ISBN: 978-93-48091-98-7

20. Agroforestry: Tree Crop Interaction and Its Management

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Abstract:

In agroforestry systems, the arrangement of trees alongside crops can occur simultaneously, where they coexist spatially and temporally, or sequentially, such as in fallow systems. When trees, soil, and crops coexist simultaneously, a complex interplay of positive and negative interactions emerges in both above and below ground environments. Understanding these interactions requires a comprehensive study of factors such as resource availability, environmental conditions, and their effects on tree, crop, and soil dynamics. Above ground factors encompass tree and crop biomass, as well as atmospheric elements like radiant energy, rainfall, wind, and temperature. Meanwhile, below ground factors include root systems, soil characteristics, water availability, and nutrient distribution. By examining these factors, researchers can discern the promoting and limiting factors within agroforestry systems. The balance between positive and negative interactions is pivotal in determining the overall impact of agroforestry systems. Interaction, as defined by Nair (1993), refers to the influence of one component within a system on the performance of other components or the system as a whole. Positive interactions often involve microclimatic improvements and enhancements in soil productivity, while negative interactions typically revolve around competition for resources such as light, water, nutrients, and allelopathic effects.

Efforts to quantify these interactions have been undertaken by organizations like the International Centre for Research in Agroforestry (ICRAF), which measures the positive effects (I) through soil fertility enrichment (F) and negative effects through competition (C). Through such quantification, researchers can better understand the nuanced dynamics of agroforestry systems and devise strategies to optimize their productivity while minimizing negative impacts. In essence, understanding the nuanced dynamics of agroforestry systems empowers stakeholders to design and implement sustainable land use practices that enhance productivity, resilience, and environmental stewardship.

Through continued research and innovation, agroforestry stands as a promising pathway towards achieving food security, biodiversity conservation, and climate resilience in agricultural landscapes.

Keywords:

Agroforestry, tree-crop interactions, productivity and sustainability

20.1 Introduction:

Agroforestry, the growing of trees or shrubs in association with crops, pastures and livestock, has been invariably identified as an ideal, ecologically and economically suitable land-use system which aims to increase the total production per unit area while maintaining or enhancing soil fertility (Dwivedi, 1992; Nair, 1993). This system with multiple faces of management in world's agriculture is commonly known as agroforestry, which strongly strives on the three important components i.e. trees, crops and animals. These basic components of agroforestry and their compatible interactions make them sustainable on the basis of social as well as economic criteria.

Among the three components, tree and crop arrangement is an integrated and complex phenomenon, because interaction between these two components provides positive as well as negative effect on systems productivity. Productivity of agricultural crops in agroforestry prominently dependent on manipulations of these interactions through various tree management practices.

Generally, in India the reduction of crop yield in agroforestry systems varied from 20-65%, whereas the increase varied from 10-20% (Rao *et al.*, 1998). Sanchez (1995) illustrated that agroforestry systems can increase total productivity, reduce land degradation and improve nutrient recycling, while producing fuelwood, fodder, fruits and timber in addition to products from annual crops by better tree management practices.

In present era of climate change and population explosion, attention needs to be focused on agroforestry tree management for increasing overall systems' productivity. Most of the scientific communities of the world have confirmed the role of agroforestry as savior of humankind against the devil of climate change (IPCC, 2007). In such a difficult situation, tree management in agroforestry is in sharp focus to highlight its importance in optimum utilization of resources (i.e. space, nutrient and light).

There is a finite amount of light, water and nutrients in any given area and this places an absolute limit on how much crop yield, timber or other wood products can be produced in a given time. Various management interventions can be applied to fine tune the interaction between trees and crops. Shading, for example, can be reduced by pollarding and pruning, and some trees can be cut and allowed to re-sprout (coppiced). In agroforestry systems, mismanagement of shade, water and nutrients, is the prominent reason of lower productivity. These interactions are classified into: above-ground and belowground interactions e.g. the planting of trees in association with light-demanding annual crops often leads to a drastic suppression in crop production as a result of competition for both above - and below-ground resources. These interactions are managed by pruning, lopping, pollarding, coppicing and thinning. Tree root pruning is a potential tool for managing below ground competition between trees and crops in agroforestry systems

