Samples of 50 random green pods were collected at second picking, and the following parameters were recorded.

Total soluble solids (TSS, %) Total soluble solids were measured using the hand refractometer, according to the method described by AOAC (1985).

Percentage of fiber pods The percentage of pods fiber was measured according to method of Rai and Mudgal (1988).

Percentage of pods' total protein The percentage of pods' total protein was calculated using the 6.25 factor to the conversion of total nitrogen to protein percentage.

Soil chemical analysis

According to the method of Tedesco et al. (1995), available N, P and exchangeable K^{++}, Ca^{++} and Mg^{++} were analyzed. The sample's soil pH was measured in water (1:2.5 v:v) using a pH meter according to Tedesco et al. (1995). The wet combustion with 5 mL of 0.167 mol L1 potassium dichromate and 7.5 mL of concentrated sulfuric acid at 170 °C for 30 min was used to estimate soil organic carbon (OC) according to Yeomans and Bremner (1998).

Economic evaluation

The amount of snap bean seeds needed to cultivate the area between the rows of almond trees was calculated based on the amount of seeds per feddan (30–40 kg) and the snap bean cultivated area under the intercropping system (2400 m^2). To determine the income of snap bean, the total yield of snap bean for the two seasons was added together and multiplied by an average market price (28 LE/kg) as follows (CIMMYT 1988):

Revenue of snap bean = average market price × quantity produced (kg) × cultivated area (m^2); Net revenue of snap bean = Revenue − Total cost of snap bean; the benefit–cost ratio of snap bean was determined according to Nahed, et al. (2015), by dividing the revenue/Total cost; Net profit from intercropped young almond trees with snap bean = Net revenue of snap bean − Total cost of almond.

Statistical analysis

Mstatic (M.S.) software was used to perform statistical analysis on all data according to Snedecor and Cochran (1981). The comparison among means of the different treatments was determined. The least significant differences test was used to compare the treatment means at the (0.05) level of significance.

Results

Effect of intercropping system on nutritional status and growth of young almond trees

The obtained results are shown in Table 1. Reveal that the intercropping of snap bean plants in-row space between almond trees has a significant effect on vegetative growth characteristics of almond trees. Almond trees intercropped with snap bean plants recorded the highest stem length, stem diameter, number of branches, number

Table 1 Effect of intercropping on almond growth

Intercropping system	Stem length (cm)	Stem diameter (mm)	No. of branches/seedling	No. of leaves/seedling	Leaf area (cm^2)	Leaf fresh weight (g)	Leaf dry weight (g)	Specific leaf dry weight (mg/cm^2)
2018								
Almond alone	71.75 B	9.75 B	5.50 B	389.25 B	2.39 B	22.46 B	17.20 B	722.03 B
Almond + Snap bean	81.00 A	12.10 A	12.20 A	600.10 A	2.55 A	28.45 A	23.46 A	919.82 A
2019								
Almond alone	70.38 B	10.50 B	7.50 B	378.75 B	2.32 B	26.12B	21.37 B	928.89 B
Almond + Snap bean	92.25 A	13.00 A	15.00 A	705.75 A	2.56 A	32.50A	25.15 A	982.39 A

Values with diferent letter across the same row are signifcantly diferent ($p < 0.05$)

Table 2 Effect of intercropping on almond leaf elemental content and total chlorophyll

Intercropping system	Leaf elemental content			Total chlorophyll
	N %	P %	K %	
2018				
Almond alone	1.20 B	0.462 B	1.35 B	36.96 B
Almond + Snap bean	1.54 A	0.530 A	1.49 A	40.42 A
2019				
Almond alone	1.23 B	0.480 B	1.38 B	37.78 B
Almond + Snap bean	1.58 A	0.557 A	1.51 A	43.02 A

Values with diferent letter across the same row are signifcantly diferent ($p < 0.05$)

of leaves, leaf area, leaf fresh weight, leaf dry weight and specific leaf dry weight in both seasons, respectively, compared to almond alone.

