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Space and time utilization in horticulture based cropping system: an income doubling approach from same piece of land

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Abstract
Today horticulture involves intensive culture of fruits, vegetables, ornamentals, herbs and other high value speciality crops but fails to optimize farmer’s benefit. Intensive horticultural systems are often based on optimising the productivity of monocultures. In those systems, crop diversity is reduced to one or very few species that are generally genetically homogeneous, the planting layout is uniform and symmetrical, external inputs are often supplied in large quantities and such systems are widely criticised today for their negative environmental impacts. Conversely, multispecies cropping systems in the same piece of land in a right sequence by optimally maintaining the space and time may often be considered as a practical application of ecological principles based on biodiversity, plant interactions and other natural regulation mechanisms thereby proves their superiority in all-round benefit of farmer as well as the environment. Methods for designing multispecies systems barely exist. Thus, this article addresses those questions, reviews concepts suitable for use in dealing with multispecies systems in horticulture based cropping systems to popularize it as an income doubling approach from same piece of land in a sustainable manner.

Keywords: Monoculture, multi-species cropping, inter cropping, horticulture based cropping system

1. Introduction

Nowadays horticulture involves intensive cultivation of fruits, vegetables, ornamentals, herbs and other high value speciality crops. This has possible because of the diverse agro-climatic condition, enormous biodiversity, wide variation in soil fertility, large cultivable land area in the geographical boundary of India. This rich cultural diversity has further contributed to the planned exploitation of crops and trees, giving rise to a large variety of culinary recipes. India is the second largest producer of fruits and vegetables in the world [1]. Horticultural crops play a major contribution in India’s GDP (30% share of Agriculture) but farmers not benefited up to their expectation. So, in the present context to meet the rising demand of increasing population with ever-decreasing cultivable land, along with detrimental effect of global warming and polluted environment it is utmost important to grow more quality food with the implementation of precession horticulture utilizing eco-friendly inputs. The improvement of crop productivity is the common aim of farmers and agriculturists. The key to sustainable agriculture probably lies in increased output per unit area together with arable land expansion. However, the recent demographic pressure has forced agricultural planners and development agencies to review the role of multiple cropping as a means to enhance agricultural production, since the extent of suitable agricultural land is static or decreasing [2]. In terms of cropping systems, the solutions may not only involve the mechanized rotational mono-culture cropping systems used in developed countries but also the poly-culture cropping system traditionally used in developing countries [3]. The main reason for using a multiple cropping system is the fact that it involves integrating crops using space and labour more efficiently [4]. Biophysical reasons include better utilization of environmental factors, greater yield stability in diverse environmental condition and soil conservation practices. Socio-economic reasons include the magnitude of inputs and outputs and their contribution to the stabilization of household food supply [5]. Diversification of present cropping pattern coupled with development of suitable technology packages is the need of the day to cope with the ever-increasing demand for diversified products and assured income. In recent years, agri-horticulture systems (i.e. integration of fruit trees with the agricultural crops) are recognized as an important agro-forestry system for improving the productivity, reducing the risk in agriculture with additional employment and sustainable use of resources [6].

Methods for designing multispecies systems barely exist. Systemic agronomy concepts (crop management sequences, cropping system), and especially the tools derived from that discipline, scarcely deal with the complexity of multispecies systems. In particular, the modelling tools widely used today in agronomy are not well adapted to simulating them. New models are required to represent, assess and design sustainable multispecies cropping systems.

This article addresses those questions, reviews concepts suitable for use in dealing with multispecies systems in horticulture based cropping systems and attempts to identify shortcomings in terms of tools, thereby proposing new avenues to popularize this approach.

2. Need of multispecies systems in horticulture

Seventy per cent of the world small farms are in China and India. This two countries account for 193 (47 %) and 93 million (23 %) small farms out of 404 million small farms in the world. Small farms are more diversified in nature. Out of 92 million farm households falling under marginal farm category having < 1 ha as operational holding size, 70 % of the farmers are having the area of below 0.50 ha. As per estimates, in India, more than 95 % holdings will be under the category of small and marginal holders by 2050 [7]. In future, the availability of land for cultivation will be a major impendent due to rapid urbanization, hydroelectric projects, dams and rivers, highway roads and also there is a degradation of fertile land due to soil erosion (120.72 million ha), soil salinity and water logging (about 8.4 million ha) [8].

