

Tree used in horticulture based alley cropping

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Abstract

Main objective of this paper is selection of tree and vegetable combination for success in new horticulture based alley cropping plantations. In alley cropping, fruit, legume and wood tree are integrated in several associations with annual vegetable, *Mangifera indica*, *Psidium guajava*, *Citrus* spp., *Leucaena* spp., *Gliricidia sepium*, *Cajanus cajan*, *Populus* spp., *Eucalyptus*, *Hevea brasiliensis* are the main tree used. *Fabaceae*, *Brassicaceae*, *Solanaceae* families and tuber crops are the main associated vegetable crops. This system can be adapted for specific farmers, regions, and countries for vegetable, fruit and wood requirements. The specific credits and subsidies can increase natural, economic, social capital of the world.

Key words: Agroforestry, fruit tree, legume tree, wood tree, annual vegetable, silvoarable system

Introduction

The horticulture associated with trees is not new; several combinations and arrangements have been developed in different parts of the world to domesticate, produce and improve some vegetable and fruit tree species. Actually, the horticulture based alley cropping systems (agroforestry) combine perennial woody crops and non-woody crops (Martin *et al.*, 2019), the vegetables are arranged spatially in order to achieve both economic and environmental benefits of the farming system (Mercado *et al.*, 2008). The choice of crops is determined by the factors like agro-climatic and edaphic conditions, crop root system, pattern of water and nutrient demands and above ground growth habits (Pandey *et al.*, 2017).

Vegetable crops recommended, in alley cropping, are short durational and shade-loving crops with high efficiency of photosynthesis and biological fixation (Singh *et al.*, 2018). Some criteria for selecting of horticultural intercrops are: 1. early maturing; 2. shade tolerance; 3. should not compete with the perennial companion crop; 4. should not be more susceptible than the main crop to diseases they have common (Dhakar *et al.*, 2013). Theoretically, C3 plants planted under shade should be able to perform better than C4 plants and could be better suited for agroforestry practices (Jose *et al.*, 2004), and, the crop variety, management of crops and trees, seasonal climate variability (Bellow *et al.*, 2008), and socio-economic suitability contribute to system performance (Dhakar *et al.*, 2013).

The tree component selection is significant for the success of agroforestry plantation. The dependent species, tree species check erosion and also ameliorate soil in terms of increasing organic matter, fixing nitrogen, and nutrient uptake and recycling through litterfall (Pande *et al.*, 2018). For example, the fast-growing wood tree species in combination with horticultural crop may increase the employment generation for the nursery growers, local labours and small scale wood industries (Shukla *et al.*, 2018), and legume tree for “fallow system” (Kang *et al.*,

1985) provides nitrogen through biological fixation, and help in solubilizing insoluble P in soil, improving the soil physical environment, increasing soil microbial activity, restoring organic matter, and also has smothering effect on weed (Ghosh *et al.*, 2007).

On the another hand, horticulture has become problematic as the drainage effluent contains drained nutrients, salts and residues of agro-chemicals and affects the health of reservoirs, rivers and inland seas into which it is discharged (Fanish and Priya, 2013). In response agroforestry is being viewed as a restoration agent, rehabilitation process, bioremediation (Asati *et al.*, 2007), ameliorate soil health (Dhewa and Daniel, 2017), and the biodrainage plantations purify our environment by absorbing greenhouse gases (Fanish and Priya, 2013). So, agroforestry systems are a biodiversity-friendly alternative to food and wood production (Oliveira *et al.*, 2019).

Finally, alley cropping system is one of the most common agroforestry practices around the world (Wolz and DeLucia, 2018). The vegetables provide regular income to the farmers during the early stages of tree establishment (Kaushik *et al.*, 2017), and is an economically feasible way to protect crop plants from extremes in microclimate and soil moisture and should be considered a potential adaptive strategy for farmers in areas that may suffer from extremes in climate (Lin, 2007). The main objective of this paper is selection of tree and vegetable combination for success in new horticulture based alley cropping plantations.

Legumes tree

The advantages of legume tree in vegetable production based agroforestry systems include: nitrogen fixation, insect pest reduction, disease prevention (Blair *et al.*, 2016; Majumdar, 2011), increase water infiltration (Chaturvedi *et al.*, 2018), promote soil health, increase nutrient availability, reduce fertilizer requirement, and soil erosion control (Palada *et al.*, 1992) and others. The production rate and nutrient concentrations determine

the type of legume tree, mainly used for “fallow system”, and the amount of nutrients provided by pruning, both depending on climate, soil type, tree species, plant part, tree density and tree pruning regime (Palm, 1995), the asynchrony of nutrient release (mulch application) from alley cropping pruning's and nutrient demand from the crops is often the leading cause for low crop N use efficiency and yield (Seiter and Horwath, 1999). Leguminous trees are used and scientifically validated for use in this type of plantations.

***Leucaena leucocephala*:** *Leucaena leucocephala* is native to Central America (Nehdi *et al.*, 2014) with diversified uses such as cattle and human food, firewood, timber, shade, green manure, soil erosion control, soil health enrichment, windbreaks, fire break, etc. (Harun-Ur *et al.*, 2018). Tree requires warm temperatures for optimal growth, and is drought-tolerant (4m x 0.5m usually recommended), the tree can repeat harvest of the foliage (7-10 month after establishment) up to 10 times a year (Honda *et al.*, 2019). Usually, application of pruning resulted in higher soil moisture retention, organic matter, exchangeable K, Ca, Mg, and also nitrate levels in the soil solution (Kang *et al.*, 1985). This tree is mostly used in horticulture based alley cropping. *Vigna* sp., *Manihot esculenta*, and *Ipomoea batatas* are some annual vegetables cultivated in *Leucaena* alley cropping.

Palada *et al.* (1992) concluded that prunings provide significant amounts of N, P, K and Ca, and four vegetables in alley cropping can reduce fertilizer requirement. Insaioo and Quarshie (2007) concluded that with adequate water, the half-rate fertilizer can be efficient particularly when combined with prunings, so that this system could reduce fertilizer requirement for *Solanum melongena*, with no significant change of pH, K and Mg levels in the soil. Moderate nitrogen fertilisation produced higher total growth parameters of *Pisum sativum* in *Leucaena* alley cropping (Zaki *et al.*, 2017). *Abelmoschus esculentus* cultivars were higher yielding in the alley than the non-alley field. *L. leucocephala* planted as alley crops have the potential to suppress nematode populations (Adekunle, 2009). Table 1 shows other vegetable crops and fruit tree in *L. leucocephala* alley cropping.

***Cajanus cajan*:** *Cajanus cajan* is a multipurpose tree (Zu *et al.*, 2006). It is an important food legume crop in the semi-arid regions of the world (Varshney *et al.*, 2010). It grows well in the P-deficient soils of the tropical environment (Fujita *et al.*, 2004), and combines high tolerance to environmental stresses, and provides high biomass productivity (Odeny, 2007). Additionally the tree improves soil fertility, is a source of fodder and firewood, and its use in mulching has provided an alternative to inorganic fertilizers and provides the much needed organic material to maintain soil productivity (Abugre and Twum, 2011). *Manihot esculenta*, *Ipomoea batatas*, and *Vigna* spp. are annual vegetables cultivated in *C. cajan* alley cropping.

