5. Tree and Vegetable Management under Vegetable-Agroforestry System

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Abstract

In intensive vegetable production systems in the uplands, monoculture systems are not sustainable, but integrating trees is feasible and offers better prospects. Tree and vegetable management in the context of Vegetable-Agroforestry (VAF) system was studied at Lantapan, Bukidnon, Philippines. The intent was to improve the net benefits of VAF through improved complementarity and reduced competition among components. This emphasized the integration of valuable trees into the system. This includes among others tree-vegetable matching, tree silvicultural and vegetable crops agronomic managements. Under Vegetable-Agroforestry system, vegetable yields can increase by up to 40%. This is due to the ameliorative effects of trees on the environment on associated vegetable crops. The Vegetable-Agroforestry system is arguably the most appropriate option for upper watersheds utilized for intensive vegetable production. It enhances the productivity and profitability of vegetable production, while reducing production risks and environmental hazards.

Keywords: Tree and vegetable management, complementarily, competition

1. Introduction

Growing woody perennials with vegetables provides a strong foundation for conservation-oriented farming. It meets shortage of timber, fuel wood, and fodder as a mechanism to provide environmental benefits. The roles of trees in minimizing leakage of nutrients from the system and recycling them, preventing soil erosion, and improving micro-climate positively influence the growth of vegetables associated with trees. This is the biological premise of Vegetable-Agroforestry (VAF) system. However, a significant concern is that tree-vegetable competition may, therefore, override the otherwise positive aspects of tree-vegetable integration.

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The key to increasing productivity in Vegetable-Agroforestry system is understanding the nature of interaction between species in the mixture (Fig. 1). The net benefit of Vegetable-Agroforestry system is simply expressed as:

Net Benefit (NB) = $2T + (Y_2 - Y_1) - 2D$

Where:

T = Value of trees

Y_1 = Yield at competition zone

Y_2 = Yield at complementarity zone

D = Crop displacement area

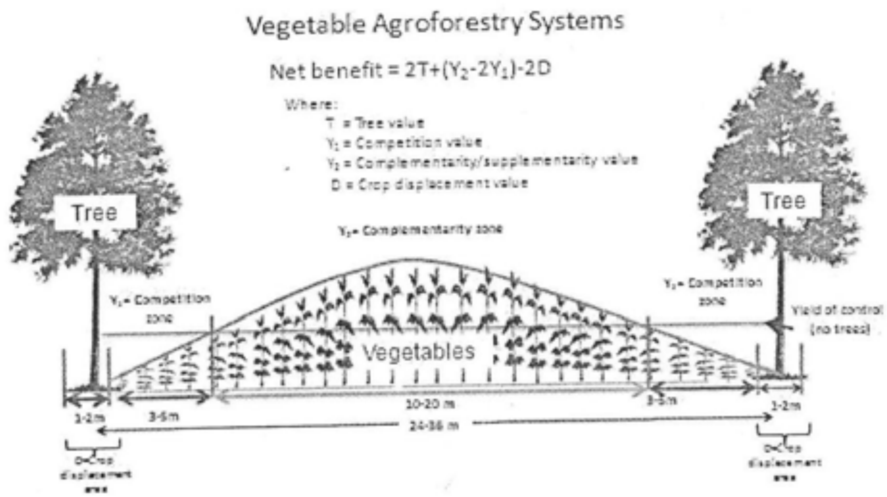

Figure 1. Schematic diagram of tree-crop interaction in Vegetable-Agroforestry (VAF) System.

Both vegetables and trees compete for growth factors such as light, water and nutrients. The outcome of this competition is the reduction of plant growth and performance of the species in mixture. Competition between species in mixed stands (*inter*specific) differs from that of between plants within monocultures (*intra*specific) in that the trees and vegetables may impose different and less severe demands on available growth resources as opposed to monocultures where the demand is greatest (Ong et al., 1996). Plants growing in monoculture are usually all of the same genotype and their growth and development proceed synchronously. When resources are not limiting, densely planted monocultures usually provide the most efficient systems. However, when one or more resources are limiting, it may be possible to improve productivity by using species mixtures that would expand resource use capture

both above- and belowground. This is commonly observed in intercropping and is often expressed in land equivalent ratio (LER). If LER is greater than 1, it has been assumed that the productivity of the mixture is superior to that of monoculture and hence complementarity has occurred.

