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Light interception under different training system and high density planting in fruit crops

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Abstract
Light is very essential for photosynthesis that convert the carbon dioxide and water in to carbohydrates. The interception of light in fruit crops affect size, shape and quality of fruits. So improvement light penetration within tree canopies has been a constant objective of fruit tree architecture manipulation through the different planting system and planting densities. The availability and utilization of photo synthetically active radiation (PAR) are the important factors that limit plant productivity. Tree size, planting geometry, spacing and training system, all have a dominant effect on the light conditions within the tree canopy. Light penetration and light interception are most considering factors under high density planting. Light is the one and only limiting factor in high density planting. It is the source of energy for photosynthesis, which influence flowering, fruit set and improve fruit quality and color development.

Keywords: Photo synthetically active radiation (PAR), canopy, light interception, photosynthesis

Introduction

One of the recent novel concepts of increasing the productivity without affecting the quality of fruits is the management and the of light interception by canopy. India is the largest producer of fruits in the world after China. However the average productivity and per capita availability of fruits in India is low as compared to many developed countries. India produced 82.631 million tones of fruit in 2014-15 while China topped the list with 154.364 million tones. The Ministry of Agriculture has also stated that fruit production in India is faster than vegetables, despite the latter constituting a larger segment of the horticulture sector. In fact, India is the world's leading producer for some fruits like banana, mango and Papaya, while it is the second largest producer of sugarcane and the third largest producer of Coconut. Among Indian states, Andhra Pradesh is the largest fruit-producing state with 13,939 tones, followed by Maharashtra, Gujarat and Tamil Nadu. The concept of high density planting (HDP) in fruit crops is one of the recent technique for increasing the productivity without affecting the quality of fruits. The main principle of HDP is best utilization of the vertical and horizontal space per unit time and to achieve maximum possible return per unit area and natural available resources. There has been much talk about the potential of high density orcharding in fruit crops, but few studies demonstrated the long-term economic benefits (Ram, 10). In some of the cases, yield was declined after few years as trees began to crowd each other. The high-density orchard provides several times (8-9) higher yields than the traditional densities as demonstrated by Ram S 1996 (10) in alternate bearing Dashehari mango in north India. In horticultural crops light or sunlight is basic unit for production and productivity. High density planting and training systems in subtropical fruit plants has been an important development in recent years leading to increased productivity, higher early yields and better income per unit area. Scientific research has established that high density planting can give more output per unit area within 3 to 4 years of planting as compared to 8 to 10 years in traditional systems. Under these circumstances the high density plantation systems has become extremely significant to increase fruit yield and productivity (Goswami *et al*., 2001) [44]. To increase fruit crops production and to optimize fruit quality, it is very important to choose the correct training system to obtain maximum light interception and photosynthetic radiation (Hampson *et al*., 2002) [38]. This combination tends to increase profitability by improving yield and/or reducing the cost of labour (Robinson, 2008) [42]. Novel architectures that enhance light interception and distribution into the canopy have been developed, ensuring early cropping, high yield, improved cropping efficiency and fruit quality (Lauri and Claverie, 2005; Long *et al*., 2005; Whiting, 2006) [23, 24, 57].

Light is very essential for photosynthesis that convert the carbon dioxide and water in to carbohydrates. The interception of light in fruit crops affect size, shape and quality of fruits. So improvement light penetration within tree canopies has been a constant objective of fruit tree architecture manipulation through the different planting system and planting densities. The availability and utilization of photo synthetically active radiation (PAR) are the important factors that limit plant productivity. Tree size, planting geometry, spacing and training system, all have a dominant effect on the light conditions within the tree canopy. Light penetration and light interception are most considering factors under high density planting (Westwood, 1988). Light is the one and only limiting factor in high density planting (G Tzul, 2016) [45]. It is the source of energy for photosynthesis, which influence flowering, fruit set and improve fruit quality and color development (Tucker *et al*., 1994) [46].