Alves *et al.* (2004) concluded that biomass incorporation in *Beta vulgaris* and *Daucus carota* crops resulted in high positive N-balance, and uptake of P increased significantly. In *Solanum lycopersicum* highest yield (9.35 tons/ha) was obtained at the highest rate of mulch/fertilizer interaction (15 tons/ha and 150 kg N/ha), and mulch reduced the dependence on inorganic fertilizers (Abugre and Twum, 2011). Table 1 shows other vegetable crops and fruit tree in *Cajanus cajan* alley cropping and another legume tree.

***Gliricidia sepium*:** *Gliricidia sepium* is a medium-size tree, native to tropical zone of Central America (Montero *et al.*, 2017), and is integrated into farming practices for poles, firewood, hedges, forage, green manure and soil stabilization. The pruning interval of 6-12 weeks is usually recommended (Suttie, 2015), and leaves release maximum nitrogen within 15 days (Kumar *et al.*, 2016). The tree grows best in tropical, seasonally dry climates (4-6m x 0.5 m usually recommended spacing) (Adekunle, 2009). It is widely used to provide crop shade for coffee, cacao and other shade-loving crops (Marak and Wani, 2018). *Manihot esculenta*, *Vigna* spp., and *Brassica oleracea* are some annual vegetables cultivated in *Gliricidia* alley cropping.

Kuntashula *et al.* (2004) concluded the highest cabbage and onion yields were obtained from manure + half-rate fertilizer application. Olanatan (2000) concluded that pruning applied (mulch) at the rate of 30 kg ha⁻¹ was more economical in *Abelmoschus esculentus* and *Solanum lycopersicum* yield than application of 60 kg ha⁻¹. Paulino *et al.* (2011) concluded that the quantity of N added to the orchard with *Gliricidia* pruning was higher than the recommended fertilization for soursop tree plots. Table 1 shows other vegetable crops and fruit tree in *Gliricidia* alley cropping.

Wood tree

Vegetable-based alley cropping synergistically fulfil the demand of vegetable crops and timber to human and industry (Bhusara *et al.*, 2018). Many farmers are inclined to intercrop young timber trees with well-fertilized annuals to confer nutrient and weeding benefits to the trees while gaining short-term returns on the land (Nissen *et al.*, 2001). Usually the rows are planted in a North-south orientation (Newman *et al.*, 1997), to derive optimal benefits from intercropping timber. Farmers should make important initial decisions on selecting tree species and planting density with a good understanding of their tradeoffs (Nissen and Midmore, 2002).

***Tectona grandis*:** Teak (*Tectona grandis*) is a species of tropical regions and is native to India, and can grow under a wide range of climatic and edaphic conditions (Singh *et al.*, 2017). It is one of the most valuable tropical hardwood species in the international timber market (Deb *et al.*, 2017). Teak alley cropping involves high-value crops, for example, banana, pineapple, fruit trees, coffee, etc. (Pachas *et al.*, 2019). Intercropping distance of 3m x 2m is recommended (Patel *et al.*, 2018). *Capsicum* spp., *Solanum tuberosum*, and *Solanum melongena* are some annual vegetables cultivated in *T. grandis* alley cropping. *S. melongena* L. exhibited increase in various growth as well as yield parameters under teak system as compared to monocrop, number of fruits per plant, fruit circumference, fruit length, average fruit weight and yield (Sondarva *et al.*, 2018). Similarly various cucurbitaceous crops under teak can provide additional income to the teak farmers (Patel *et al.*, 2018). Table 2 shows another vegetable crops and fruit tree in *Tectona grandis* alley cropping.

***Hevea brasiliensis*:** *Hevea brasiliensis* is a tree belonging to the *Euphorbiaceae* family, indigenous to the tropical forests of the Amazon basin (Wadeesirisak *et al.*, 2017), and is the worldwide primary commercial source of natural rubber (Zhang *et al.*, 2019). It is susceptible to low temperatures (Chen *et al.*, 2019). The