2. Ways of improving the economic benefits of vegetable agroforestry

Nair (1993) argued that agroforestry has environmental and biological benefits, which result in economic improvement. In the context of Vegetable-Agroforestry system as expressed in Figure 1, it is indicated that the economic net benefit (NB) is the result of the sum values of the tree products (T), the yield in the complementarity zone (Y_2) minus the yield of competition zone (Y_1), and minus the opportunity cost of the crop displacement area (D). The basic principle underlying this tree-vegetable integration is that competition or complementarity between trees and vegetables depend on their ability to capture and use the most limiting and essential growth resources effectively. Growth resources captured such as light, water and nutrients depends on the number, surface area, distribution, effectiveness and efficiency of the individual elements in the canopy or root systems of the tree and vegetable in the mixture involved. The use of the acquired resources depends on the conversion efficiency of the tree and vegetable species involved in the mixture as well as the environmental conditions and management strategies being used. Thus, tree and vegetable management are central to the success of Vegetable-Agroforestry system. Tree and vegetable management includes among others the selection of appropriate tree and vegetable species that are adapted to Vegetable-Agroforestry system and the silvicultural management to reduce negative impacts on associated vegetables.

The ways in which the net benefit of Vegetable-Agroforestry system as expressed in Figure 1 can be improved are as follows:

1. Increase the value of trees (T)
2. Increase the value of complementarity zone (Y_2)
3. Decrease or eliminate the value of competition zone (Y_1)
4. Decrease or eliminate the value of crop displacement area (D)

These ways are the basic elements in understanding tree-vegetable integration, particularly in the context of hedgerow intercropping. They can also be applied on flatlands, and more importantly, on sloping lands where tree rows are aligned along the contour to act as filters to control soil erosion. The same basic principles can also be applied when trees are planted as field boundary or windbreaks, except that the numbers of trees are fewer. Random tree planting may have different tree-vegetable interactions that would not necessarily follow those of either hedgerow intercropping or boundary planting.

2.1 Increase the value of trees

Increasing the economic values of the tree species being used is one of the important considerations in Vegetable-Agroforestry system. It may be achieved by:

A. Optimizing the vertical use of aboveground resources (space and light) by using multi-storey hedgerow systems such as integration of trees + banana + forage grasses (Fig. 2). The integration of multi-level canopy plant combinations allows vertical stratification of light capture, which provides higher overall light capture as opposed to flat plane canopies in monoculture systems. Trees can be rubber, fruit or timber trees, which provide better and long-term economic outcomes. Bananas and forage grasses provide short and medium term income. These range of economic outcomes (short, medium and long term) are important considerations in introducing upland technical innovations to subsistence smallholders.

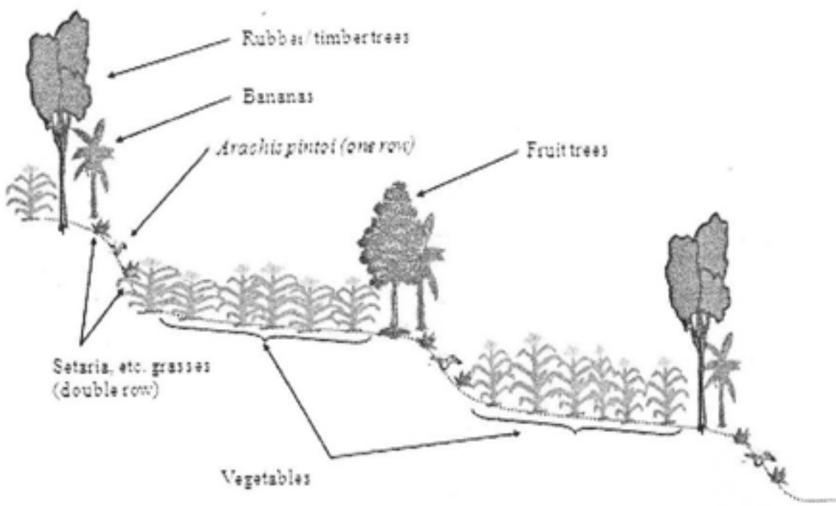

Figure 2. Schematic diagram of an improved multi-storey hedgerow system.