Light interception

Light is the set of electromagnetic radiation emitted by the Sun. The Sun behaves almost like a black body which emits energy according to Planck's law at a temperature of 6000 K. The solar radiation ranges goes from infrared to ultraviolet. In the interception of light (LI) by a canopy, difference between the solar incident radiation and reflected radiation by the soil surface (Villalobos *et al*., 2002), is a determining factor in crop development and provides the energy needed for fundamental physiological processes such as photosynthesis and transpiration (Carlos Campillo, 2014) [43]. Interception of light by a canopy is a fundamental requirement for crop growth and is important for biomass production and plant growth modeling. Solar radiation is an important parameter for photosynthesis and evapotranspiration. Plant light interception efficiency is a crucial determinant of carbon uptake by individual plants and by vegetation. The influence of architectural traits and crown architecture on light interception efficiency has been studied, (R.A. Dursma, D.S. Falster *et al* 2011) [47]. Light interception is the forcing factor for photosynthesis and determines the productivity of fruit trees. In addition, light is involved in the flower-initiation process and in a number of important fruit-quality parameters, such as color, flavour, and the sugar:acid ratio (Arthey, 1975) [1, 26]. Shading can cause smaller fruit size but it not a single factor that reduce fruit size, crop load, temperature, moisture and age of trees can also enhance this problem (Palmer and Wertheim, 1981) [13].

Light quality manipulation could be achieved by reflective films and colored nets in orchard systems. Although the positive effects of this technology are normally associated to improving the PAR use for net C assimilation, different reports demonstrated that, irrespective PAR availability, reflective films and colored nets alter widely the light quality composition in the UV, B, and R light with ensuing effects on PHY and CRY plant mediated responses such as shoot growth, color development, and fruit growth.

Light quality composition

Sunlight composition changes widely in orchard canopies, inducing different plant responses in fruit trees mediated by phytochrome (PHY) and cryptochrome (CRY) activity. High proportion of far-red (FR) in relation to red (R) light increases shoot elongation, while blue (B) light induces shoot dwarfing. Red and ultraviolet (UV) light increases fruit skin anthocyanin synthesis, while FR light shows a negative effect (Richard M. Bastías, 2012) [37]. The accessory pigments complement the absorption of light in this region, supplementing the chlorophylls.

- 620-700 nm (red): A greater absorption bands of chlorophyll.
- 510-620 nm (orange, yellow- green); Low photosynthetic activity.
- 380-510 nm (purple, blue and green): Is the most energetic. Strong absorption by chlorophyll.
- < 380 nm (ultraviolet). Germicides effects, even lethal < 260 nm.

The PAR radiation is subdivided into various bands and the most important for plant physiological processes are B (400-500 nm), Green (G, 500-600 nm) and R (600-700 nm) light (Nobel, 1983; Grant, 1997; Combes *et al*., 2000; Corelli-Grappadelli, 2003) [36].

Effect of Light on Growth and Development of fruit crops

Light interception provides a free energy source for growth and development of plants but only the photo-synthetically active part of the spectrum (400–700 nm) can directly drive photosynthesis. It is defined as Photo-synthetically Active Radiation (PAR)]. The ability to absorb and convert PAR immediately reflects crop biomass productivity, which is the foundation of crop economic yield. The most important variable affecting plant growth is light exposure, and it is therefore important to measure the amount of light your plants receive. The most important concept to understand when growing plants is the rule of limiting factors, which determines plant quality. Hydroponics cannot compensate for poor growing conditions, such as improper temperature, insufficient irrigation, nutrient deficiencies, pest and disease problems, or poor light. Light is the most important variable influencing plant growth. If plants do not receive enough light, they will not grow at their maximum rate or reach their maximum potential, regardless of how much of any other variable water, growth medium or fertilizer – they receive..

Photo-morphogenesis influences the following aspects of plant growth, among others

- Seed germination (photoblasty and photodormancy)
- Synthesis of chlorophyll (photosynthesis);
- Stem and leaf growth towards visible light (etiolation and phototropism);
- Flowering time based on the length of day and night (photoperiodism);
- Reaction to various light colors. (Prof Gert Venter, 2017) [53].

The plants have grown under different conditions of light exposure, and have made a special study of the tendency to become reproductive or to remain vegetative under varying daily lengths and intensities of exposure, (Garner and Allardio 1920). Generally vegetative growth of plant is proportional to the length of daily exposure to light. The short length of light resulted short, slender plants of greatly reduced size. In short exposure the rate of growth was much slower, and the total size attained was reduced. The inception of the flowering or reproductive phase was greatly influenced by length of exposure to light. Many of the species worked with were thrown into flowering and fruiting by the shorter exposures, while with certain other species and varieties, reducing the period of illumination had little effect upon the inception of fruiting. (J. R. Magness 1990) [16] Botanical Gazette, Vol. 70, No. 3 (Sep., 1920), pp. 246-248.

The quantity of Photosynthetic active radiation provide the energy and carbon needed for sustained tree and fruit growth.

