HortFlora Research Spectrum, 1(3): 193-198 (2012) ISSN : 2250-2823

DYNAMICS OF TREE-CROP INTERFACE IN RELATION TO THEIR INFLUENCE ON MICROCLIMATIC CHANGES—A REVIEW

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ABSTRACT: Integration of trees with crops adds a significant element of biological diversity to agronomic systems and promotes sustainable, protective and productive land use. The biological interactions between the major components i.e., trees and crops are of primary importance and introduce challenges and complexities not present in sole cropping. Specifically, it must be demonstrated that satisfactory growth and yields of both trees and crops can be achieved in the microenvironment of the agroforestry land-use system that varies considerably with time. Compared to an open environment, the modified microclimate under trees will have reduced solar radiation, a lowered red: far-red light ratio, a more moderate temperature regime, higher humidity, lower rates of evapo-transpiration and higher soil moisture levels. All of these factors will change as a function of tree development and tree management practices. The spacing arrangement chosen for trees will also be a factor in determining how rapidly the changes come into play. During the establishment phase, tree shade will be minimal and have little significant effect on the understory companion crops. However, as the trees grow, the changes in the microclimate will become more pronounced, which might strongly affect the growth and compatibility of the understory companion crop.

Keywords : *Agroforestry, microclimate, solar radiation, energy balance.*

Agroforestry system is a complex and living system which integrates the trees and results in changes in the microclimate which in turn influence the growth of all components of the system. Agroforestry techniques were designed with the aim of increasing soil fertility, there is now growing evidence of improved soil nutrients, microclimatic condition and increased crop production beneath large isolated trees due to efficient recycling of nutrients. If we try to understand and predict the results of combining tree and crops under different circumstances, it is important to know the functioning that control these changes and to appropriate their potential effects on plant growth and development. To explain why particular agroforestry system work in one environment and not in another, and how to manage them, requires a better understanding in order to cover the large number of possible plant combinations and their adaptability in wide range of climate and the development of appropriate management practices. A large number of changes occur when a tree is introduced into a field. The combined effect of these changes control the energy balances of both the overstorey and the understorey, thus influencing plant water use and productivity. Temporal and spatial complimentarity of resource capture by tree and crops in a agroforestry system is a major determinant of the ability of the system to improve crop yields and overall productivity (Cannell *et al.,* 7; Ong and Black, 36). Agroforestry research has largely concentrated on understanding above-ground interaction, such as light interception and microclimate modification (Corlet *et al.,* 9). To understand the main microclimatic effects that occur in tree-crop interface (agroforestry) this paper explains the specific microclimatic changes by radiation, wind, air, humidity and temperature and their effect on evaporation of water and growth in the context of agroforestry practices.

1. Solar radiation dynamics and their influence on microclimate:

In all agroforestry systems the planting of trees changes the average radiation incident on

Received : 16.3.2012 Revised : 19.5.2012 Accepted : 28.6.2012

understorey plants. These changes are often considered a disadvantage although some authors have found that they are advantageous (Vandenbeldt and Williams, 38). Under clear sky conditions negative balance of solar radiation causing night time cooling of the atmosphere, this is because the sky is cooler than the soil or vegetation, however under a tree canopy downward long wave radiation fluxes would be similar to upward long wave fluxes from crops, thus rates of cooling of understoreys are considerably slower. This proves that less frost is observed under trees or in forests than in open fields, and may be an important function of 'shade tree' in coffee and tea plantations where these are susceptible to frost or chilling damage. When plant growth is not limited by water or nutrients, production is limited by the amount of radiant energy that foliage can intercept (Monteith *et al.,* 22; Monteith, 23).

Various studies have examined the mechanism of competition for light between trees and annual crops (Monteith *et al.* 22; Knowles *et al.,* 18; Gillespie *et al.,* 13). Biomass growth is dependent upon the fraction of incident photosynthetically active radiation (PAR, 400 to 700 mm wave length) that each species intercepts and the efficiency with which the intercepted radiation is converted by photosynthesis (Ong *et al.,* 26). These factors, in turn influenced by time of day aspect, temperature, CO_2 level, species combination, photosynthetic pathway (C_3 vs C_4), canopy structure, plant age and height, leaf area and angle and transmission and reflectance traits of the canopy (Brenner and Jarvis, 5; Kozlowski and Pallardy, 19). Shading by associated tree species has been shown to be a factor in reducing yield in temperate agroforestry systems. Low PAR levels resulting from overhead shading significantly reduced yield of winter wheat near tree row in a paulownia-winter wheat temperate cropping system in China (Chirko *et al.,* 8). Nissen *et al.* (25) also reported that both shading and belowground competition decreased the yield of cabbage (*Brassica oleracea*) in a eucalyptus based alley cropping system in the Phillippines. Maize and soybean yields were reduced to 75% of the sole crop yield, respectively, when grown in alley cropping configurations involving popular (*Populus deltoids*).