B. Optimizing the use of vertical and horizontal belowground resources (space, water and nutrients) by using plant combinations with different rooting patterns such as shallow, moderate and deep rooted trees exemplified by *Acacia mangium (*Mercado, 2007), *P. phelthoporum* (van Noordwijk et al., 1995), and *Eucalyptus* spp. (Nissen and Midmore, 1999). This combination allows extraction of growth resources at different soil layers leading to greater overall uptake of growth resources as opposed to uniform rooting patterns in monoculture systems. The combination such as rubber + banana + forage legume (*Arachis pintoi*) and grass (*Setaria splendida*) (Fig. 2) has different rooting patterns. The forage legume and grass roots occupy the surface soil layer; banana roots the mid-layer; while the rubber roots are deep. In the context of sloping lands, these different rooting patterns are important, particularly in areas prone to landslides or landslips. The shallow roots of *A. pintoi, S. splendida* and bananas provide soil binding functions due to their high root length densities that keep the soil surface intact and protected from dispersing and eroding, while the deep roots of rubber or other trees provide the soil anchorage function.

C. Optimizing the use of inert resources such as atmospheric nitrogen (N_2) and carbon dioxide (CO_2) by using N_2-fixing trees and fast growing trees that are able to accumulate more carbon.

D. Choosing tree species that have valuable tree products with greater economic values such as latex, fruits and timber. The overall economic benefit of Vegetable-Agroforestry system is highly influenced by the income from the tree products (Fig. 1). The choice of tree species such as *Leucaena leucocephala, Gliricidia sepium* or *Desmodium rhinzonii*, which have no economic return per se, in conventional hedgerow intercropping system (SALT 1) (Watson and Laquihon, 1987), did not entice farmers to adopt the system. The lack of economic benefits from the trees pulled down the overall economic benefit of the system and provided farmers lower income than the opportunity costs of such labor use and the crop area loss (Mercado et al., 2001). Farmers plant trees because of the perceived long-term benefits and better return to labor which is the most important farm capital asset they can invest. Tree planting with greater economic benefits is also a risk aversion mechanism in the context of climate change.

E. Increase the complementarity effect. Increasing the value of the complementarity zone (Y_2) through the use of:

- Optimum tree line/hedge spacing

As indicated in chapter 3, the complementarity zone begins at 3.5 m and extends up to 16 m from the tree line, over which the growth and yield of vegetables are better than those without trees. Thus, the optimum tree row spacing must be the distance from the tree line to the peak of the complementarity zone multiplied by two, and equals 20-25 m. This is contrary to the conventional recommendation of 6-8 m intervals (Watson and Laquihon, 1987; Kang and Wilson, 1987), which had been recommended for many years. The recommended tree line spacing was too close, i.e. less than twice the width of competition zone, which is 8-12 m at both sides of the tree rows (3-5 m in each side of the tree line). The crop yield in this zone averages only 60% of the open field control. This yield reduction was somewhat alleviated by using leguminous hedgerows where prunings were used as mulch or green manure. This spacing must be observed carefully as competition for nutrients, particu- larly N at the competition zone (Fig. 1), is more severe if trees used were not N_2-fixing. The caveat for adopting such a wide spacing is the potential soil erosion, which is beyond the tolerable 10 tons per ha for deep soil such as at Lantapan. Mercado et al. (1999) found that natural vegetative filter strips spaced more than 12 m apart generated soil erosion greater than 12 tons per ha per year on a slope of 60%. Since much of sloping lands farmed for vege- tables in Lantapan have slopes greater than 60%, hedgerow spacing must not be wider than 12 m apart. The best approach is to put two grass strips be- tween tree lines (Fig. 3) and vegetables can be sustainably planted on the al- leyways without fear of losing soils, while optimizing the complementarity effects of trees to the associated vegetables. The grasses can be used for ani- mal feed which can generate manures for the vegetables and income to the household from the animal products (meat and milk).