The changes in light quality and quantity affect the plant growth and development (i.e. spectral composition of sunlight). Its processes regulated by specific pigment-based photoreceptors, including red (R) and far-red (FR) light absorbing phytochromes (PHY) and ultraviolet (UV) and blue (B) light absorbing cryptochromes (CRY) and phototropins (PHO) (Fankhauser and Chory, 1997; Kasperbahuer, 2000; Smith, 2000; Lin, 2002) [48, 50, 51]. Light is crucial for photosynthesis and plant growth. The effects of light on plant growth and development are complex; the entire spectrum of light is not beneficial for plants. Living organisms generally harvest the visible electromagnetic spectrum, which we will hereafter refer as "light". Apart from photosynthesis, light also controls flowering time and morphogenesis. Two major photoreceptors-phytochromes (absorbs red/far-red-light) and cryptochromes (absorbs blue/ultraviolet A (UV-A) light)-are responsible for plant morphological and developmental changes. Md. Mohidul Hasan (2017) [52].

Effect of light on flowering and fruiting in fruit crop

Flowering, the first step of sexual reproduction is of paramount importance in agriculture, horticulture and plant breeding. Flowering process is controlled by the duration and quantity of light. Flowerings is photoperiodic phenomenon. In fruit plants, vegetative growth or produce flowers is ultimately determines by the duration of the photoperiod or the dark period.Different fruit crops (Tropical, Sub-tropical and Temperate) require different periods of light or dark for full flowering (Arkendu Ghosh, 2016) [17]. It is now evident that the different environmental signals influence the flowering time/flowering control such as photoperiod, light quality, vernalization and other environmental factors like ambient temperature besides nutrient status and moisture stress (Sreekumar *et al*., 2014) [54]. The sunlight use efficiency (i.e. converting light energy to dry matter) has long been the main research focus to obtain sustainable fruit production and quality in orchard systems. In the recent years, however, more technological innovation are required for adequate light management in fruit trees, due to changes of paradigm of efficiency in orchard systems, which must include other factors, such as climate change, energy cost, and need of reduction of environmental impact (Palmer, 2011; Blanke, 2011) [55, 56]. In strawberry, the duration of length of daily light period influenced the flower formation. A decreased the amount of light induces flower formation at the expense of runners, while the longer day length tends to induce runner rather than flower formation. Although short day favours flower formation, regardless of temperature, yet temperature to a certain extent modifies the day length response. In general any decrease in temperature shortens the day length, which will permit the flower formation. Konsin *et al*., (2001). Shortening the nursery period by adjusting light quality and light period increased fruit production efficiency compared to standard cultivation conditions (H. Yoshida, S. Hikosaka, 2012) [18].

Effect of light on fruit yield and fruit quality in fruit crops

Light is the driving force for photosynthesis, a plant process that changes sunlight into chemical energy. During photosynthesis, water is split in a chemical reaction in which it is separated into oxygen and hydrogen, and carbon dioxide (CO_2) is converted into sugar. A general rule of thumb is that 1% more light will give you a similar percentage increase in plant growth, resulting in a 1% higher yield. Light interception by leaves is essential for the growth and survival of fruit trees because it enables plants to convert energy from light into sugar to fuel flowering and fruit growth. Although the green skin of developing fruit can produce sugar via photosynthesis, fruit is primarily a sink, requiring input of supplemental sugars from surrounding leaves. The leaves closest to an individual fruit serve as the primary source and provide the majority of sugars required for development. Light is necessary for plant survival and fruit production, excessive light and temperature can damage both leaves and fruit. The proteins and enzymes in fruit and nut tree plant cells function best at intermediate temperatures. When temperatures increase above a critical level, often as a result of excessive light exposure, proteins and enzymes begin to break down resulting in cell damage and death. (Fruit & Nut Research & Information Center 2019) [58]. Fruit yield and quality is depends on light intensity, which improved from bottom to top and from the inner to outer canopy. Light is a crucial aspect which influenced the vegetative growth, yield and fruit quality. Extensive studies have been conducted on this aspect in temperate fruit crops like apple and peach, while very little work has been done on tropical and sub-tropical fruits crops. Morphological growth and fruit productivity are the functions of light interception and translation of light energy into chemical energy via photosynthesis. The production of good quality fruit is a function of absorbed light. After a more or less linear increase, a plateau is reached which may even be followed by a decrease (Jackson, 1989). Light interception is directly proportional to the yield of fruit trees (Jackson, 1980, Palmer, 1989) [34, 35]. Poor light distribution affects flowering, fruit set, fruit colour, size and chemical compostion (Lasko *et al* 1989) [27]. Fruit skin color depends on the concentration of various pigments, such as anthocyanins, chlorophylls, and carotenoids, but red color is due to anthocyanin pigments, mainly cyanidin 3-galactoside (Ju *et al*., 1999; Awad *et al*., 2001; Layne, 2001) [20, 59]. Anthocyanin biosynthesis is another important light-depending process and has been widely used as a model to study the effect of light quality in vegetative tissues, while its formation is controlled by a high-energy photoreaction and has a photo-protective function to excess light (Mancinelli, 1985; Arakawa *et al*., 1985; Arakawa, 1988; Steyn *et al*., 2002). Cover orchard floor with reflective materials are used for improving light penetration and produces important effects on improving of fruit color, fruit size, and return bloom in apple orchard (Ju *et al*., 1999; Widmer *et al*., 2001; Blanke, 2011) [20, 19, 56], as well on better fruit firmness, sugar content, advanced in maturity and source:sink relationships in peach and sweet cherry (Layne, 2001; Whiting *et al*., 2008) [59, 57]. The main effect of reflective film is the increases of PAR reflection by reflecting light incoming to floor back into the tree canopy, improving widely the light availability to shading parts of the tree canopy (Widmer *et al*., 2001) [19].