Table 1. Legume tree + annual vegetable and fruit tree

Legume tree	Annual vegetable and fruit tree	Reference
<i>Leucaena leucocephala</i> <i>Leucaena</i> spp.	(1) <i>Vigna</i> sp., (2) <i>Manihot esculenta</i> , (3) <i>Ananas comosus</i> , (4) <i>Dioscorea</i> spp., (5) <i>Solanum melongena</i> , (6) <i>Solanum tuberosum</i> , (7) <i>Coriandum sativum</i> , (8) <i>Solanum lycopersicum</i> , (9) <i>Capsicum annuum</i> , (10) <i>Brassica oleracea</i> , (11) <i>Curcuma longa</i> , (12) <i>Abelmoschus esculentus</i> , (13) <i>Pisum sativum</i> , (14) <i>Ipomoea batatas</i> , (15) <i>Allium cepa</i> , (16) <i>Cucurbita</i> sp., (17) <i>Tagetes minuta</i> , (18) <i>Ocimum basilicum</i> , (19) vegetables.	(1) (Akinnifesi <i>et al.</i> , 1998; Atta-Krah, 1990; Chaturvedi <i>et al.</i> , 2001; Duguma <i>et al.</i> , 1988; Ghosh <i>et al.</i> , 2007; Hulugalle and Kang, 1990; Jha and Chaturdevi, 1995; Kang <i>et al.</i> , 1985; Lal, 1989; Lawson and Kang, 1990; Mittal and Singh, 1989; Ngambeki, 1985; Paningbatan, 1986; Schroth, 1995; Singh and Van den Beldt, 1989; Ssekabembe, 1985; Vanlauwe <i>et al.</i> , 1998; Vinaya and Suresh, 1988), (2) (Atayese <i>et al.</i> , 1993; Barreto and Fernandes, 2001; Bayard <i>et al.</i> , 2007; Dhakar <i>et al.</i> , 2013; Ernst, 1994; Fagbola <i>et al.</i> , 1998; Hy <i>et al.</i> , 2002; Leihner <i>et al.</i> , 1996; Liasu <i>et al.</i> , 2006; Moura <i>et al.</i> , 2017; Osonubi <i>et al.</i> , 1995; Oyetunji and Osonubi, 2007; Oyetunji <i>et al.</i> , 2003; Schroth, 1995; Singh, 1987; Tonye, 1989; Tonye <i>et al.</i> , 1994), (3) (Adinya <i>et al.</i> , 2010; Asati <i>et al.</i> , 2007; Firoz <i>et al.</i> , 2012; Gogoi, 2015), (4) (Budelman, 1990; Dhakar <i>et al.</i> , 2013; Schroth, 1995), (5) (Insaideo and Quarshie, 2007), (6) (Brook, 1992; Yamoah <i>et al.</i> , 1989), (7) (Schroth <i>et al.</i> , 2000), (8) (Palada <i>et al.</i> , 1992), (9) (Soreng and Kerketta, 2017), (10) (Mappaona <i>et al.</i> , 1994), (11) (Adekunle, 2009; Narain <i>et al.</i> , 1997), (12) (Palada <i>et al.</i> , 1992), (13) (Zaki <i>et al.</i> , 2016), (14) (Balasubramanian and Sekayange, 1991), (15) (Kuntashula <i>et al.</i> , 2004), (16) (Sampaio <i>et al.</i> , 2015), (17) (Thakur <i>et al.</i> , 2005), (18) (Verma <i>et al.</i> , 2017), (19) (Upadhyay and Yadava, 2009).
<i>Cajanus cajan</i>	(1) <i>Theobroma grandiflorum</i> and <i>T. cacao</i> , (2) <i>Musa</i> spp., (3) <i>Citrus aurantium</i> , (4) <i>Citrus reticulata</i> , (5) <i>Coffea</i> spp., (6) <i>Cocos nucifera</i> , (7) <i>Citrus aurantifolia</i> , (8) <i>Carica papaya</i> , (9) fruit tree.	(1) (Oelbermann <i>et al.</i> , 2004; Sampaio <i>et al.</i> , 2015; Schroth <i>et al.</i> , 2000; Singh, 1987), (2) (Schroth and Sinclair, 2003; Singh, 1987; Wilson and Swennen, 1989), (3) (Abd-allah <i>et al.</i> , 1999), (4) (Abd-allah <i>et al.</i> , 1999), (5) (Schroth <i>et al.</i> , 2000), (6) (Schroth and Sinclair, 2003), (7) (Dyal <i>et al.</i> , 1996), (8) (Hymavathi <i>et al.</i> , 2010), (9) (Hymavathi <i>et al.</i> , 2010).
<i>Gliricidia sepium</i> <i>G. maculata</i>	(1) <i>Manihot esculenta</i> , (2) <i>Ipomoea batatas</i> , (3) <i>Vigna</i> spp., (4) <i>Dacus carota</i> , (5) <i>Ananas comosus</i> , (6) <i>Capsicum annuum</i> , (7) <i>Beta vulgaris</i> , (8) <i>Phaseolus</i> spp., (9) <i>Dioscorea</i> spp., (10) <i>Solanum lycopersicum</i> .	(1) (Akondé <i>et al.</i> , 1997; Atayese <i>et al.</i> , 1993; Ernst, 1994; Leihner <i>et al.</i> , 1996; Lose <i>et al.</i> , 2003; Murray and Bannister, 2004; Salami <i>et al.</i> , 2005), (2) (Brook, 1992; Isaac <i>et al.</i> , 2003; Kang, 1993; Murray and Bannister, 2004; Nedunchezhiyan <i>et al.</i> , 2012), (3) (Blair <i>et al.</i> , 2016; Kang, 1993; Kang <i>et al.</i> , 1985; Singh, 2016), (4) (Alves <i>et al.</i> , 2004; Isaac <i>et al.</i> , 2003), (5) (Firoz <i>et al.</i> , 2012; Murray and Bannister, 2004), (6) (Palada <i>et al.</i> , 1992), (7) (Alves <i>et al.</i> , 2004), (8) (Alves <i>et al.</i> , 2004; Isaac <i>et al.</i> , 2003), (9) (Murray and Bannister, 2004), (10) (Abugre and Twum, 2011).
	(1) <i>Prunus</i> sp., (2) <i>Mussa</i> sp., (3) <i>Citrifolia sinensis</i> , (4) <i>Santalum yasi</i> , (5) <i>Carica papaya</i> , (6) <i>Psidium guajava</i> , (7) <i>Annona squamosa</i> , (8) <i>Acharus sapota</i> , (9) <i>Tamarindus indica</i> .	(1) (Alves <i>et al.</i> , 2004; Murray and Bannister, 2004), (2) (Sangwan <i>et al.</i> , 2015), (3) (Harrison and Harrison, 2016), (4) (Harrison and Harrison, 2016), (5) (Jakhar <i>et al.</i> , 2010), (6) (Pareek and Awasthi, 2008), (7) (Pareek and Awasthi, 2008), (8) (Pareek and Awasthi, 2008), (9) (Pareek and Awasthi, 2008).
	(1) <i>Theobroma cacao</i> , (2) <i>Carica papaya</i> , (3) <i>Musa</i> sp., (4) <i>Mangifera</i> sp., (5) <i>Annona muricata</i> , (6) <i>Cocos nucifera</i>	(1) (Amara <i>et al.</i> , 1996; Barreto and Fernandes, 2001; Böhringer and Leihner, 1996; Evensen <i>et al.</i> , 1995; Ghuman <i>et al.</i> , 1991; Kass <i>et al.</i> , 1992; Lose <i>et al.</i> , 2003; Moura <i>et al.</i> , 2017; Oelbermann <i>et al.</i> , 2004; Okon, 2011; Osonubi <i>et al.</i> , 1995; Kass 1987.; Salami and Osonubi, 2003; Tonye <i>et al.</i> , 1994; Wilson <i>et al.</i> , 1986), (2) (Budelman, 1990; Budelman and Pinners, 1987; Duguma <i>et al.</i> , 1988; Evensen <i>et al.</i> , 1995; Hulugalle and Kang, 1990; Lawson and Kang, 1990; Paningbatan, 1986), (3) (Schroth, 1995), (4) (Kuntashula <i>et al.</i> , 2004; Mafongoya and Jiri, 2016; Ribeiro <i>et al.</i> , 2018), (5) (Adekunle, 2009; Olanatan, 2000; Schroth <i>et al.</i> , 1995), (6) (Iijima <i>et al.</i> , 2003), (7) (Mafongoya and Jiri, 2016; Palada <i>et al.</i> , 1992), (8) (Olanatan, 2000; Wilson <i>et al.</i> , 1986), (9) (Mafongoya and Jiri, 2016), (10) (Brook, 1992), (11) (Upadhyay and Yadava, 2009).
<i>Acacia auriculiformis</i> <i>A. lenticularis</i> , <i>A. stenophylla</i> , <i>A. tortilis</i> , <i>A. indica</i>	(1) <i>Capsicum annuum</i> , (2) <i>Ipomoea batatas</i> , (3) <i>Vigna radiata</i> , (4) <i>Manihot esculenta</i> , (5) <i>Pisum sativum</i> , (6) <i>Vicia faba</i> , (7) <i>Dacus carota</i> , (8) <i>Solanum tuberosum</i> , (9) <i>Cicer arietinum</i> , (10) <i>Allium sativum</i> , (11) <i>Pachyrhizus erosus</i> , (12) <i>Solanum lycopersicum</i> , (13) <i>Cucumis sativum</i> , (14) <i>Raphanus raphanistrum</i> , (15) <i>Ananas comosus</i> .	(1) (Chaturvedi <i>et al.</i> , 2001; Shapo and Adam, 2008), (2) (Brook, 1992; Chaturvedi <i>et al.</i> , 2001), (3) (Chaturvedi <i>et al.</i> , 2001), (4) (Chaturvedi <i>et al.</i> , 2001), (5) (Schroth <i>et al.</i> , 2000), (6) (Shapo and Adam, 2008), (7) (Shapo and Adam, 2008), (8) (Chaturvedi <i>et al.</i> , 2001), (9) (Hymavathi <i>et al.</i> , 2010), (10) (Chaturvedi <i>et al.</i> , 2001), (11) (Chaturvedi <i>et al.</i> , 2001), (12) (Hanada, 1990), (13) (Hanada, 1990), (14) (Hanada, 1990), (15) (Bhatt <i>et al.</i> , 2006).
	(1) <i>Mangifera indica</i> .	(1) (Escaño and Tababa, 1998).
<i>Prosopis cineraria</i>	(1) <i>Vigna aconitifolius</i> , (2) <i>Cyamopsis tetragonoloba</i> , (3) <i>Brassica tourneforti</i> , (4) <i>Euruca sativa</i> , (5) <i>Capsicum</i> sp.	(1) (Dhakar <i>et al.</i> , 2013; Handa and Newaj, 2017; Kaushik <i>et al.</i> , 2003; Singh, 2009), (2) (Dhakar <i>et al.</i> , 2013; Kaushik <i>et al.</i> , 2003), (3) (Kaushik <i>et al.</i> , 2003), (4) (Kaushik <i>et al.</i> , 2003), (5) (Ranashinghe and Newman, 1993).
	(1) <i>Psidium guajava</i> , (2) <i>Zizyphus mauritiana</i> .	(1) (Dalal <i>et al.</i> , 2015; Nedunchezhiyan <i>et al.</i> , 2012), (2) (Singh and Singh, 2015).