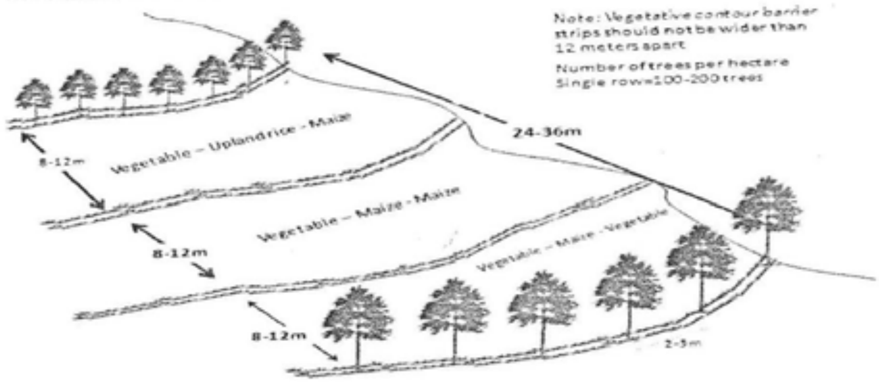

Figure 3. Schematic diagram of widely spaced single line tree hedgerow with double grass strips VAF system.

- Responsive vegetables to micro-climate improvement

Leafy vegetables are more responsive to micro-climate amelioration associated with the presence of trees than climbing and fruit vegetables (chapter 3). For the commercial vegetables, Chinese cabbage – carrots – bell pepper – cabbage – tomato was the order of vegetable species performance tested under VAF system (chapter 3). Yard-long bean and eggplant also showed good performance. Correct choice of crop species is important to achieve better results from VAF system.

- Optimum tree pruning regime (silviculture)

Vegetable farmers at Lantapan severely prune trees prior to the estab-

lishment of vegetables. Some farmers remove up to 90% of canopies to re- duce tree competition. This severe pruning practice reduced complementarity effect as well (chapter 3). Figure 4a shows the relationship between canopy left after planting and the net complementarity. It indicates that the optimum canopy left must be 40-60% in order to achieve reasonable net complementar- ity. This level of pruning is traditionally recommended as proper silvicultural management for tree plantation which is also applicable for VAF system.

- Decrease competition between trees and vegetables

Reducing or eliminating competition between tree and vegetable spe- cies is a tall order in VAF system as well as in any other agroforestry sys- tems. However, there are ways that this competition can be reduced, if not eliminated, by using:

Adapted vegetables. The adaptability index is a simple tool used in chapter 5 to identify vegetables adapted to tree-based systems. Adaptability indices close to 1 indicated that those vegetables were less negatively influ- enced by the trees. The farmers' practice was to avoid planting vegetable close to the trees. Our survey indicated that many farmers planted 3-4 m away from the tree line. In the context of smallholders, leaving this width of land was considered substantial. Our immediate approach was to plant vegetables as close as possible to the tree line (Fig. 5) as long as yields were not severely affected by the trees. Among the commercial vegetables, carrots and bell pep- per were performing better than tomato, Chinese cabbage and common cab- bage for planting closer to the trees.