Intensive agricultural or horticultural systems are often based on optimising the productivity of monocultures. In those systems, crop diversity is reduced to one or very few specialized crop species that are generally genetically homogeneous, the planting layout is uniform and symmetrical, and external inputs are often supplied in huge quantities. Such systems are widely criticised today for their negative environmental impacts, such as soil erosion and degradation, chemical contamination, loss of biodiversity, and fossil fuel use [9, 10, 11]. Conversely, multispecies cropping systems may often be considered as a practical application of ecological principles based on biodiversity, plant interactions and other natural regulatory mechanisms. They are assumed to have potential advantages in productivity, stability of outputs, resilience to disruption and ecological sustainability, although they are sometimes considered harder to manage [12].

Crop diversification is the desired strategy for agricultural growth in any farming community. Sustainable horticulture seeks to at least use nature as the model for designing agricultural systems. The level of biological diversity in the environment has been substantially reduced when human kind produces a limited selection of crop plants over focusing to popularize more crops. The practices that promote diversity and stability on the farm are enterprise diversification, crop rotation, use of wind breaks and provision of more habitats for microorganisms, intercropping and integration of crop farming [13, 14]. Horticulture items like fruit and vegetables are play a key role in these efforts, particularly for smallholder farmers, as average farm size has declined over time and higher returns per hectare are needed to improve the living standards of a growing population.

3. Principles followed to implicate multispecies systems approach in horticulture

The aim of cropping system research has traditionally been to design patterns in time and space that would maximize crop production. Commonly cropping system refers to temporal and spatial arrangement of crops and management of soil, water and vegetation in order to optimize the biomass production per unit area, per unit time and per unit input. In other words, definitions of cropping systems have been limited to the systematic arrangement of crops as influenced by local factors of crop production. So, it is advised that farmers should implement the whole space and time utilization technique by merging the concept of intercropping, multi-layer cropping, relay cropping, off-season cultivation and crop regulation to increase productivity of the same piece of land with more crops throughout the year rather than the single crop. The combined approach provides year-round ground cover, or at least for a longer period than monocultures, in order to protect the soil from desiccation and erosion. By growing more than one crop at a time in the same field, farmers maximize water use efficiency, maintain soil fertility, and minimize soil erosion, which are the serious drawbacks of mono-cropping [15]. Not all the approach but merging each one concept for both space and time utilization may be in use enough to serve the purpose.

Table 1: Principles to utilize the space and time management for improving the productivity of the same piece of land

<table>
<tr><th>Sl. No.</th><th>Technique or systems</th><th colspan="2">Principle</th></tr>
<tr><td colspan="4">Space management ways</td></tr>
<tr><td>1.</td><td>Row intercropping</td><td colspan="2">Growing two or more crops together at the same time with at least one crop planted in rows.</td></tr>
<tr><td>2.</td><td>Strip intercropping</td><td colspan="2">Growing two or more crops together in strips wide enough to separate crop production using machines, but close enough to interact.</td></tr>
<tr><td>3.</td><td>Mixed cropping</td><td colspan="2">Growing two or more crops together in no distinct row arrangement.</td></tr>
<tr><td>4.</td><td>Multi-layer cropping</td><td colspan="2">Growing plants of different height in the same field at the same time</td></tr>
<tr><td colspan="4">Time management ways</td></tr>
<tr><td>5.</td><td>Sequential cropping</td><td colspan="2">In this type of cropping system, two or more crops are grown in sequence on the same piece of land in a year. The succeeding crop is sown or planted after the preceding crop has been harvested.</td></tr>
<tr><td rowspan="4"></td><td rowspan="4"></td><td>Double cropping</td><td>In this type of sequential cropping two crops per year are grown in a sequence</td></tr>
<tr><td>Triple cropping</td><td>In this system of cropping three crops are grown in a sequence on the same field.</td></tr>
<tr><td>Quadruple cropping</td><td>In this type of sequential cropping four crops are grown per year in a sequence.</td></tr>
<tr><td>Relay cropping</td><td>It is the system of cropping in which a significant part of the life cycle of the second crop overlaps with the cropping cycle of the first crop.</td></tr>
<tr><td>6.</td><td>Off-season cultivation</td><td colspan="2">Production of a particular not in its natural harvesting time</td></tr>
<tr><td>7.</td><td>Crop regulation</td><td colspan="2">Forced a crop to produce in desired time avoiding its natural cropping pattern with physical (bending technique in guava) or chemical spray (urea, NAA spray for flower shedding in guava, pomegranate, citrus etc)</td></tr>
</table>