Table 2. Wood tree + annual vegetable and fruit tree

Wood tree	Annual vegetable and fruit tree	Reference
<i>Tectona grandis</i>	(1) <i>Capsicum</i> spp., (2) <i>Solanum tuberosum</i> , (3) <i>Solanum melongena</i> , (4) <i>Vigna</i> spp. (5) <i>Ocimum</i> spp., (6) <i>Manihot esculenta</i> , (7) <i>Curcuma longa</i> , (8) <i>Piper nigrum</i> , (9) <i>Ananas comosus</i> , (10) <i>Abelmoschus esculentus</i> , (11) <i>Cicer arietinum</i> , (12) <i>Cucumis sativus</i> , (13) vegetables. (1) <i>Mangifera indica</i> , (2) <i>Carica papaya</i> , (3) <i>Cocos nucifera</i> , (4) <i>Theobroma cacao</i> , (5) <i>Psidium guajava</i> , (6) <i>Pyrus pyrifolia</i> (7) <i>Musa</i> sp., (8) fruit trees.	(1) (Handa and Newaj, 2017; Weersum, 1982), (2) (Singh, 1987; Weersum, 1982), (3) (Bhoyar <i>et al.</i> , 2016; Bhusara, 2014; Gunaga, 2017), (4) (Bhoyar <i>et al.</i> , 2016; Chaturvedi <i>et al.</i> , 2001), (5) (Kumar <i>et al.</i> , 2017, 2015), (6) (Weersum, 1982), (7) (Singh, 1987), (8) (Singh, 1987), (9) (Dhewa and Daniel, 2017; Singh, 1987), (10) (Gunaga, 2017), (11) (Bhoyar <i>et al.</i> , 2016), (12) (Patel <i>et al.</i> , 2018), (13) (Hymavathi <i>et al.</i> , 2010). (1) (Gunaga, 2017; Sureshbhai <i>et al.</i> , 2017; Toppo <i>et al.</i> , 2016), (2) (Handa and Newaj, 2017; Verma <i>et al.</i> , 2017), (3) (Singh, 1987), (4) (Singh, 1987), (5) (Anand <i>et al.</i> , 2016), (6) (Rani <i>et al.</i> , 2016), (7) (Bhusara, 2014), (8) (Hymavathi <i>et al.</i> , 2010).
<i>Hevea brasiliensis</i>	(1) <i>Ananas comosus</i> , (2) <i>Manihot esculenta</i> , (3) <i>Dioscorea floribunda</i> , (4) <i>Amomum villosum</i> , (5) <i>Passiflora edulis</i> , (6) <i>Piper nigrum</i> . (1) <i>Musa</i> spp., (2) <i>Coffea</i> sp., (3) <i>Carica papaya</i> , (4) <i>Cocos nucifera</i> , (5) <i>Citrus reticulata</i> .	(1) (He <i>et al.</i> , 2012; Kumar <i>et al.</i> , 2012; Malézieux <i>et al.</i> , 2009; Rajasekharan and Veeraputhran, 2002), (2) (Rajasekharan and Veeraputhran, 2002), (3) (Rao <i>et al.</i> , 2004), (4) (Rao <i>et al.</i> , 2004), (5) (Newman, 1985), (6) (Newman, 1985). (1) (Newman, 1985; Rajasekharan and Veeraputhran, 2002; Ranashinghe and Newman, 1993; Rani <i>et al.</i> , 2016), (2) (Newman, 1985; Ranashinghe and Newman, 1993), (3) (Newman, 1985; Ranashinghe and Newman, 1993), (4) (Kumar <i>et al.</i> , 2012; Newman, 1985), (5) (Khaunkub <i>et al.</i> , 2008).
<i>Poplar</i> spp.	(1) <i>Brassica juncea</i> , (2) <i>Solanum tuberosum</i> , (3) <i>Allium cepa</i> , (4) <i>Capsicum</i> sp., (5) <i>Solanum melongena</i> , (6) <i>Solanum lycopersicum</i> , (7) <i>Zea mays</i> (sweet corn), (8) vegetables (1) <i>Prunus</i> spp., (2) <i>Psidium guajava</i> , (3) <i>Mangifera indica</i> , (4) <i>Citrus</i> spp., (5) <i>Pyrus communis</i> .	(1) (Ghimire, 2010), (2) (Devender <i>et al.</i> , 2012), (3) (Yadav, 2006), (4) (Yadav, 2006), (5) (Yadav, 2006), (6) (Yadav, 2006), (7) (Bhushan and Khare, 2018), (8) (Jose <i>et al.</i> , 2008). (1) (Dhillon <i>et al.</i> , 2012, 2010; Sangwan <i>et al.</i> , 2015), (2) (Dhillon <i>et al.</i> , 2012, 2010; Sangwan <i>et al.</i> , 2015), (3) (Handa and Newaj, 2017; Verma <i>et al.</i> , 2017), (4) (Dhillon <i>et al.</i> , 2012, 2010; Sangwan <i>et al.</i> , 2015; Verma <i>et al.</i> , 2017), (5) (Dhillon <i>et al.</i> , 2012).
<i>Eucalyptus</i>	(1) <i>Manihot esculenta</i> , (2) <i>Vigna</i> spp., (3) <i>Capsicum</i> sp., (4) <i>Brassica oleracea</i> , <i>B. chinensis</i> (5) <i>Coriandrum sativum</i> , (6) <i>Solanum melongena</i> , (7) <i>Cicer arietinum</i> , (8) <i>Solanum tuberosum</i> , (9) <i>Solanum lycopersicum</i> , (10) vegetables. (1) <i>Mangifera indica</i> , (2) <i>Theobroma cacao</i> , (3) <i>Litchi chinensis</i> , (4) <i>Pouteria sapota</i> , (5) <i>Citrus lemon</i> , (6) <i>Pyrus pyrifolia</i>	(1) (Dhyani <i>et al.</i> , 2013; Singh, 1989), (2) (Asati <i>et al.</i> , 2007; Nissen and Midmore, 2002), (3) (Schroth, 1995), (4) (Vinaya and Suresh, 1988), (5) (Sureshbhai <i>et al.</i> , 2017), (6) (Sureshbhai <i>et al.</i> , 2017), (7) (Asati <i>et al.</i> , 2007), (8) (Asati <i>et al.</i> , 2007), (9) (Asati <i>et al.</i> , 2007), (10) (Upadhyay and Yadava, 2009). (1) (Verma <i>et al.</i> , 2017), (2) (Handa and Newaj, 2017; Lakaria <i>et al.</i> , 2012; Verma <i>et al.</i> , 2017), (3) (Upadhyay and Yadava, 2009), (4) (Sureshbhai <i>et al.</i> , 2017), (5) (Sureshbhai <i>et al.</i> , 2017), (6) (Rani <i>et al.</i> , 2016).
<i>Populus tomentosa</i> , <i>P. euramericana</i> , <i>P. deltoides</i> , <i>P. nigra</i>	(1) <i>Brassica alba</i> , <i>B. nigra</i> , <i>B. oleracea</i> , (2) <i>Citrullus lanatus</i> (3) <i>Cicer arietinum</i> , (4) <i>Cucurbita pepo</i> , (5) <i>Dacus carota</i> , (6) <i>Vicia faba</i> , (7) <i>Pisum sativum</i> , (8) <i>Vigna</i> sp., (9) <i>Solanum tuberosum</i> , (10) <i>Solanum lycopersicum</i> , (11) <i>Capsicum</i> sp. (1) <i>Coffea</i> spp., (2) <i>Malus</i> spp., (3) <i>Pyrus pyrifolia</i>	(1) (Asati <i>et al.</i> , 2007; Burgess <i>et al.</i> , 2005; Sangwan, 2014; Singh, 1989), (2) (Jiang and Qin, 2007; Tolunay <i>et al.</i> , 2007), (3) (Asati <i>et al.</i> , 2007; Tolunay <i>et al.</i> , 2007), (4) (Akbulut <i>et al.</i> , 2003), (5) (Tolunay <i>et al.</i> , 2007), (6) (Burgess <i>et al.</i> , 2005), (7) (Burgess <i>et al.</i> , 2005), (8) (Chauhan <i>et al.</i> , 2013), (9) (Asati <i>et al.</i> , 2007; Chaturvedi <i>et al.</i> , 2001), (10) (Asati <i>et al.</i> , 2007), (11) (Asati <i>et al.</i> , 2007). (1) (Kumar <i>et al.</i> , 2012), (2) (Dhakar <i>et al.</i> , 2013; Kumar <i>et al.</i> , 2012), (3) (Rani <i>et al.</i> , 2016).
<i>Grewia optiva</i>	(1) <i>Withania somnifera</i> , (2) <i>Cicer arietinum</i> , (3) <i>Solanum tuberosum</i> , (4) <i>Brassica oleracea</i> , (5) <i>Solanum lycopersicum</i> , (6) <i>Capsicum</i> sp. (1) <i>Prunus</i> spp., (2) <i>Coffea</i> sp., (3) <i>Malus domestica</i> , (4) <i>Mangifera indica</i>	(1) (Verma and Thakur, 2010), (2) (Asati <i>et al.</i> , 2007), (3) (Asati <i>et al.</i> , 2007), (4) (Asati <i>et al.</i> , 2007), (5) (Asati <i>et al.</i> , 2007), (6) (Asati <i>et al.</i> , 2007). (1) (Bijalwan, 2012; Verma and Thakur, 2010), (2) (Dhyani <i>et al.</i> , 2013) (3) (Bijalwan, 2012), (4) (Verma and Thakur, 2010).
<i>Bambusa</i> spp.	(1) <i>Vigna unguiculata</i> , <i>Vigna umbellata</i> , (2) <i>Cucumis sativus</i> , (3) <i>Lablab purpureus</i> , (4) <i>Solanum nigrum</i> , (5) <i>Ocimum basilicum</i> , (6) <i>Momordica charantia</i> , (7) <i>Capsicum frutescens</i> , (8) <i>Manihot esculenta</i> (1) <i>Psidium guajava</i> , (2) <i>Mangifera indica</i>	(1) (Behera <i>et al.</i> , 2016), (2) (Christanty <i>et al.</i> , 1997), (3) (Christanty <i>et al.</i> , 1997), (4) (Christanty <i>et al.</i> , 1997), (5) (Christanty <i>et al.</i> , 1997), (6) (Christanty <i>et al.</i> , 1997), (7) (Christanty <i>et al.</i> , 1997), (8) (Christanty <i>et al.</i> , 1997). (1) (Hymavathi <i>et al.</i> , 2010), (2) (Christanty <i>et al.</i> , 1997).
<i>Alnus japonicum</i> <i>A. nepalensis</i> <i>A. rubra</i>	(1) <i>Zea mays</i> , (2) <i>Amomum subulatum</i> (3) <i>Vigna radiata</i> , (4) <i>Solanum tuberosum</i> , (5) <i>Capsicum</i> sp. (6) <i>Colocasia</i> spp., (7) <i>Ananas comosus</i> , (8) <i>Phaseolus multiflorus</i>	(1) (Seiter and Horwath, 1999; Stelen, 1997), (2) (Ranashinghe and Newman, 1993; Singh, 1989), (3) (Panigbatan, 1986), (4) (Handa and Newaj, 2017), (5) (Handa and Newaj, 2017), (6) (Handa and Newaj, 2017), (7) (Chauhan <i>et al.</i> , 1993), (8) (Dhakar <i>et al.</i> , 2013).