20.1.1 Agroforestry Areas:

Iin India the current area under agroforestry is estimated at 25.32 Mha, or 8.2 % of total geographical area of the country. This includes 20.0 Mha in cultivated lands (7.0 Mha in irrigated and 13.0 Mha in rainfed areas) and 5.32 Mha in other areas such as shifting cultivation (2.28 Mha), home gardens and rehabilitation of problem soils (2.93 Mha). Moreover, agroforestry is also providing livelihood opportunities through lac, apiculture and sericulture cultivation and suitable trees for gum and resin have been identified for development under agroforestry (Dhyani, 2012)

20.1.2 Scope of Agroforestry in India:

Agroforestry has tremendous scope and a large hectare is available in the form of boundaries, bunds, wastelands where this system can be adopted. This system permits the growing of suitable tree species in the field where most annual crops are growing well. Agroforestry assures permanent sources of higher income even in extreme adverse conditions. Realizing such scope, an All India Coordinated Research Project on Agroforestry was initiated in 1983 to initially operate at eight Research Institute of the Indian Council of Agricultural Research (ICAR) and twelve Agricultural Universities, and now it is being extended to large number of universities and institutes. Since Agroforestry involves intensive use of land under proper management without deterioration of it fertility that results in more output this adds in national economy. Thus, bright future of Agroforestry in India is inevitable.

20.2 Tree-Crop Interactions:

Interaction is defined as the effect of one component of a system on the performance of another component and/or the overall system (Nair,1993). Regarding this, ICRAF researchers have developed an equation for quantifying tree-crop interaction (I), considering positive effects of tree and crop yield through soil fertility enrichment (F) and negative effects through crop competition(C) for growth resources between tree and crop $I=F-C$. If $F > C$, interaction is positive, if $F < C$ interaction is negative and if $F=C$ interaction is neutral.

Interaction occurs both above and below ground and includes a complex set of interaction relating to radiation exchange, the water balance, nutrient budget and cycling, shelter and other microclimatic modifications.

Interactions help to know:

- How the components of agroforestry utilize and share the resources of the environment, and
- How the growth and development of any of the component will influence the others

Factors affecting tree crop interaction:

- Effect of species: Proper choosing of compatible tree-crop combinations.
- Effect of sun light: Light crown tree, either selection of shade tolerant crops or management of tree crop for reducing shade on agricultural crops.
- Effect of density: Numbers of trees/ha, planting of tree at optimum numbers of tree in a given area for reducing competition among crop and tree.
- Effect of age: At early stage of tree crop, competition is minimal.
- Effect of site factors: Relates about the carrying capacity of the site, site quality.
- Effect of management: Level of management for tree crop for benefits of agricultural crops or improving the total productivity of the system.

Advantages of tree-crop studies:

- Choice of Species: Proper selection of both trees as well agricultural crops.
- Design of agroforestry system: Either parallel rows of trees and crops or concentric rows of crops around the tree.
- Management of agroforestry System: Degree of management, at what time, etc

20.2.1 Negatives Effects:

1. Competition:

When plants grow in proximity to each other they interact either in positive ways (complementary) or in negative ways (competition). The biophysical bottom line of agroforestry is how to manage the interaction for light, water and nutrients between the tree component and the crop and/or livestock components for the benefit of the farmer. Competition may be above and below ground competition for resources uptake. However, the extent of below-ground competition is often not apparent.

Above ground competition: Competition for solar radiation is the most prominent above ground competition between trees and companion crops. Low light intensity is one of the important constraints for higher yield. Dhillion *et al*. (2005) concluded that the causes of reduction in growth and yield losses due to *Eucalpytus* tree plantation was due to direct competition for moisture, light and nutrients from the nearby rows of pear trees.

Below -ground competition: Tree roots can compete with annual crop roots for available water and nutrients in the top soil. Below ground root competition for moisture, nutrients and space is relatively more important in agroforestry systems than above ground crown competition as concerned in Indian situation. Since light is more relatively more abundantly available than moisture and nutrients. It is necessary to have information on the nature of root development in two types of crop plants.

2. Allelopathy:

The phenomenon of one plant having detrimental effect on another through the production and exertion of toxic chemical compounds is called 'allelopathy'**.** Allelopathy substance was first detected by Davis in black walnut (*Juglans regia*) whose foliar leachate containing Juglone was found to damage germination and seedling growth of crops beneath the tree. Allelopathy is one of the widely considered limitations for promotions and adoption of agroforestry at the field scale.