Effect of light on physiological traits of fruit crops

The vegetative and reproductive growth of trees depends on assimilate production which is controlled by tree architecture and leaf functions, both modulated by environmental interactions (Flore and Lakso, 1989; Lakso, 1994). At branch scale, Massonnet *et al*. (2004) showed that two apple cultivars differed in transpiration rate, suggesting that this may result either from variability in branch structure, which affects light interception within the tree crown, or from differences in leaf physiological functions, or from both. Architectural diversity has been characterized among apple cultivars: Lespinasse (1992) and Costes *et al*. (2003) classified apple cultivars into four groups (types I to IV) based on branching and fruiting patterns. Massonnet (2004) showed that two group IV apple cultivars (‘Fuji’ and a new hybrid ‘X3305’) have a spatial leaf distribution conferring greater light interception by the canopy than two group III cultivars (‘Braeburn’ and ‘Ariane’). Stomatal conductance (gsw) and net CO2 assimilation rate (An) in C3 fruit species depend upon conditions such as solar irradiance (Marini and Sowers, 1990; Francesconi *et al*., 1997). The efficiency of radiation interception is also influenced by the levels of nutrients in plants, mainly by nitrogen (Dewar, 1996; Scott Green *et al*., 2003). High crop RUE is directly dependent on obtaining the maximum leaf photosynthetic rate (Sinclair and Horie, 1989; Hammer and Wright, 1993). Nearly 70% of the soluble protein in leaf is concentrated in the carboxylation enzymes (i.e., Rubisco). A positive relationship between leaf nitrogen content per unit area (specific leaf nitrogen) and photosynthetic rates has been reported for a number of crops. (Muchow & Sinclair, 1994; Sinclair & Shiraiwa, 1993; Sinclair & Horie, 1989; Hammer and Wright, 1993; Evans, 1983; Marshall and Vos, 1991; Giminez, *et al* 1994; Anten, *et al*, 1995; Peng, *et al*, 1994 and Vos & Van Der Putten, 1998 as cited in Subbarao *et al* 2005).

Light interception under different HDP and Training system

Light interception is directly proportional to the total dry matter production of crops (Monteith, 1977) [31]. This also held true for the yield of fruit trees (Jackson, 1980; Hunt~r and Proctor, 1986; Barritt, 1989; Palmer, 1989; Robinson and Lakso, 1989) [34, 33, 32, 35, 27], although the partitioning of dry matter is also dependent on light distribution within the tree canopy. The achievement of an adequate yield and good quality of fruit and the setting of flower buds depend on light conditions, which can be improved through the formation of an adequate tree canopy. Overall effects of shade on fruit quality are very clear, but the processes responsible for these effects are not. Shade reduces photosynthetically active radiation (PAR) and, therefore, reduces local photosynthetic activity, canopy temperature and changes wavelength distribution of transmitted light. Light interception is determined by the amount and spatial distribution of leaves. Small trees at high densities generally achieve greater light interception and a greater proportion of well-illuminated leaf area than do large trees at low densities. Consequently, the associated production increases with light interception and density (Forshey and McKee, 1970; Jackson, 1978; Robinson *et al*., 1993) [28, 29, 30]. Palmer *et al*. (1992) found a positive correlation between yield, light interception, and tree density up to 80% light interception and 8300 trees per ha. Data on higher densities are limited.