Regarding the effect of the intercropping system on leaf elementals and total chlorophyll content of almond trees, Table 2 shows that the intercropping treatment significantly increased N, P and K percentages in leaves and total chlorophyll content compared to the alone tree system during the two growing seasons.

Effect of intercropping system on growth, yield and quality of snap bean plants

As indicated in Table 3, intercropping had a considerable impact on the vegetative growth characteristics of the green snap bean. Intercropping snap beans with almond trees resulted in the highest growth parameters (plant length, number of leaves per plant, number of branches per plant, fresh weight of plant and leaf chlorophyll content).

Concerning yield and quality parameters, data in Table 4 show that the yield of green snap beans was significantly affected by intercropping treatments. Intercropping green beans on almond trees had a significant effect on pod parameters, i.e., length, diameter, fresh weight, dry weight, total yield, protein, fibers and TSS in the two study seasons. The highest values of yield and yield parameters were obtained with intercropping systems compared to sole plants.

Soil chemical analysis

As snap beans were incorporated into the soil after harvesting, the chemical characteristics of the soil changed when compared to that had not been incorporated

Table 3 Effect of intercropping on snap bean growth

Intercropping system	Plant length (cm)	No. of leaves/ plant	No. of branches / plant	No. of pods/plant	Total plant fresh weight (g)	Dry matter (%)	Chlorophyll (SPAD)
2018							
Snap bean alone	43.15 B	12.4 B	3.40 B	15.20 B	66.23 B	14.35 B	26.31 B
Almond + Snap bean	75.32 A	19.5 A	5.91 A	18.45 A	81.23 A	19.45 A	31.20 A
2019							
Snap bean alone	51.36 B	11.2 B	4.56 B	14.56 B	67.83 B	15.46 B	25.61 B
Almond + Snap bean	81.20 A	18.5 A	6.12 A	17.56 A	91.26 A	18.24 A	28.45 A

Values with diferent letter across the same row are signifcantly diferent ($p < 0.05$)

Table 4 Effect of intercropping on snap bean yield and pod quality

Intercropping system	Pod length (cm)	Pod diameter (cm)	Fresh weight pod (g)	Dry weight pod (g)	Total yield (ton/fed)	Protein (%)	Fibers (%)	TSS (%)
2018								
Snap bean alone	9.23 B	0.51 B	4.56 B	1.50 B	3.91 B	22.7 B	7.1A	4.6 B
Almond + Snap bean	11.00 A	0.81 A	5.89 A	1.91 A	5.11 A	27.8 A	5.3 B	5.3 A
2019								
Snap bean alone	8.45 B	0.47 B	3.80 B	1.46 B	4.12 B	21.1 B	6.5 A	3.2 B
Almond + Snap bean	12.45 A	0.73 A	4.63 A	1.86 A	6.23 A	28.3 A	4.9 B	4.9 A

Values with diferent letter across the same row are signifcantly diferent ($p < 0.05$)

Table 5 Soil chemical characteristics with and without snap bean incorporation

Intercropping system	pH	OC (g/kg)	N (mg/kg)	P (mg/kg)	K^{++} (mg/kg)	Ca^{2+} (mg/kg)	Mg^{2+} (mg/kg)
2018							
Without incorporation	7.49 B	7.09 B	17.20 B	4.20 B	64.83 B	46.03 B	26.85 B
With incorporation	7.53 A	18.18 A	40.38 A	14.05 A	88.44 A	60.04 A	37.71 A
2019							
Without incorporation	7.32 B	7.12 B	17.33 B	4.69 B	64.94 B	46.79 B	28.65 B
With incorporation	7.82 A	18.37 A	39.73 A	15.77 A	88.04 A	67.59 A	39.30 A

Values with diferent letter across the same row are signifcantly diferent ($p < 0.05$)

Table 6 Economic analysis of intercropping almond with snap bean

Item value	Price (LE)	
	Snap bean	Almond
Fertilizers	1955	1391
Irrigation	6420	4550
Workers	4150	4120
Snap bean seeds	720	–
Total	13.245	10.061
Revenue of snap bean	26.880	
Net revenue of snap bean	13.635	
Benefit cost ratio	2.03	
Net profit	3.574	

(Table 5). Incorporation resulted in a difference in soil pH and organic carbon content 60 days after application compared to soil without incorporation during the two seasons of the study. Incorporation enhanced the content of available N, P and exchangeable K, Ca and Mg in both seasons.