Source: Mehta et al. (2007) [16]; Ouma and Jeruto (2010) [17]

To optimize plant density, the seedling rate of each crop on the mixture is adjusted below the full rate to reduce competition from overcrowding. The crops will yield well in the mixture [18, 19]. Planning intercrop with staggered maturity dates or developmental periods utilize variations in peak resource demands for nutrients, water and sunlight [20, 21].

Plant architecture allows one intercrop to capture sunlight that would not otherwise be available to others. This is important to growth and yield of ground level crops [13, 22]. Intercrops should be with characteristics of variation in their duration of growth, peak periods of growth of the two crop species should not coincide, and quick maturing crop should complete its life cycle before the other crop start i.e. following the principle of temporal complementary and with admixture of both food crops and cash crops to ensure both sustenance and cash income [16]. Off season crop production technologies can make an important contribution to the year-round availability of nutrient-rich food to consumers, and to the income of farmers. Some of the fruit crops bloom throughout the year without any resting period and produces two or three crops (bahar) in a year but yield and quality is not so good in all crop harvest. It is very essential to understand the flowering and fruiting behavior of crops and which bahar will give good crop with considering all the factors associated with a particular bahar. The main objective of crop regulation is to force the tree for rest and produce profuse blossom and fruits during any one of the two or three flushes thereby regulating a uniform and good quality of fruits and to maximize the production as well as profit to the grower [23].

4. Feasibility of space and time utilization with horticultural crops

Horticultural crops especially fruits and plantation crops are perennial in nature and long pre-bearing period (Mango, Coconut, Areca nut, Cashew). Crops have wider spacing and are tall growing eg: Coconut (7.5 × 7.5m, 15-20m ht.), Areca nut (2.7 × 2.7m, 15-20m height), Oil palm (9 × 9m, 10-15m height). Canopy cover (Occupation of space) is very slow, took years together and more than 60-70% inter space is not effectively utilized (Mango, Sapota, Coconut, Areca nut). Crop geometry and rooting pattern among perennials, semi-perennials and annual crops could be compatible without any adverse effect on main crops (Arecanut, Cocoa, Banana, Ginger, Turmeric and Pineapple). Some crops are shade loving and tolerance to dripping of rain drops and high humidity (Banana, Cocoa, Turmeric, Ginger, Pineapple and Pepper). There are a good number of horticultural crops which are the good source of bio-mass and by-products which are easily recyclable and decomposable (Cocoa, Coconut, Areca nut, Cashew, Tree spices, Turmeric, Ginger, Mango and Guava). Many crops encompass different harvesting time and period which facilitates for sustainable income (Banana, Cocoa, Coconut, Areca nut, Pineapple, Ginger and Turmeric). Suitability or tolerance to prevailing micro – climatic condition (Black pepper, Cocoa, Pineapple, Tree spices, Heliconia, Marigold, Jasmine) [8]. Many tropical medicinal plants are well adapted to partial shading, moist soil, high relative humidity and mild temperatures [24], allowing them to be intercropped with timber and fuel wood plantations, fruit trees and plantation crops. Some well known medicinal plants that have been successfully intercropped with fuel wood trees (e.g, *Acacia auriculiformis*, *Albizia lebbeck*, *Eucalyptus tereticornis*, *Gmelina arborea*, and *Leucaeana leucocephala*) in India, include safed musli (*Chlorophytum borivilianum*), rauvolfia (*Rauvolfia sarpentina*), turmeric (*Curcuma longa*), wild turmeric (*C. aromatica*), *Curculigo orchioides*, and ginger (*Zingiber officinale*) [25-27].

5. Tools to evaluate the performance of the multi-cropping system

Sustainability of any cropping system, including multi-storey cropping system, lies in the fact that how much diversified the agro-eco production system is and the positive interaction among the diverse components of the system.