intercropping system generally adopted in rubber cultivation in India (6.7 x 3.4 m) allows intercropping with a variety of crops during the initial three years. Integration of other crops with rubber is not commonly practiced in older plantations due to the

limited light availability and concerns of unfavourable effect on the performance of rubber (Jessy *et al.*, 2017). *Ananas comosus*, *Manihot esculenta*, and *Piper nigrum* are some annual vegetables cultivated in *H. brasiliensis* alley cropping.

Glomus deserticola significantly increased *M. esculenta* biomass accumulation and nutrient yield of alley crop. Root tuber nutrient yield for nitrogen, potassium and phosphorus was significantly increased by *G. deserticola* inoculation (Okon, 2011). The results showed that, under this pattern, the pineapple was able to grow and develop normally, and the fruit quality of Tainong NO. 16 pineapple slightly declined, without a significant difference. On the other hand, there was not any negative effect on the rubber's growth and development (He *et al.*, 2012). Table 2 shows other vegetable crops and fruit tree in *H. brasiliensis* alley cropping.

***Populus deltoides*:** Poplar (*Populus deltoides*) is a fast-growing, deciduous, and tall tree (Thakur *et al.*, 2012), and is rated among the most promising species for the energy generation because of its minimum fertilizer requirement and its ability to grow on unfertile marginal lands (Rawat *et al.*, 2013). It is highly suitable for horti-agroforestry system (Devender *et al.*, 2012), by permitting enough sunlight for cultivation of horticultural crops, and intercropping results in increased growth rate of poplar due to frequent irrigation. Chauhan *et al.* (2013) concluded that *Curcuma longa* and *Vigna radiata* initially showed better performance in yield and yield contributing parameters under partial shade, and decreased as poplar canopy advanced with the age of tree.

Akbulut *et al.* (2003) concluded that *Cucurbita pepo* in *Populus euramericana* alley cropping might contribute to increasing beneficial arthropod diversity compared with monocrops. Dhillon *et al.* (2012) concluded that growth increment of poplar was significantly higher when planted with fruit crops (*Psidium guajava*, *Citrus reticulata*, *Pyrus communis*, *Prunus persica*, *Prunus americana*) as compared to sole poplar planting. Table 2 shows other vegetable crops and fruit tree in *Populus deltoides* alley cropping, and other wood trees.