Economic return of intercropping almond trees with snap bean

The study did not include almond trees and snap bean plants because the fixed production costs, such as soil rent and electricity usage, are the same for both. Table 6 shows the economic analysis influenced by the intercropping system of both almond and snap bean. Snap bean revenue is roughly 26.880 LE, and the difference between the total cost and revenue is the net revenue from snap bean cultivation, which is around 13.635 LE.

The profit percentage was represented by the benefit–cost ratio, which was calculated as a revenue-to-cost (R/C) ratio, with its value representing the economic feasibility of the proposed treatment. When the R/C ratio is less than one, the proposed treatment is not feasible in terms of cost to revenue. However, if the R/C ratio is greater than one, the project is profitable (Abd-Alrahman and Aboud 2021). Based on the R/C ratio of 2.03 and the net profit for farmers after deducting the cost of almond trees of roughly 3.574 LE (Table 6), intercropping with snap beans yielded a high return or profit and was economically viable.

Discussion

Effect of intercropping system on nutritional status and growth of young almond trees

Almond trees intercropped with snap bean plants recorded the highest vegetative growth characteristics in both seasons, compared to almond trees alone. The intercropping treatment significantly increased N, P and K percentages in leaves and total chlorophyll content compared to a single tree system in both seasons. This might be attributed to the good effect of snap beans on soil fertility and physiological properties that lead to enhanced growth and nutritional status of almond trees. These results are in accordance with those obtained by El-Karamity et al. (2020) when they intercropped maize with soybean. This is mostly due to the ability of soybean as a legume plant to fix N2 in poorly fertilized fields (Toamia 2006), leading to a significant amount of residual nitrogen for maize plants and encouraging their growth through an increased rate of photosynthesis, producing more dry matter, increasing the meristematic activity and stimulation of cell elongation.

The promotive effect of intercropping on almond leaf chemical constituents, which was proved here, agreed with those stated by Ali et al. (2019) on pomegranate trees when intercropped with sweet basil and rosemary. Also, Abdrabbo et al. (2013) found that growth characteristics and NPK content in the leaves of orange trees were increased when intercropped with potato plants. Moreover, Surucu and Demirkiran (2013) discovered that using barley, vetch or a blend of vetch and barley as intercropping plants had no negative impact on pistachio tree nutrient content.

Effect of intercropping system on growth, yield and quality of snap bean plants

The yield and quality of green snap beans were significantly affected by intercropping with almond trees. Intercropping green beans on almond trees had a significant effect on pod parameters, i.e., length, diameter, fresh weight, dry weight, total yield, protein, fibers and TSS in both seasons. These findings are consistent with those of Srivastava et al. (2007), Mousavi and Eskandari (2011) and Gebru (2015). This can be explained on the basis of the advantages of intercropping with legumes observed in previous studies (Olasantan 1991; Costa and Pereram 1998).

Soil chemical analysis

Incorporating soil with organic carbon was found to increase the content of available N, P and exchangeable K, Ca and Mg in both seasons. The incorporation of snap beans after harvest for a short period of time (60 days) increased the levels of several chemical components in the soil, implying that this strategy could improve soil fertility quickly. These findings are consistent with those of Astier et al. (2006), Partey et al. (2014) and Carvalho et al. (2015). This may be due to legume species having positive effects on increasing element soil content after decomposition, which contains high quantities of N, P, K, Ca and Mg and aids in the release of important nutrients for crops. The findings showed that adding snap beans to the soil altered the pH, indicating that soil pH is sensitive to short-term changes in soil quality caused by various soil or crop management strategies. As shown in prior studies, incorporation enhances soil organic carbon (OC) (Dou and Hons 2006; Huang et al. 2010). Legumes, according to Carvalho et al. (2015), increase soil microbial activity. Microbial growth is also proportional to soil organic matter decomposition (Sicardi et al. 2004), which could be attributed to increased availability of organic carbon and other nutrients.