Appropriate tree species. Choosing the right tree species is the general rule in any agroforestry systems. This involves looking both the above- and belowground characteristics of the trees as well as their functional character- istics. Van Noordwijk and Luisiana (2000) used tree crown architectures as a tool in choosing the right tree species for agroforestry. They preferred light conical canopies like that of *Eucalyptus* spp. as opposed to thick broad cano- pies like that of *Gmelina arborea* and *Acacia mangium*. In chapter 3, we iden- tified relationships between tree species and net complementarity under farm- ers' management. The species that have light to moderate and conical cano- pies similar to that of *Eucalyptus* spp. had higher net complementarities as opposed to *G. arborea* and *M. indigofera*. Although *A. mangium* has broad and thick canopies, its nitrogen fixing property improved the net complemen- tarity. N_2-fixation is an important functional characteristic to be considered in choosing appropriate tree species for Vegetable-Agroforestry system. Mercado (2007) found that 2-year old *A. mangium* planted at 8 m x 2 m as contour hedgerows in Claveria, Philippines, contributed 69 kg N per hectare to the alleycrop maize crop, while the trees had 144 kg N per hectare from N_2 fixation that was equivalent to 42% of total tree N. The availability of this substantial amount of N from N_2 fixation reduced pressure on the inherent soil N and spared it to the adjacent crop. In the context of low input systems, this N_2 fixation is important in order to meet N requirements for both trees and crops. The deep rooting characteristic is one of the important criteria in choosing appropriate tree species for Vegetable-Agroforestry system. This is to reduce tree surface lateral roots extending towards the shallow rooted vegetable crops and extracting water and nutrients from the same soil layers. Van Noordwijk and Purnomosidhi (1995) suggested the use of fractal branching analysis as a simple tool in determining tree competitiveness to the adjacent annual crops. Mercado (2007) used relative root length density (RRLD) as a tool in assessing tree competitiveness. Although a more tedious process than fractal branching method, it is a more realistic estimate of tree root competitiveness. For rapid analysis, root fractal branching is more appropriate. Mercado (2007) found that *A. mangium* has a higher RRLD in soil deeper than 60 cm, while 60% of *G. arborea* root mass was found in the first 60 cm soil depth, growing in the same soil layer as the associated maize crop.

Lateral branch pruning. Figure 4a shows the relationship between tree canopy height and vegetable net complementarity. This indicates that pruning the lateral branches will allow more light to penetrate, thus improving the performance of vegetables beneath the trees. Mercado (2007) found that removing 40-50% of 2-year old *A. mangium* and *G. arborea* canopies, particularly the lower branches, increased light transmission from 20 to 60%, which brought the maize yield to similar level with the open field control.

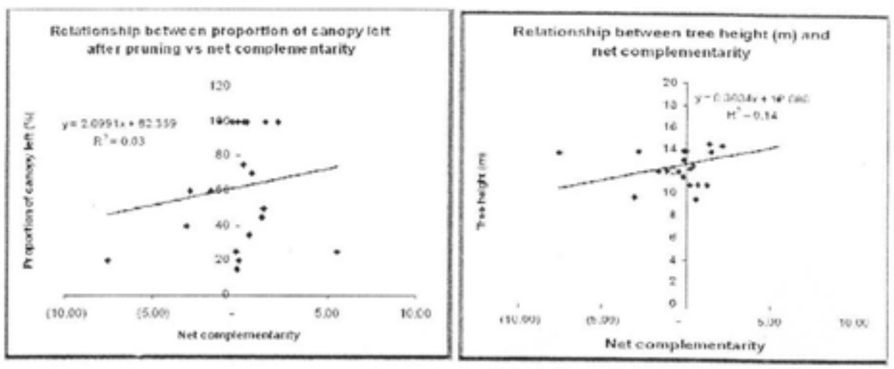

Figure 4. Proportion of canopy left after pruning and net complementarity (a), relationship between tree height and net complementarity (b). Lantapan, Bukidnon, Philippines.

Root pruning and laying out of plastic barrier. Table 1 shows the effect of root pruning and root barrier on the net complementarity effect of trees on bell pepper. This mechanical action make tree roots grow into the subsurface soil avoiding direct competition with the adjacent bell pepper crop resulting in better net complementarity. Root pruning may not have a long-term effect on reducing tree-vegetable competition as the roots will recover later, but a plastic barrier will provide a longer effect. Garrity et al. (1995) found that roots grew over or under in a 50 cm width plastic barrier, thus a 100 cm width plastic (Table 1) avoided this problem.

Table 1. Effect of drip irrigation and root pruning on the biomass and marketable yield of bell pepper in wet and dry season. Lantapan, Bukidnon, Philippines.

Management	Wet season			Dry season		
	Marketable yield (t/ha)	Total biomass at final harvest (t/ha)	Total (t/ha)	Marketable yield (t/ha)	Total biomass at final harvest (t/ha)	Total (t/ha)
Control	3.0	4.7	7.7	1.2	2.8	4.0
Drip irrigation	4.6	6.1	10.7	1.8	3.5	5.3
Root barrier	3.9	6.9	18.8	2.1	4.2	6.3
Mean	3.8	5.9	12.4	1.7	3.5	5.2

Figure 5. Adapted vegetables, like carrots, can be planted close to the trees. Lantapan, Bukidnon, Philippines.