20.2.2 Complementary Effect (Positive Effect):

There are a several complementary effects of tree crop interaction such as increased productivity, improved soil fertility, efficient and balanced nutrient cycling, improved Soil conservation management and improvement of Microclimate which are very important in the way of overall agroforestry health and its productivity.

Factors affecting tree-crop interactions:

I. **Species-** Tree functional characteristics, canopy type, seasonality.
II. **Sunlight-** Light crown tree, either selection of shade tolerant crops or management of tree crop for reducing shade on agricultural crops.
III. **Density-** Numbers of trees per hectare, planting of tree at optimum number in a given area for reducing competition among crop and tree.
IV. **Age factor-** At early stage of tree crop, competition is minimal.
V. **Site factors-** Relates about the carrying capacity of the site, site quality.
VI. **Management-** Level of management for tree crop for benefits of agricultural crops or improving the total productivity of the system.
VII. **Type of Crop planted-** Erect v/s broad leaves, shade demander/light demander, root architecture

Interaction of agroforestry components with the atmospheric elements:

1. Interception of radiant energy by foliage is a major determinant of biomass production.
2. Interception of rainfall determines how soil water get recharged.
3. Saturation water vapor pressure deficit determines water loss by transpiration per unit of biomass produced.
4. Temperature determines the rate of growth and development

20.3 Types of Interactions:

a) Complementary: when the interaction is positive, there is complementarily between the components.

- Spatial complementarily
- Temporal complementarily

b) Supplementary: Complementary force = Competitive force

c) Competitive: if interaction is negative, competition is seen instead of complementarity.

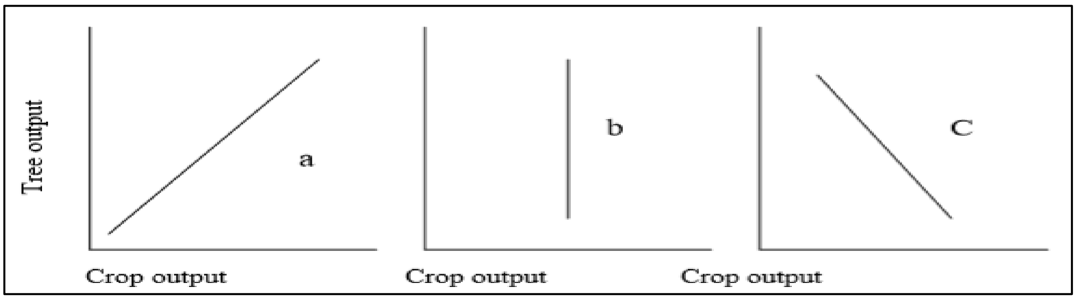

Figure 20.1: Types of Interactions

Table: 20.1 Analyses of tree-crop interaction based on effects of soil fertility (F) and competition (C)

Tree species (Age 8 years)	Fertility effect (%)	Competition effect (%)	Interaction (%)
Leucaena leucocephala	152	-159	-7
Calliandra calothyrsus	120	-115	+5
Peltophorum dasyrrachys	58	-26	+32
Flemingia congesta	37	-89	-52
Gliricidia sepium	19	-60	-41

Noordwijk and Hairiah (2000), reported on effects of soil fertility and competition on maize yield relative to control are summarized in this table 20.1. The relative success of the local tree Peltophorum in this Experiment was not due to very pronounced positive effects +58, but small negative effects (-26) peltophorum is less competitive than the others, partly because of a deeper root system and shape of the canopy the shape of its canopy {concentrated near the tree trunk}, which gives it a high mulch to shade ratio (Table 20.1)

Table 20.2: Analysis of Interaction Between Two Population

Type of interaction	Effect of the interaction on the population		Nature of interactions	Agroforestry example
	A	B		
Mutualism	+	+	Interaction favourable to the populations	Mycorrrhizae, rhizobium-legume
Facilitation	+	0	Interaction favourable for A but not obligatory: B not affected	Windbreaks, shade trees, alley cropping (well managed)
Commensalism	+	0	Interaction obligatory for A; B not affected	Support trees for vines, improved fallows
Neutralism	0	0	None of the populations affects the other in crop lands	Scattered trees
Parasitism /predation	+	-	Interaction obligatory for A; B is inhibited	Pest and disease
Ammensalism	-	0	An inhibited; B not affected	Allelopathy
Competition and interference	-	-	Each population is inhibited by the others use of growth resources	Alley cropping (poorly managed)