Economic return of intercropping almond trees with snap bean

To reduce the total cost in the first stage before fruiting, this economic consideration recommends intercropping snap bean plants between the rows of almond trees. Intercropping fruit trees with vegetable crops, on the other hand, ensures proper orchard management and increases the output and productive life of fruit trees. As a result, these vegetable crops can be thought of as contributing crops that increase tree productivity at the expense of yield. Farmers' net returns improve as a result of the additional revenue gained from orchards due to intercropping of vegetable crops (Singh et al. 2018).

The high cost–benefit ratio of these cropping systems may be due to the high yield and market price of products with low investment involved in their cultivation (Nair et al. 2000; Ghosh and Bandopadhyay 2011; Kumar et al. 2013); the present finding was in agreement with the results of Nair et al. (2000), Ghosh and Bandopadhyay (2011), Kumar et al. (2013) and Singh et al. (2015). Kashyap et al. (1989) and Prasanna et al. (1995) found similar results (1995). The high cost of planting materials may be to blame for the high cost of cultivation in the growing of intercropping systems. However, investigations indicated that intercropping enhanced the net return per hectare in many fruit orchards due to the additional income generated by intercrops (Hugar et al. 1991; Singh et al. 2015, 2016).

Conclusion

The study highlighted the positive effects of intercropping almond with snap bean and tillage it in the soil after harvesting on chemical properties and soil fertility, and growth, nutritional status of almond trees. Intercropping had significant effects on the vegetative growth of green beans, yield and snap bean pods quality than sole plants. Therefore, we can recommend cultivating snap bean Bronco cv. between rows of almond trees and incorporate it in the soil after harvesting in order to maximize the utilization of the unit area and obtain the greatest profit.

Abbreviations

SLDW: Specific leaf dry weight; TSS: Total soluble solids.

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Authors' contributions

This work was carried out in collaboration between all authors. NEK designed this study and wrote the protocol. AMR, TSMM and NMM applied the field works, following up the intercropping the almond young trees with snap beans, collected samples, measured its physical measurements and performed the chemical analysis of the samples and the statistical analysis. TSMM wrote the first draft of the manuscript. AMS consulted the study design, protocol and treatments and reviewed the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are included in this published.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Department of Horticultural Crops Technology, Agricultural and Biological Research Institute, National Research Centre, 33 El Bohouth St. (Former El-Tahrir St.), Dokki, Giza P.O. 12622, Egypt. [2]Department of Vegetable Research, Agricultural and Biological Research Institute, National Research Centre, 33 El Bohouth St. (Former El-Tahrir St.), Dokki, Giza P.O. 12622, Egypt.

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References
Abd-Alrahman HA, Aboud FS (2021) Response of sweet pepper plants to foliar application of compost tea and dry yeast under soilless conditions. Bull Natl Res Cent 45:1–9. https://doi.org/10.1186/s42269-021-00578-y

Abdrabbo MA, Farag AA, Abul-Soud M (2013) The intercropping effect on potato under net house as adaption procedure of climate change impacts. Researcher 5:48–60

Ali AA, Elmasry SMA, Abdelkader MAI (2019) Response of productivity and competitive indices of pomegranate trees and sweet basil and rosemary to different intercropping systems. Int J Environ 8:32–42

AOAC (1985) Official methods of analysis. Association of Official Agricultural Chemists. 14th edn. Benjamin Farnklin Station, Washington, DC, USA, pp 490–510

Astier M, Maass JM, Etchevers-Barra JD, Pena JJ, Gonzalez FL (2006) Short-term green manure and tillage management effects on maize yield and soil quality in an Andisol. Soil till Res 88:153–159

Brito AU, Puiatti M, Cecon PR, Finger FL, Mendes TDC (2017) Viabilidade agroeconômica dos consórcios taro com brócolis, couve-chinesa, berinjela, jiló, pimentão e maxixe. Revista Brasileira De Ciências Agrárias 12:296–302