Supplementary irrigation at competition zone. Table 1 shows the effect of drip irrigation on net complementarity. Providing water through drip irrigation eliminates some tree-vegetable competition, thus increasing net complementarity. Competition for water can be intense in agroforestry systems, particularly in low rainfall areas. In the humid tropics of Southeast Asia, annual rainfall is generally high but distribution has been problematic causing plant drought stresses. Using drip irrigation will be able to alleviate this problem (Table 1).

F. More application of leaf pruning and fertilizers at competition zone. The competition zone is where the demand for plant growth resources is intense. In this area, both trees and vegetables extract nutrients from the same volume of soil and in competition particularly if the nutrients are insufficient. The best approach is to reduce, if not eliminate, nutrient competition by skewing the application of nutrients in the competition zone. This management strategy is important particularly if the tree species are producing valuable products such as rubber, fruits or premium timber where the overall economics of the system is largely influenced by their value.

G. Orient the tree rows parallel to the direction of the sun (ideally east-west). Table 2 shows the effect of tree row orientation relative to the path of the sun on net complementarity. Vegetables planted on the east side had better yield and had less competition for light than those planted at the west side. The reason for this was the longer exposure of vegetables to the sun particularly in Lantapan where rainfalls occurred in the afternoon. Orienting the tree rows parallel to the direction of the sun eliminated this problem. The vegetables there experienced similar exposure to the sun on either side of the tree row.

Table 2. Effect of aspects on vegetable net complementarity in Vegetable-Agroforestry system. Lantapan, Bukidnon, Philippines.

Aspects	Net complementarity
East (vegetable on west side)	-2.09
West (vegetable on east side)	-0.54
North (vegetable on south side)	-1.06
South (vegetable on north side)	-1.74

H. Decrease or eliminate the value crop displacement area (D)

Ensure that the value of hedge area (T) is greater than opportunity cost of the displacement area (D). This refers to the planting of valuable trees that provide valuable products (such as latex, fruits and timber) that are more

valuable than vegetables, given that this hedge area could have been planted with vegetables and not with trees. The indirect benefits, such as micro-climate amelioration, that improved vegetable yields, carbon stocks, organic matter due to litter-falls and root hydraulic lift provided both nutrients and water to the shallow rooted vegetables from the subsurface will also be quantified as additional benefits coming from the trees in vegetable systems.

Use early maturing hedges (e.g. clonally propagated trees such as rubber, coffee, timber and fruit trees). Clonally propagated trees shorten the gestation period as well as improve the tree productivity. Laxman (per comm) indicated that asexually propagated rubber trees produce 2-3 times more latex than from seedlings. Clonally propagated fruit trees reduce gestation period from 8-10 years to 3-4 years and also produce more fruits.

Use underneath vegetation such as banana forage grasses and legumes (Fig. 2). Growing shade-tolerant forage legumes and grasses (*A. pintoi* and *S. splendida*) would provide fodder for livestock, which generates additional income as well as fertilizer from the manure that can be applied back to the vegetables grown between the hedges. On sloping lands, banana, fodder grass and legumes also provide additional benefit of soil erosion control as well as controlling landslips during high rainfall as their high root length densities act as soil binding function at the soil surface area (0-30 cm). On the other hand, the trees provide the soil anchorage function. Plant combinations of high soil binding and anchorage functions such as multi-tiered hedgerow system (Fig. 2) reduce if not totally eliminate landslides and landslips in sloping land areas. Bananas also provide medium-term income to the VAF households.

Reduce the displacement area by having fewer hedges (e.g. 20 m instead of 5-6 m apart) thus enhancing the agroforestry complementarity effect. The rule of thumb of the conventional sloping land agricultural technology was to space hedgerows at 6-8 m intervals. This is not possible under VAF system because the tree competition zone extends up to 5-6 m tree lines, and both sides of the hedgerow have a total of 10-12 m. In other words, the technology was not able to capitalize the benefit on the presence of trees to enhance vegetable yields by exploiting their micro-climate ameliorative effects. Making the hedgerows spacing wider reduces the relative vegetable displacement area while enhancing the ameliorative effects of trees.