5.1. Multiple Cropping Index or Multiple Cropping Intensity (MCI): Multiple Cropping Index or Multiple Cropping Intensity is the ratio of total area cropped in a year to the land area available for cultivation and expressed in percentage [28] (sum of area planted to different crops and harvested in a single year divided by total cultivated area times 100).

5.2. Cultivated Land Utilization Index (CLUI): Cultivated land utilization Index is calculated by summing the products of land area to each crop, multiplied by the actual duration of that crop divided by the total cultivated land times 365 days [29].

5.3. Crop Intensity Index (CII): Crop intensity index assesses farmers actual land use in area and time relationship for each crop or group of crops compared to the total available land area and time, including land that is temporarily available for cultivation [30]. It is calculated by summing the product of area and duration of each crop divided by the product of farmers total available cultivated land area and time periods plus the sum of the temporarily available land area with the time of these land areas actually put into use.

5.4. Land Equivalent Ratio (LER): Land Equivalent Ratio (LER) is the most frequently used efficiently indicator in cropping system. LER can be defined as the relative and sole crop that would be required to produce the equivalent yield achieved by intercropping [31]. LER of more than 1 indicates yield advantage, equal to 1 indicates no grain or no gain or no loss and less than 1 indicates yield loss. It can be used both for replacement and additives series of intercropping.

5.5. Relative Yields Total (RYT): The mixture yields of a component crop expressed as a portion of its yields as a sole crop from the same replacement series is the relative yield of crop and sum of the relative yields of component crop is called Relative Yields total (RYT) [32]. In RYT yields advantages is to measure not only unit area, but also on unit population. This is mainly used for replacement series.

5.6. Area Harvest Equivalency Ratio (AHER): Area Harvest Equivalency Ratio (AHER) was proposed by Balsubramanian and Sekayange (1990) [33]. AHER measures the resources use efficiency of cropping system. The concept of AHER combines the area time factors in a practical sent quantifying intercrop yield advantage particularly in multi-season.

6. Advantages of the space and time utilization approach

Mixing plant species will create new habitats for associated species, mainly when the structure of the system is modified (introduction of trees, for instance). The advantage of a mixture has often been assimilated to a higher yield of the mixture when compared with an equal area divided between monocultures of the components in the same proportion as they occur in the mixture [34]. Mixing species can also influence product quality, although different processes may interfere. In coffee (*Coffea arabica* L.) based agroforestry systems in Central America, shade due to timber or shade trees promotes slower and more balanced filling and uniform ripening of berries, thus yielding a better-quality product than a monoculture of un-shaded plants [35]. Nutrient use efficiency of the individual crops in an intercrop is mostly lower than their respective sole crops. However, the cumulative nutrient use efficiency of an intercropping system was in most cases higher than either of the sole crops [36]. Solar radiation, water and some nutrients would be wasted during early growth stages of long-term crops, but they can be utilized by an associated crop growing between the rows [2]. Multispecies systems may increase soil cover, root presence in the topsoil and obstacles to run-off on the soil surface, hence decreasing soil erosion, having a positive impact, on a watershed scale, on the water quality of rivers, and on the intensity of floods [37]. Multispecies systems can sequester carbon over pure crop stands. Trees and/or cover crops may also enhance the soil carbon content, thus participating in climate change mitigation [12, 38]. There is reduction of insect/mite pest populations due to the diversity of crops grown and reduction of plant diseases because the distance between plants of the same species is increased due to the planting of other crops between them, alteration of more beneficial insects especially when flowering crops are included in the cropping system, increase of total farm production and profitability and reduction of weed population through allelopathy and efficient crop production [39]. Gomez-Rodriguez *et al*. (2003) [40] reported that intercropping with marigold as a trap crop induced a significant reduction in tomato early blight caused by *Alternaria solani*. Trap crops are plant stands that are, per se or via manipulation, deployed to attract, divert, intercept and/or retain targeted insects or the pathogen they vector, in order to reduce damage to the main crop [41]. The reducing effect of crop mixes on diseases or nematode damage has been reported from a good number of studies [42, 43, 44]. Beside these advantages, this multi-cropping system also beneficial for providing partial guaranty against market glut of single commodity; growing crop according to market demand; maintaining an ecological balance, creating several secondary outputs from the system, and generating higher income per unit area with ensuring food, nutrition, and income security to the farmers [45, 46, 47] and regular employment also [48]. Examples of some successful multi-cropping models in horticulture based cropping systems are summarized in Table 2.