Brito AU, Puiatti M, Cecon PR, Puiatti GA (2018) Viabilidade agroeconômica do consórcio mangarito com milho verde em quatro épocas de associação. Revista Ceres 65:364–372

Camili EC, Azevedo CCBV, Bocuti ED, Miranda Silvério J, Costa Barros K, Silva ARB, Seabra Júnior S (2013) Cultivo consorciado de alface sob diferentes arranjos espaciais e manejo do dossel de taioba. Agrarian 6:110–120

Carvalho NS, Oliveira ABB, Pessoa MMC, Neto VPC, de Sousa RS, da Cunha JR, Coutinho AG, dos Santos VM, de Araujo ASF (2015) Short-term effect of different green manure on soil chemical and biological properties. Afr J Agric Res 10:4076–4081. https://doi.org/10.5897/AJAR2015.9885

CIMMYT (1988) An economic training manual: from agronomic data to farmer recommendations, Mexico, pp 1–25

Costa WA, Pereram JM (1998) Effect of bean population and row arrangement on the productivity of Cilli/Dwarf bean intercropping in Sir Lanka. J Agron Crop Sci 180:53–58

Daizy R, Batish R, Kumar K, Shibu JH, Pal S (2008) Ecological basis of agroforestry. Taylor & Francis, New York, p 400

Dou F, Hons FM (2006) Tillage and nitrogen effects on soil organic matter fractions in wheat-based systems. Soil Sci Soc Am J 70:1896–1905

El-Karamity AE, Nagwa RA, Aya NM (2020) Effect of intercropping of some oil summer crops with maize under levels of mineral N and nano N Fertilizers. Sci J Agric Sci 2:90–103. https://doi.org/10.21608/sjas.2020.42913.1038

FAO (2010) Food and Agriculture Organization of the United Nations. Faostat: Statistical Database.

Gadre NA (1997) Economics of production of papaya for papain production. PKV Research-Journal 21:142–145

Gajbhiye RC, Pawar SN, Zote VK, Sawant BN (2020) Intercropping of different vegetable crops in new cashew plantation under Konkan conditions of Maharashtra, India. Int J Curr Microbiol Appl Sci 9:448–455

Gebru H (2015) A review on the comparative advantage of intercropping systems. J Biol Agric Healthc 5:28–38

Ghosh DK, Bandopadhyay A (2011) Productivity and profitability of coconut based cropping systems with fruits and black pepper in West Bengal. J Crop Weed 7:134–137

Ghosh SN, Pal PP (2010) Effect of inter-cropping on plant and soil of Mosambi sweet orange orchard under rainfed conditions. Indian J Hort 67:185–190

Huang S, Sun Y, Rui W, Liu W, Zhang W (2010) Long-term effect of no-tillage on soil organic carbon fractions in a continuous maize cropping system of Northeast China. Pedosphere 20:285–292

Hugar LB, Murthy PSS, Umesh KB, Reddy BS (1991) Economic feasibility of guava cultivation under scientific management empirical evidence. Agric Situat India 46:211–214

Kashyap R, Singh J, Beohar BB (1989) Economics of intercropping in newly planted mango orchard with guava as filler crop in eastern Madhya Pradesh. In: International symposium on horticultural economics in developing countries, Atemaya (Ethiopia).

Kumar A, Pandey SD, Rai RR (2013) Intercropping of vegetables with pre-bearing litchi plants in relation to profitable and sustainable production system. Veg Sci 39:128–131

Kumar NP (2020) Effect of intercropping on fruit crops: a review. Int J Curr Microbiol Appl Sci 9:745–755. https://doi.org/10.20546/ijcmas.2020.912.090

Mousavi SR, Eskandari H (2011) A General overview on intercropping and its advantages in sustainable agriculture. J Appl Environ Biol Sci 1:482–486

Nahed MM, El-Sayeda H, El-Badawy M, Hager IT (2015) Response of sweet pepper plants to some organic and bio-fertilizers and its effect on fruit yield and quality. Middle East J Agric 4:435–445