Fruit trees

The production of horticultural trees as intercrops was found to be more effective for improvement in soil fertility and productivity (Verma *et al.*, 2017). Fruit trees have a long gestation period (4-5 years) to provide income; so the interspaces can be used for cultivation of crops profitably till the main crop develop canopy (Gunaga, 2017). One of the main motivations for farmers to simultaneously grow a variety of vegetables and fruits is to reduce the overall risk on production through a diversification effect (Paut *et al.*, 2018), and helps in strengthening the farmers economy (Gupta and Arora, 2015). The outcomes of various intercropping practices confirm that vegetable crops are economically and ecologically most suitable and viable intercrops for fruit plantation at early phase of growth, however, there is need of synchronization of cultural practices adapted for intercrops with the requirements of fruit trees (Singh *et al.*, 2018).

***Mangifera indica*:** Mango (*Mangifera indica* L.) belongs to *Anacardaceae* family (Lieb *et al.*, 2019), and the tree takes 10-12 years to grow and attain its full production potential (Kumar *et al.*, 2008). It can be intercropped with vegetable crops (Musvoto and Campbell, 1995) to efficiently utilize resources such as water, and light (Swain *et al.*, 2012). Intercropping, besides providing income to the grower, suppresses weed growth, improves soil fertility and prevents leaching of nutrients and erosion of soil, achieves higher gross return per unit area (Kumari *et al.*, 2016). The light intensity below the mango trees decreased with the

increasing tree age, the decrease was more pronounced at a distance of 3 m from the trunk, 5 x 5 m (Ali *et al.*, 2018) to 10 x 10 m (Swain, 2014) recommended spacing. The changing light profile within the orchard due to the growing plant canopy influence the choice of intercrop to be grown at different ages (Das *et al.*, 2017).

For mango, selective intercrops have been recommended for adoption up to 8-10 years (Negi, 2000), or up to 15 years of age of mango plantation (Swain, 2014). *Solanum melongena* L. is a common intercrop (Singh *et al.*, 2011). On the other hand, leguminous intercrops were used for improved availability of soil nutrients caused by nitrogen fixation, reduction in soil and nutrients erosion, and incorporation and decomposition of intercrop residues in soil of the orchard (Pradhan *et al.*, 2018). Table 3 shows vegetables crops and fruit tree in *Mangifera indica* alley cropping.

***Psidium guajava*:** Guava (*Psidium guajava*), an important fruit in tropical regions (Etemadipoor *et al.*, 2019), belongs to the family *Myrtaceae*. It grows on different soils and in both humid and dry climates (Hiwale, 2015), and is a small tree (Hoseinifar *et al.*, 2019). The inter-row space in guava orchards is underutilized in the early growing period, may be used for growing intercrops (Singh *et al.*, 2016). Intercropping with vegetables can fetch better returns besides generating more employment (Mitra, 2005). The plant starts bearing 3 years after planting and reach their maximum bearing capacity within 6-7 years after planting (5 x 5 planting recommended) (Bhatt *et al.*, 2016).

Selection of suitable intercrops in the guava orchard to improve the soil fertility status mainly depends upon the agro-climatic condition of the area where the crop is grown (Swain, 2016). Guava plants have responded well to especially tuber crops (Singh *et al.*, 2016). Table 3 shows other vegetables crops and fruit tree in *Psidium guajava* alley cropping.

***Citrus spp.*:** *Citrus* is a large genus that includes several major cultivated species, including *Citrus sinensis* (sweet orange), *C. reticulata* (tangerine and mandarin), *C. limon* (lemon), *C. grandis* (pummelo) and *C. paradisi* (grapefruit) (Xu *et al.*, 2013). The intercropping of perennial lemon with vegetables has enhanced the profitability in the irrigated areas (Dubey *et al.*, 2016), intercropping of legumes in citrus orchards is beneficial for the citrus production. Intercrop improves fruit production of the orchard as compared to non-intercropped orchard (Gill *et al.*, 2018). As intercrop, citrus (4 x 4 recommended spacing) (Vijaykumar *et al.*, 2018) provides income to the growers, controls weed population, checks soil erosion, conserves soil moisture and organic matter and protects the soil from leaching of nutrients (Hnamte *et al.*, 2013).

Leguminous crops and ginger is beneficial in terms of economic returns (Lachungpa, 2004); other authors recommended *Cucumis melo*, and *Brassica oleracea* (Dubey *et al.*, 2016), *Capsicum* spp., *Curcuma longa*, *Ocimum basilicum*, *Vigna unguiculata*, *Abelmoschus esculentus* and *Cucumis melo*, to be compatible with citrus intercrop (Aiyelaagbe, 2001). Table 3 shows other vegetables crops and fruit tree in *Citrus* alley cropping.