Table 2: Successful model of multi-cropping approach in horticulture based cropping systems

Cropping system/sequence	Place of report	Remarkable outcome of the system	Reference
Coconut + Cocoa + Banana + Moringa + Pineapple	AICRP, Aliyarnagar	This cropping system with 75 % NPK + organic recycling with vermicompost recorded highest nut yield of 182 per palm and highest net income (Rs. 3.80 lakhs per ha) and B:C ratio (2.71).	Nimbolkar *et al.* (2016) [6]
Coconut + cocoa + lime + banana + drumstick	AICRP, Arasikere	With all physical and chemical quality of coconut, this system recorded net income of Rs. 2, 94,810 per hectare compared to mono crop (Rs. 68,200/ha).	Roy *et al.* (2001) [49]
In an area of 1 ha 150 coconut (7.5 X 7.5 m) + black pepper (1.25 m away from coconut base –150 vines) + cocoa (2.5 m between 2 rows of coconut – 525 plants) + pineapple (1-2 m in the rows, two rows of pineapple-4900 plants)	Coastal region of southern state of India	This model recorded higher yield of coconut (20%) and net returns compared to mono cropping of coconut, besides enhancing soil fertility due to recycling of byproducts.	Khan and Krishnakumar (2002) [50]
Mango+ cowpea+ Indian mustard	Todapur Research Orchard of Horticulture Division, IARI, New Delhi	This system recorded significantly highest values of system productivity, gross returns, net returns and benefit: cost ratio during both the crop seasons.	Mirjha and Rana (2016) [6]
Mango + *Phaseolus acutifolius* cv, "Frijol Escumite" + *Cajanus cajan* (Pigeon Pea)	Mango orchards in the Soconusco, Chiapas, Mexico	The biomass of *Cajanus cajan* and *Phaseolus acutifolius* (Frijol Escumite) and their incorporation to the ecosystem produced positive effects on the quality and yield of mango. Likewise the intercropping of mango with *Cajanus cajan* or *Phaseolus vulgaris* influences the insect diversity in these systems.	Agreda et al. (2006) [51]
Mango+ mandarin / Egyptian clover + date palm .	-	These systems could be used for the higher net return per unit area and also to combat desertification in sandy soil in arid lands regions.	Abouziena *et al.* (2010) [52]
Mango+ cowpea (Kharif) + bengal gram (Rabi)/ Mango+ pigeon pea + tomato	Madhya Pradesh	First system gave maximum productivity per hectare whereas second system came up with maximum monetary returns.	Baghel *et al.* (2003) [53]
Coconut + Black pepper + Banana + Elephant Foot Yam	East Coast Region of Tamil Nadu	This system considered as the most suitable intercropping system in coconut based on the feasibility, marketability, soil health and economic viability.	Thivruvarssan *et al.* (2014) [53]
(Aonla+ ber + cluster bean+ fennel), (Aonla + bael + cluster bean + Coriander), (Aonla + khejri + cluster bean + ajowain)	Arid regions of Rajasthan	These systems were reported as sustainable and remunerative under the arid ecosystem	Hare Krishan *et al.* (2013) [54]
(Aonla + ber + karonda + cluster bean + brinjal), (Aonla + ber + karonda + mothbean [*Vigna acontifolia* Jacq. Marechal] + indian mustard (*Brassica juncea* (L) Czernj & Cosso)	Arid regions of Rajasthan	Plant height, number of branches/plant, fruits/plant and yield was found to be superior in these multi-species cropping systems as compared to sole cropping.	Arya *et al.* (2010) [55]

7. Conclusion

Mixing of crop species in horticulture based cropping systems may lead to a wide range of benefits that can be assessed by short-term (increase in crop yield and quality) and long-term (agroecosystem sustainability) benefits as well as societal and ecological sustainability (recreation, aesthetics, water and soil quality, enrichment of biodiversity etc.). The horticulture based multi-cropping systems not only give additional return to the farm families but also generate additional working days for rural youths in a sustainable manner.

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