Some studies have investigated the physiological basis of observed yield reduction in response to shading in agroforestry systems (Jose *et al.,* 17). Shading is known to change quality of light reaching the understorey canopy; overhead canopies absorb mostly the red and blue portion of the solar spectrum so that diffuse radiation will be richer in orange, yellow and green wavelengths to influence the amount of growth regulating amount harmones and thereby growth (Baraldi *et al.,* 4). Lack of adequate red light is known to influence tillering in grasses (Davis and Simmons, 10), stem production in clover (*Trifolium spp.*) (Robin *et al.,* 33), flowering (Davis and Simmons, 11) and other basic plant growth processes (Sharrow, 36). Contrary to an expected yield decrease in maize (a C_4 species) in response to shading, Gillespie *et al.,* (13) reported no effect in two alley cropping systems in Midwestern United States. The researchers found that, irrespective of shading, no apparent yield reduction was observed when belowground competition for nutrient and water was eliminated through trenching and polyethylene barriers. Leihner *et al.,* (20) also reported similar finding in maize and concluded that shading played only a minor role in competition at the tree crop interface.

Positive effects of moderate shading on crop growth have been reported in some cases. Lin *et al.,* (21) found that two native warm season legumes, *Desmodium canescens* and *D. poniculatum,* exhibited shade tolerance and had significantly higher dry weight at 50% and 80% shade than in full sunlight. Burner and Brauer (1) reported that orchard grass (*Dactylis glomerata*) yield across six harvests did not differ among loblolly pine (*Pinus toeda*) and short leaf pine (*Pinus echinata*) silvopastures compared to yield in open pastures. In another study of a loblolly Pine-mixed grass/forb silvopasture, Burner and Brauer (6) showed that herbage yield was unaffected at alley widths of 4.9 m and above. Light transmittance was as high as 90 % at this spacing. Alley widths below 4.9 m had a profound influence on light transmittance.

2. Solar radiation and their influence on energy balance:

Changes in wind speed and radiation caused by introducing tree have very important effects on the energy balance of the plant. Plant must lose the same amount of energy they absorb if they are to remain at a constant temperature. Although a certain amount of energy is stored as chemical bond energy, photosynthesis and physical storage of heat, energy is lost mainly by evaporation and convection (Jones, 16). Nearly all land plants have stomata, some species have stomata on both sides (amphistomatous) and others have stomata on the lower side only (hypostomatous). The main environmental variables to which stomata respond are to photosynthetic quantum flux density, vapour pressure deficit, leaf water status, leaf temperature and internal CO_2 concentration.

Table 1: Stomatal (gs), canopy (gc) and boundary layer (ga) conductances for a variety of vegetative surfaces.

Vegetation type	Stomatal conductance (mm s^{-1}) on a leaf area basis	Canopy conductance (mm s^{-1}) on ground area basis	Boundary layer conductance (mm s^{-1}) on ground area basis
Grassland	10	20	5-20
Agricultural crops	20	50	20-50
Plantation forest	6	20	100-330

(**Source:** Jarvis, 15).

Shading by overstorey causing changes in stomatal conductance. Competition for water between overstorey and understorey changes leaf water status and shelter changes microclimate. So plants growing under tree may have different conductances from those grown in monoculture, changing their evaporation and photosynthetic rates. Conductance of a canopy is generally taken as average stomatal conductance multiplied by plant leaf area index. Many developmental processes are temperature controlled with their rate increasing linearly above a base temperature (Jones, 16). The rate of germination of millet seed, for example, increase linearly with soil temperature from 10-12°C to an optimum temperature of 32-33 °C, then decreases linearly to a lethal temperature at around 48°C. It has been suggested that one of the major causes of improved crop growth under a canopy of *Faidherbia albida* is reduction of soil temperatures at the beginning of the season, as a result of shading of the soil by the tree canopy since in the semi-arid tropics soil temperatures can exceed 50°C (Vandenbeldt and Williams, 38). Soil temperature particularly affects germination and early growth of cereals since the meristem remains below ground level for the first 3 weeks of plant development (Ong, 28; Corlett *et al.,* 9). Optimum temperatures for growth processes depend upon the species and process. For example, leaf extension in millet was found to correspond well to meristem temperatures, with the rate expansion decreasing above 32°C (Ong, 29; Terry *et al.,* 37). However, optimum temperatures for grain yields and tillering were lower, between 20°C and 27°C (Russell *et al.*, 34). Temperature also affects the duration of the growth stages, so that advantages of faster rates of increase may be offset by shorter duration of that advantages of faster rates of increase may be offset by shorter duration of that growth stage (Ong and Monteith, 27).