(Rizvi *et al.*,2019)

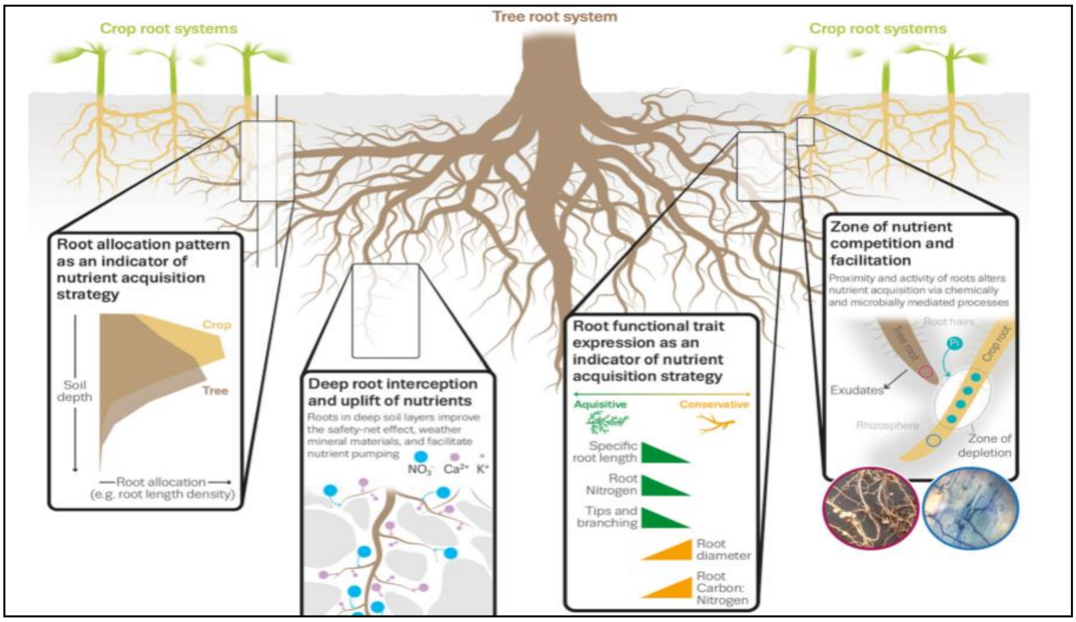

Figure 20.2: Nutrient Acquisition in Agroforestry Systems

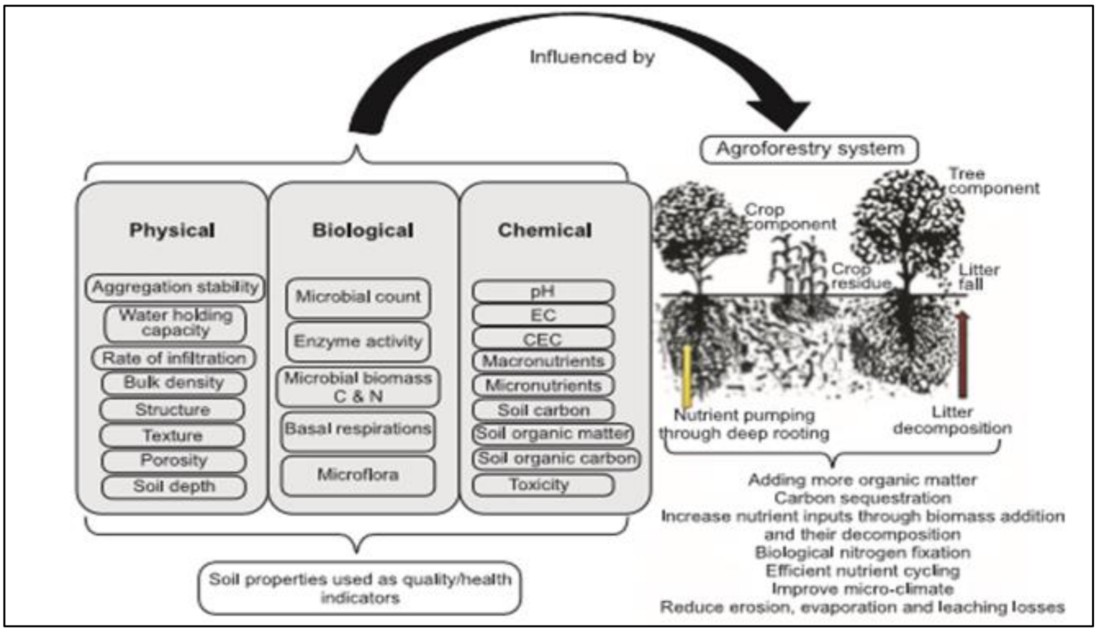

Figure 20.3. Soil quality/health indicators influenced through different soil improving processes in agroforestry system

(Rizvi *et al*.,2019)

Possible interactions at TCI:

Positive Interaction:

a. Shading trees (stress reduction)
b. Efficient use of light (PAR) or reduce waste of light resources
c. Biomass contribution
d. Microclimatic amelioration
e. Balanced utilization of nutrients
f. Efficient use of aerial space
g. Water conservation
h. Weed suppression
i. Soil conservation

Negative interaction:

a. Shading
b. Root competition
c. Host of each other's insect pest
d. Weed growth increasing
e. Allelopathy

Table 20. 3: Allelopathic activity of some agroforestry species

Agroforestry species	Target spp.	Plant parts/ allelochemicals	Uses of agroforestry spp.
Azadirachta indica	Rice,Peanut, Wheat, Maize, and no. of microorganisms	Leaf, wood and leaf litter leachates, litter and mature leaf extracts	Timber/manure/ oil/ fuel/food/pest control
Leucaena leucocephala	Lettuce, Rice, Sorghum	Aqueous leachate/extracts of leaves/litter/dry leaf mulch(mimmosine)	Fuelwood/pole/timber/food/soil conservation/
Melia azedirach	Cabbage, cress (Lepidium sativum)	Leaf leachate	Crop shade/ fuel wood/ timber/lumber
Populus deltoides	Sugarcane, wheat	Soil, leachate	timber
Tamarindus indica	*Amaranthus spinosus*	Ethanolic extracts of leaves and seeds	Beverage/fruit/fuelwood/ shade tools/rituals
Eucalyptus globulus	*Cucumber, Blackgram, lettuce*	Leaf extract and leachate, soil percolate, canopy effect	Lumber/essential oil/pole

Rizvi *et al.*, 2015