Further studies: Agroforestry seems to be a viable and

Table 3. Fruit tree and annual vegetable

Fruit tree	Annual vegetable	Reference
<i>Citrus</i> sp., <i>C. sinensis</i> , <i>C. reticulata</i>	(1) Legumes crops, (2) <i>Cicer arietinum</i> , (3) <i>Coriandrum sativum</i> , (4) <i>Capsicum annum</i> , (5) <i>Fagopyrum esculentum</i> , (6) vegetables, (7) <i>Zingiber officinale</i> , (8) <i>Colocasia esculenta</i> , (9) <i>Manihot esculentam</i> , (10) <i>Solanum lycopersicum</i> , (11) <i>Solanum tuberosum</i> .	(1) (Blair <i>et al.</i> , 2016; Workman <i>et al.</i> , 2003), (2) (Goswami <i>et al.</i> , 2014a; Hnamte <i>et al.</i> , 2013; Jose <i>et al.</i> , 2008), (3) (Sureshbhai <i>et al.</i> , 2017), (4) (Bhatt and Misra, 2003; Bhoyar <i>et al.</i> , 2016; Goswami <i>et al.</i> , 2014a), (5) (Gogoi, 2015), (6) (García <i>et al.</i> , 2018; Jalón <i>et al.</i> , 2018; Verma <i>et al.</i> , 2017; Workman <i>et al.</i> , 2003), (7) (Tabin <i>et al.</i> , 2015), (8) (Goswami <i>et al.</i> , 2014b; Hnamte <i>et al.</i> , 2013), (9) (Goswami <i>et al.</i> , 2014a; Hnamte <i>et al.</i> , 2013), (10) (Goswami <i>et al.</i> , 2014a; Hnamte <i>et al.</i> , 2013), (11) (Goswami <i>et al.</i> , 2014a).
<i>Mangifera indica</i>	(1) <i>Capsicum annum</i> , (3) <i>Manihot esculenta</i> , (4) <i>Vitis</i> spp., (5) <i>Coriandrum sativum</i> , (6) <i>Brassica oleraceae</i> , (7) <i>Ipomea batatas</i> , (8) <i>Chrysopogon fulvus</i> , (9) <i>Heteropogon contortus</i> , (10) <i>Cenchrus</i> spp., (11) <i>Vigna</i> spp.,	(1) (Bhoyar <i>et al.</i> , 2016; Bhusara, 2014; Chaturvedi <i>et al.</i> , 2001), (3) (Harrison and Harrison, 2016), (4) (Kumar <i>et al.</i> , 2012), (5) (Sureshbhai <i>et al.</i> , 2017), (6) (Sureshbhai <i>et al.</i> , 2017), (7) (Chaturvedi <i>et al.</i> , 2001), (8) (Jha and Chaturdevi, 1995), (9) (Jha and Chaturdevi, 1995), (10) (Jha and Chaturdevi, 1995), (11) (Mirjha and Rana, 2016).
<i>Prunus domestica</i> , <i>P. armeniaca</i> , <i>P. persica</i> , <i>P. avium</i>	(1) <i>Pisum sativum</i> , (2) <i>Solanum lycopersicum</i> , (3) <i>Fragaria</i> sp., (4) <i>Zea mays</i> (sweet corn), (5) <i>Cucurbita</i> sp., (6) <i>Capsicum</i> sp., (8) <i>Vitis vinifera</i> , (9) vegetables, (10) <i>Cicer arietinum</i> , (11) <i>Brassica napus</i> , (12) <i>Vigna</i> sp.	(1) (Bhutia <i>et al.</i> , 2015; Jose <i>et al.</i> , 2008; Williams and Gordon, 1992), (2) (Jose <i>et al.</i> , 2008; Williams and Gordon, 1992), (3) (Jose <i>et al.</i> , 2008; Williams and Gordon, 1992), (4) (Blair <i>et al.</i> , 2016), (5) (Williams and Gordon, 1992), (6) (Juárez and Fragoso, 2014), (8) (Nerlich <i>et al.</i> , 2013), (9) (Tolunay <i>et al.</i> , 2007), (10) (Jose <i>et al.</i> , 2008), (11) (Nerlich <i>et al.</i> , 2013), (12) (Shah <i>et al.</i> , 2017).
<i>Artocarpus heterophyllus</i> , <i>A. altalis</i>	(1) <i>Ananas comosus</i> , (2) <i>Manihot esculenta</i> , (3) <i>Ipomoea batatas</i> , (4) Vegetables	(1) (Gogoi, 2015; Harrison and Harrison, 2016; Hasan <i>et al.</i> , 2008), (2) (Harrison and Harrison, 2016), (3) (Chaturvedi <i>et al.</i> , 2001), (4) (Verma <i>et al.</i> , 2017).
<i>Zizyphus mauritiana</i>	(1) <i>Cyamopsis tetragonoloba</i> , (2) <i>Vigna</i> spp., (3) <i>Manihot esculenta</i>	(1) (Korwar and Pratibha, 2005; Meghwal and Henry, 2006; Sharma, 1996, 2014), (2) (Korwar and Pratibha, 2005; Sharma, 1996), (3) (Meghwal and Henry, 2006).
<i>Malus</i> spp.	(1) Legumes crops, (2) <i>Rubus</i> spp., (3) <i>Ribes nidigrolaria</i> , (4) <i>Fragaria</i> sp., (5) (<i>Zea mays</i>), (6) <i>Vigna</i> spp. (7) (Anjulo, 2009), <i>Cicer arietinum</i> , (8) <i>Solanum lycopersicum</i>	(1) (Blair <i>et al.</i> , 2016), (2) (Rivera <i>et al.</i> , 2004), (3) (Rivera <i>et al.</i> , 2004), (4) (Sereke <i>et al.</i> , 2014), (5) (Schroth <i>et al.</i> , 1995; Tolunay <i>et al.</i> , 2007), (6) (Verma <i>et al.</i> , 2017), (7) (Anjulo, 2009), (8) (Anjulo, 2009).
<i>Sysigium</i> spp.	(1) <i>Vigna</i> spp., (2) <i>Brassica nigra</i>	(1) (Chaturvedi <i>et al.</i> , 2001; Pareek and Awasthi, 2008), (2) (Rizvi <i>et al.</i> , 2011).
<i>Psidium guajava</i>	(1) <i>Vigna</i> spp., (2) <i>Capsicum</i> sp., (3) <i>Cyamopsis tetragonoloba</i> , (4) <i>Piper nigrum</i> , (5) <i>Vigna</i> spp., (6) <i>Curcuma longa</i> , (7) vegetables	(1) (Das <i>et al.</i> , 1993; Dhakar <i>et al.</i> , 2013; Krishnan, 2016; Sharma <i>et al.</i> , 2017; Yadav, 2017), (2) (Bhoyar <i>et al.</i> , 2016; Verma <i>et al.</i> , 2017), (3) (Meena, 2015), (4) (Gogoi, 2015), (5) (Pareek and Awasthi, 2008; Sharma, 2011), (6) (Bhatt <i>et al.</i> , 2006; Hembram, 2014; Jain and Sharma, 2011), (7) (Verma <i>et al.</i> , 2017)
<i>Musa</i> sp.	(1) <i>Ipomoea batatas</i> , (2) <i>Manihot esculenta</i> , (3) <i>Vigna</i> sp., <i>Vigna radiata</i> , (4) <i>Colocasia esculenta</i> (5) <i>Zingiber officinale</i> , (6) <i>Curcuma longa</i> , (7) <i>Dolichos lablab</i> , (8) <i>Abelmoschus esculentus</i> , (9) <i>Ananas comosus</i> , (10) <i>Telfairia occidentalis</i> , (11) vegetables	(1) (Balasubramanian and Egli, 1986; Kanmegne and Degrande, 2002; Nedunchezhiyan <i>et al.</i> , 2012), (2) (Balasubramanian and Egli, 1986; Kanmegne and Degrande, 2002), (3) (Aiyelaagbe and Kintomo, 2002; Balasubramanian and Egli, 1986), (4) (Balasubramanian and Egli, 1986), (5) (Rahman <i>et al.</i> , 2012), (6) (Rahman <i>et al.</i> , 2012), (7) (Rahman <i>et al.</i> , 2012), (8) (Rahman <i>et al.</i> , 2012), (9) (Ranashinghe and Newman, 1993), (10) (Aiyelaagbe and Jolaoso, 1992), (11) (Verma <i>et al.</i> , 2017).
<i>Pyrus</i> sp., <i>Pyrus silvestris</i>	(1) <i>Pisum sativum</i> , (2) legumes, (3) <i>Vigna</i> spp., (4) <i>Manihot esculenta</i> , (5) <i>Solanum tuberosum</i> , (6) <i>Colocasia esculenta</i> , (7) <i>Capsicum annum</i> , (8) <i>Zingiber officinale</i> , (9) <i>Solanum lycopersicum</i>	(1) (Jose <i>et al.</i> , 2008; Nerlich <i>et al.</i> , 2013), (2) (Nerlich <i>et al.</i> , 2013), (3) (Goswami <i>et al.</i> , 2014b), (4) (Goswami <i>et al.</i> , 2014b), (6) (Goswami <i>et al.</i> , 2014a), (7) (Goswami <i>et al.</i> , 2014a), (8) (Goswami <i>et al.</i> , 2014a), (9) (Goswami <i>et al.</i> , 2014a).
<i>Morus alba</i>	(1) <i>Cicer arietinum</i> , (2) <i>Solanum tuberosum</i> , (3) <i>Brassica oleracea</i> , (4) <i>Brassica nigra</i> , (5) <i>Solanum lycopersicum</i> , (6) <i>Capsicum</i> sp., (7) <i>Solanum tuberosum</i>	(1) (Asati <i>et al.</i> , 2007), (2) (Asati <i>et al.</i> , 2007), (3) (Asati <i>et al.</i> , 2007), (4) (Asati <i>et al.</i> , 2007), (5) (Asati <i>et al.</i> , 2007), (6) (Asati <i>et al.</i> , 2007), (7) (Benavides, 2002).
<i>Cocos nucifera</i>	(1) <i>Ipomoea batatas</i> , (2) <i>Piper nigrum</i> , (3) tuber crops, (4) <i>Capsicum</i> sp., (5) <i>Maranta arundinacea</i> , (6) <i>Ananas comosus</i> , (7) <i>Manihot esculenta</i>	(1) (Chaturvedi <i>et al.</i> , 2001; Nedunchezhiyan <i>et al.</i> , 2012), (2) (Gogoi, 2015; Kumar <i>et al.</i> , 2012), (3) (Bavappa, 1990a, 1990b) (4) (Bavappa, 1990a), (5) (Bavappa, 1990a), (6) (Peng <i>et al.</i> , 1999), (7) (Kumar, 2006)
<i>Coffea arabica</i> L.	(1) <i>Lycopersicum esculentum</i> , (2) <i>Vigna sesquipedalis</i> , (3) <i>Capsicum</i> sp. (4) <i>Passiflora edulis</i> , (5) <i>Ipomoea batatas</i>	(1) (Iijima <i>et al.</i> , 2003), (2) (Iijima <i>et al.</i> , 2003), (3) (Nuberg and Evans, 1993), (4) (Ranashinghe and Newman, 1993), (5) (Nedunchezhiyan <i>et al.</i> , 2012).
<i>Carica papaya</i>	(1) <i>Abelmoschus esculentus</i> , (2) <i>Citrullus lanatus</i> , (3) <i>Ipomoea batatas</i> , (4) <i>Solanum gilo</i> , (5) <i>Solanum lycopersicum</i>	(1) (Aiyelaagbe and Jolaoso, 1992), (2) (Aiyelaagbe and Jolaoso, 1992), (3) (Aiyelaagbe and Jolaoso, 1992), (4) (Aiyelaagbe and Jolaoso, 1992). (5) (Kumar <i>et al.</i> , 2000).