Nair AK, Nair SA, Dubey RR, Ravisankar N, Pramanik SC (2000) Evaluation of cucurbitaceous vegetables as intercrops in coconut (Cocus nucifera) plantations of Andamans. Indian J Agric Sci 70:241–242

Olasantan FO (1991) Response of tomato and Okra to nitrogen fertilizer in sole cropping and intercropping with Cowpea. Hortic Sci 66:191–199

Pardon P, Reubens B, Reheul D, Mertens J, De Frenn P, Coussement T, Janssen P, Verheyen K (2017) Trees increase soil organic carbon and nutrient availability intemperate agroforestry systems. Agric Ecosyst Environ 247:98–111

Partey ST, Preziosi RF, Robson GD (2014) Short-term interactive effects of biochar, green manure, and inorganic fertilizer on soil properties and agronomic characteristics of maize. Agric Res 3:128–136

Philip JS, Neil IH, Patricia M, Gudeta WS, Festus KA, Julia W, Fergus S (2017) Accurate crop yield predictions from modelling tree-crop interactions in gliricidia–maize agroforestry. Agric Syst 155:70–77

Prasanna KP, Kanakamany MT, Joseph T, Sasidhar VK (1995) Intercropping of irrigated banana (Musa AAB Nendran) with tapioca, groundnut and vegetables. J Trop Agric 33:94–96

Rai SN, Mudgal VD (1988) Synergistic effect of sodium hydroxide and steam pressure treatment on compositional changes and fiber utilization of wheat straw. Biol Wastes 24:105–114

Shampazuraini S, Yusoff MM, Ramlan MF, Sulaiman Z, Md Isa I (2021) Enhanced intercropping productivity of sweet corn and okra in young Rubber plantation. Asian J Plant Sci 20:428–434. https://doi.org/10.3923/ajps.2021.428.434

Shehata SA, Ahmed YM, Emad AS, Omaima SD (2011) Influence of compost rates and application time on growth, yield and chemical composition of snap bean (*Phaseolus vulgaris* L). Aust J Basic Appl Sci 5:530–536

Sicardi M, García-Prechac F, Frioni L (2004) Soil microbial indicators sensitive to land use conversion from pastures to commercial *Eucalyptus grandis* (Hill ex Maiden) plantations in Uruguay. Appl Soil Ecol 27:125–133

Singh SK, Prasad J, Singh PK (2015) Studies on economic potential of various vegetable crops as intercrops under plantation of guava (*Psidium guajava* L.). Bioved 26:219–222

Singh SK, Sharma M, Singh PK (2016) Combined approach of intercropping and INM to improve availability of soil and leaf nutrients in fruit trees. J Chem Pharm Sci 9:823–829

Singh SK, Singh SK, Singh S (2018) Vegetable crops as most efficient and economical intercrops: a brief review. Plant Arch 18:923–929
Snedecor GW, Cochran WG (1981) Statistical Methods, 7th edn. Iowa State University Press, Iowa, p 507
Srivastava AK, Huchche AD, Ram L, Singh Sh (2007) Yield prediction in intercropped versus monocropped citrus orchards. Sci Hortic 114:67–70
Surucu A, Demirkiran AR (2013) Effects of intercropping on mineral content of pistachio in southeast of Turkey. J Food Agric Environ 11:883–886
Tedesco MJ, Gianello C, Bissani CA (1995) Análises de solos, plantas e outros materiais. UFRGS, Porto Alegre, p 230
Toamia SEA (2006) Effect of intercropping soybean, cowpea and guar with maize on yield and its components. J Agric Sci Mansoura Univ 31:55–70
Vieira JCB, Puiatti M, Cecon PR, Bhering AS, Silva GCC, Colombo JN (2014) Viabilidade agroeconômica da consorciação do taro com feijão-vagem indeterminado em razão da época de plantio. Revista Ceres 61:229–233
Yeomans JC, Bremner JM (1998) A rapid and precise method for routine determination of organic carbon in soil. Comm Soil Sci Pl Anal 19:1467–1476

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