Tree Management options in competitive tree-crop interface:

Table 20.4: Examples of tree management practices in Agroforestry

Name of the MPTs	Mgmt. practice	Specification	Purpose
Hardwickia binata	Lopping	Lower two third	Fodder
	Pollarding	Advanced age	Multiple shoot production
Prosopis cineraria	Lopping (once in three year)	Old twigs & branches	Maximize fodder production
Salix species	Pollarding and pruning	Three years interval	Fuel wood, minor timber, handicrafts
Dalbergia sissoo	Thinning	Closer spacing	Straight timber & quality timber production
	Pruning	Every year	Clean stem & pest & disease free
Grewia optiva	Lopping	branches	Green fodder
	Pollarding	Tree cut back 2m ht	Green fodder
Acacia nilotica	Lopping	Branches	Fodder & fuelwood
Ailanthus excelsa	Lopping	4^{th} yr onwards	Fodder
	Thinning	7^{th} year	For timber production

(Chavan *et al.*, 2018)

20.4 Conclusion:

Understanding the balance between negative and positive interactions within agroforestry systems is crucial for assessing their overall impact. While quantifying complementarity, particularly belowground, poses challenges, it's essential for prioritizing research and designing sustainable land use systems. Management strategies have proven effective in yielding positive outcomes, including increased productivity compared to monocropping. Moreover, agroforestry promotes biodiversity, benefiting both plant and animal species, while also offering solutions to combat climate change through carbon sequestration, aligning with the objectives of carbon markets. Thus, embracing agroforestry practices holds promise for fostering productive, sustainable, and resilient agricultural landscapes.

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