2.2 Impact of trees on vegetable yields

With proper choice of tree and vegetable species and spacing, the yield of commercial vegetables across two seasons increased up to 40% (Table 3) without any additional inputs apart from trees planted on lines spaced 20-25 m apart. These yield increases were due to the micro-climate improvement created by the presence of the trees such as reduction of wind speed, increased relative humidity, increased soil moisture and higher organic matter due to the tree litter-falls. Trees reduce evapotranspiration of adjacent vegetables whereby 'conserved' soil water can be used to maintain increased biomass growth of those vegetables (Nuberg and Mylius, 2002) and trees reduce wind and soil erosion thus making nutrients more available to vegetables (Cleugh, 2003; Stirzaker et al., 2002). Trees can also improve water supply through increased fog drip by intercepting atmospheric moisture that would otherwise be unavailable to vegetables. This has been found to be more nutrient enriched than rainfall (Liu et al., 2005).

The micro-climate amelioration effects of trees also impacts soil moisture and soil temperature relations (Nair, 1993). Temperature, humidity and movement of air as well as temperature and moisture of the soil directly affect photosynthesis, transpiration and the energy balance of associated vegetables. The net effect will translate into increase of vegetable yields (Nair, 1993; Rosenberg et al., 1983). Where soil structure is degraded, trees can enhance water movement into the soil and improve infiltration in their vicinity so that there is more soil water available to vegetables growing around trees (Stirzaker et al., 2002; Wilson et al., 2006). Increased soil water infiltration and storage capacity are more evident near trees than distant from them, whereby roots, or their remains, create macropores within the soil, through which water can circulate (Stirzaker et al., 2002).

Table 3. Yield increases of commercial vegetables under VAF system. Lantapan, Bukidnon, Philippines.

Vegetables	Wet season (June – Sept)	Dry season (Feb – May)	Average
Chinese cabbage	37	30	34
Cabbage	13	0	7
Tomato	40	10	25
Bell pepper	20	10	15
Carrots	37	30	34
Mean	29	16	18

Trees generally have a deeper root system than annual species particularly vegetables, and the presence of macropores would permit water circulation and drainage to the lower soil horizons (Zapata-Sierra and Manzano-

Agugliaro, 2008). Increased infiltration under trees has been linked with increased soil nutrient concentrations – elevated concentrations of carbon, mineralized nitrogen and extractable phosphorus, potassium and calcium have been found in soils below trees and their surroundings compared to open fields (Bird et al., 1993; Eldridge and Freudenberger, 2005). Trees provide important associations with ectomycorrhizal fungi which aid in the uptake of nutrients from nutrient-poor soils (Bird et al., 1993; Oliver et al., 2006). Leguminous species can introduce nitrogen into vegetable systems while litterfall from certain trees can recycle cations from depth and reverse the acidification of surface soils (Stirzaker et al., 2002) through root hydraulic lift (Keertisinghe, per comm). The total amount of tree litter and soil nutrient concentrations of extractable phosphorus, total nitrogen and organic carbon decreased with increased distance from the tree (Oliver et al., 2006). This high concentration of nutrients is believed to be due to the large quantities of litter accumulation around trees and the root activity within the soil, sourced from rainfall and wind-blown materials or through fog drip as well as being deposited by arboreal insects, birds and mammals using the trees (Oliver et al., 2006).

3. Conclusions

Tree and vegetable management are key elements in improving the economic benefits of VAF system. Optimal management includes silvicultural and agronomic practices, and choice of species and plant combinations that are compatible in the context of VAF. These management strategies lead to increasing the value of trees, reducing competition among components, and enhancing complementarity effects, which will relate to increased yields of vegetable by up to 40%. Integration of trees into intensive vegetable production systems offers better prospects than monoculture systems. These prospects include increased economic benefits, enhanced biodiversity due to the presence of arboreal birds and mammals, and higher system carbon sequestration, while controlling soil erosion and degradation particularly on the upper watersheds. VAF is a unique mechanism for effective sustainable agriculture and resources management of the upper Asian watersheds, which are mostly used for intensive cultivation of vegetables to cater for the needs of the population in the lowland towns and cities.

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