3. Influence of temperature and humidity on microclimatic changes

The effect of trees on soil and air temperature is an important parameter for the agroforestry system, since the photosynthesis-respiration relationship, which depends largely on ambient temperature, playes a vital role in the accumulation of carbohydrate and in the control of the survival of crops in those systems (Sanchez, 35). Lower temperature beneath tree crowns may reduce water stress and increase biomass of below-crown species (Amundson *et al.,* 1), if competition for light or soil moisture does not overcome the benefits of reduced temperature to the species beneath the tree crown. In an study it was found that soil and air temperature were, on an average 15.6 and 2.8°C cooler under the crown of *Z. joazeiro* trees, respectively, when compared to patches of *C. ciliaris*. In contrast, the presence of *P. juliflora* trees had no significant effect on soil temperatures and contributed to a decrease of only 1.4°C in below crown air temperatures. Similarly, previous studies have shown that soil temperature were 5 to 12°C lower under the crowns of *Acacia tortilis* and *Adansonia digtata* trees in Kenyan savannas (Rhoades, 32). It is reported that air temperatures beneath tree crowns in a seven-year old *A. tortilis* plantation during a monsoon season were 0.1 to 2°C lower than temperature recorded in the open. The different effect of *Z. joazeiro* and *P. juliflora* on soil and air temperatures is different in crown structure between these two tree species. The crown of *P. juliflora* intercepted only 20 to 30 % of the total solar radiation during the same period.

Temperature reductions can help reduce heat stress of crops and/or animal in agroforestry systems. Crops such as cotton (*Gossypium hirsutum*) and soyabean (*Glycine max*) have been observed to have higher rates of field emergence when at moderate temperatures. Ramsey and Jose (31) in their study of a pecan (*Carya illinoesis*) cotton alley cropping system in the southern United States, observed earlier germination and higher survival rates of cotton under pecan canopy cover due to cooler and moisture soil conditions than in also system. A study in Nebraska, Midwestern United States, showed earlier germination, accelerated growth and increased yields of tomato (*Lycopersicon esculentum*) and snap bean (*Phaseolus vulgaris*) under simulated narrow alleys compared to wider alleys (Bagley, 2; Garrett and McGraw, 12). Studies on paulownia-wheat (*Triticum aestivum*) intercropping in temperate China have shown increased wheat quality due to enhanced microclimate conditions (Wang and Shogren, 39).

4. Wind dynamic and their influence on micro-climate:

The changes the wind pattern in a field both by altering the horizontal wind speed and turbulence; thus absorb momentum and force the air to flow around them. The velocity of the air flow increases with distance from an object that absorbs momentum, whether leaf or agroforest, and if the extent of the surface is sufficient, an air-flow profile develops that is characteristic of that surface. This characteristic profile defines the boundary layer, and affects the fluxes of energy and mass to and from the surface. A relatively simple level from which to start to scale up boundary layers for agroforests is a leaf. Boundary layer conductance at the agroforest scale depends on surface roughness (widely spaced trees are aerodynamically rougher than pastures), extant of surface and speed and turbulence of incident air flow. A characteristic boundary layer might develop above an extensive and uniform agroforestry system at around 1 m of characteristic boundary layer for each 200 m of system (Monteith *et al.,* 24), but many agroforestry systems are small in extent, thus its boundary layer would be constantly in transition between the agroforest and the surrounding vegetation.

Shelter within agroforestry system may limit mechanical damage or improve quality in other ways. Such improvements with shelter have been noted in various crops, *e.g.* more palatable pasture, less fibrous oats with higher protein content, higher sugar content in sugar beet, larger and finer tobacco leaves, non-spoiled asparagus, higher sugar level in citrus, improve flower set in avocados, and higher exportable crop in kiwi fruit (Baldwin, 3). Jaffe (14) showed mechanical rubbing of leaves inhibited wheat growth by 11%, considerably less than more sensitive crops such as maize (28%) and beans (45%).

In nutshell it can be concluded that major interactions between tree and crop demands, better understanding of the behavior and management of agroforestry system, for example, the effect of solar radiation due to increased leaf area of an upper canopy in an agroforestry system, reduces the energy available for photosynthesis and consequently also reduces the temperatures of soil and optimum for a specific plant growth process. It also reduce the risk of frost because of the increase in the downward flux of long wave radiation relative to an open sky, and reduces energy available for evaporation from soil and crop. The relative importance of these processes in terms of productivity varies between different environment and agroforestry systems.

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