economically feasible solution for the farmers to meet the challenges of food, nutrition, energy, employment and environmental security (Verma *et al.*, 2017). Further studies should be carried out related to water use efficiency, biofertilizers,

weed management, technical support, integration of fruit trees and vegetables of high commercial value, biological control, mechanized harvesting, integration of indigenous fruit trees and indigenous vegetables, carbon credits, birds, predators, bees,

policies, credits, and subsidies to increase global food production and conserve the environment.

Discussion

The legumes have great potential for inclusion in horticulture (Zaki *et al.*, 2017) in various ways, for example, fix atmospheric nitrogen, nitrogen green manure, transform and increase the soil mineral N pool (Del Grosso *et al.*, 2006), reduce resilience on mineral forms of N fertilizer (Seran and Brintha, 2010), and reduce the environmental damage through NO₃ leaching and N₂O emission (Meena *et al.*, 2018). It is a natural mini-nitrogen manufacturing factory in the field and can play a vital role in increasing indigenous nitrogen production (Ghosh *et al.*, 2007), seven times faster compared to natural forests (Pavlidis and Tsihrintzis, 2018). Legume green manuring improves SOC, nutrient availability, physicochemical and biological properties of soil, and crop productivity (Meena *et al.*, 2018). It can help improving the soil physical environment, increasing soil microbial activity, restoring organic matter, and also has smothering effect on weed, and solubilizing insoluble P in soil (Hymavathi *et al.*, 2010) for bacterial phytase enzymes activity for release as free phosphorus over time (Blair *et al.*, 2016), so nitrogen and phosphorus efficiency is higher (Khan *et al.*, 2017).

The excessive application of chemical fertilizers has enormously increased (especially nitrogen), which has been designated as a severe environmental threat especially of air and groundwater pollution (Khan *et al.*, 2017). Among the pollutants, nitrates, and phosphoric compounds from agricultural activities are the most common and hazardous to environment and human health (Pavlidis and Tsihrintzis, 2018). Alley cropping is a strategic tool for food and wood production and environment protection. Legume tree offers advantages to the horticultural crops, and mitigates challenges mainly related to the growing population, climate changes and loss of biodiversity (Ribeiro *et al.*, 2018).

Smallholder farmers are inclined to intercrop young timber trees with well-fertilized annuals to confer nutrient and weeding benefits to the trees while gaining a short-term return on the land (Nissen and Midmore, 2002). Recommended principles for designing the cropping system based on this approach include: selecting species for complementary functional traits, developing complex trophic levels, and reproducing ecological succession (Lovell *et al.*, 2017; Malézieux, 2012). Agroforestry systems can be significant sink of atmospheric carbon (C) due to their fast growth and high productivity (Tiwari *et al.*, 2017). Under the Kyoto Protocol's Article 3.3, A&R (afforestation and reforestation) with agroforestry as a part has been recognized as an option for mitigating greenhouse gases (Sureshbhai *et al.*, 2017), and the potential of C sequestration is dependent on the tree component (Nair *et al.*, 2009; Sureshbhai *et al.*, 2017).

The selection of fruit and vegetable species must be prioritized for regional economic potential and specific interactions between crops (Lovell *et al.*, 2017). The success towards ecologically and economically sound agroforestry systems lies in identification of compatible tree-crop units under varying spatial arrangements and limited solar energy available underneath (Thakur *et al.*, 2018). Satisfactory growth and yields of both woody and crop plants can be achieved in the microenvironment of the agroforestry land-

use system that is established, a microenvironment that varies considerably with time (Lin *et al.*, 1998).

The modification in microclimate is one of the important features of agroforestry (Kumar *et al.*, 2018). Alley cropping provides climate change adaptation potential and ecological benefits by buffering alley crops to weather extremes, diversifying income to hedge financial risk, increasing biodiversity, reducing soil erosion, and improving nutrient and water use efficiency (Wolz and DeLucia, 2018). It has potential to address the problems of food insecurity especially in developing countries and conservation of natural resources (Gunaga, 2017), reducing vulnerability, increasing resilience of farming systems and buffering households against climate-related risk in addition to providing livelihood security (Sureshbhai *et al.*, 2017).

Trees can maintain the stability of internal microclimates, and are strong assets for extreme weather adaption (Wu *et al.*, 2016). The presence of trees modifies site microclimate in terms of temperature, water vapor content or partial pressure, and wind speed, among other factors, and, temperature reductions can help reduce heat stress of associated crops (Jose *et al.*, 2004). Temperature reductions in the alleys can help to reduce heat stress of crops by lowering rates of foliar evapo-transpiration and soil evaporation (Jose *et al.*, 2008). In vegetable crops, photosynthetically active radiation and temperature are reduced, while the humidity is increased (Chauhan, 2016; Sangwan *et al.*, 2017), water use efficiency and carboxylation efficiency under shade conditions are essential factors (Sangwan *et al.*, 2015).

Appropriate selection of tree and vegetable combination promises the success of plantation. *Mangifera indica*, *Psidium guajava*, *Citrus* spp., *Leucaena* spp., *Gliricidia sepium*, *Cajanus cajan*, *Populus* spp., *Eucalyptus*, and *Hevea brasiliensis*, are the main tree used. *Fabaceae*, *Brassicaceae*, *Solanaceae* families and tuber crops are the main associated vegetable crops.

Climate change and its variability pose significant challenges influencing the performance of horticulture crops. The extreme weather events of hot and cold wave conditions have been reported to cause considerable damage to many fruit crops. The various impacts need to be addressed in concerted and systematic manner in order to prepare the horticulture sector to face the imminent challenges (Malhotra, 2017). Diversifying nature of alley cropping allows farmers to make the best use of their land by maximizing the crop yields as well as diversify income, and help in increasing resilience to global threat of climate change (Gunaga, 2017).

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