The light intensity is always decreased rapidly with increasing depth of foliage and it was studies that lower and central portions of the tree received very low light intensities. Heinicke (1966) and Looney (1968). Similar results obtained in other research that full light intensity (100%) was at the top of round headed apple tree whereas, intensity decreased to 34% at a depth of one meter Jackson (1970) [25] Verheij and Verwer (1973). According to observation the relationship of tree density, light interception and yield among four apple orchard. They found linear relationship between yield and tree density for 3 pyramid shape systems. However, Y-trellis had greater yield than was predicated for its tree density due to maximum light interception in the tree canopy. Robinson and Lakso (1989) [27]

Interception of light distribution into the Y-shape tree canopy was 35% higher as compared to central spindle canopy. Mean light interception was almost similar in all the three training 7 systems with values of 74% in the Y-shaped, 71% in the open vase, 69% in the central spindle trees. It was observed that interception of light in guava cv. Sardar planted at three spacing *viz*., 6m x 4m, 6m x 5m and 6m x 5m. The interception was recorded highest (65.7%) in plants at widest spacing followed by medium (63.6%) and closest (61.3%) spacing. More than 70 per cent of total light was intercepted in the upper 1/3rd part of the canopy of plants during the actively growing season of the plants. Peach cv. Shan-i-Punjab were trained to modified training system with spacing of 6m x 6m, 3m x 3m whereas, Y shaped trees were planted at 6m x 1.5m Singh (2003). It was reported that trees which were planted at 6m x 1.5m spacing intercepted significantly higher (75.1%) mean total radiation during the year as compared to those planted at 6m x 6m (68.6%) and 3m x 3m (65.9%) distances. The 6m x 1.5m planted trees intercepted 52.5%, 12.9% and 9.7% of the total irradiances in the upper, middle and lower parts of the tree canopy, respectively. The intercepted irradiance in the 6m x 6m planted trees was 50.4%, 10.9% and 7.3% whereas, 3m x 3m intercepted 49.7%, 9.9% and 6.3% irradiance in the three tree parts mentioned above (Singh and Kanwar, 2004). According to Farina *et al* (2005) peach fruit cv. 9 “Elegant Lady‟ had more uniform crop load distribution within the canopy in combination with a light penetration gradient which resulted in greater variability of quality parameters for perpendicular „Y‟ than Delayed vase. Effect of different training system, spacing and cultivar on the production of peach trees, observed that central leader and vase training system were suitable for peach cv. Marciel with 10m x 10m spacing (Singh *et al* 2005 and Singh and Dhaliwal, Luciano *et al*, 2007) [22, 39]. When trees of guava (*Psidium guajava* L.) cv. Allahabad Safeda were planted in at different spacing 1.5 × 3.0, 3.0 × 3.0, 3.0 × 6.0 and 6.0 × 6.0 m in 4 replications to determine the effect of planting distance on tree growth, yield, fruit quality and light penetration. Photo-synthetically active radiation (PAR) was found less in closely spaced trees than medium and low ones. Overall, better light penetration was observed in the trees planted at 6.0 ×6.0 and 3.0 × 6.0 m than the other distances at NS/EW canopy edge, inside tree centre, centre between tree in the rows and centre between rows (G. Singh, A.K. Singh, D. Mishra 2007) [22, 39].

It was proved the mean total radiation intercepted by the trees was significantly higher (65.7%) in the wider (6m2) spacing relative to the trees planted at 6x5m (63.6%) and 6x4m (6l.3%) spacings. The different parts of the tree canopy (upper, middle and lower) also had a significant effect on radiation interception. The upper part of the tree canopy intercepted significantly higher (45.4%) radiation compared to the middle (1l.96%) and lower (6.15%) canopy parts irrespective of the planting distances. (Ajitpal 2003). In studies its evaluated that grapes 10 performance on two different training system *viz*., Modified VSP' (slope trunk with a vertical shoot positioning training system) and F-MT (Fan training system with multiple trunks). It was proved that bigger total leaf area per vine, improved light transmittivity and increased PAR level in the fruiting zone in M-VSP (Guo *et al*, 2015). In red gold nectarine light interception and gas exchanges were linearly related which confirmed that the amount of carbon potential was proportional with light intercepted. Curvilinear relationship was also found with light interception and fruit quality. The penetration of light into the canopy is related to training system and planting density for a given training system. Canopy which was exposed to sun in all directions (NS/EW) received higher PAR with (61.0-59.0%, 64.0-57.0%, 65.0-62.0% and 51.0-63.0%) in trees spaced at 1.5m x 3.0m and 3.0m x 3.0m followed by 3.0m x 6.0m and 6.0m x 6.0m (in guava). (Morandi *et al*, 2008).

Conclusion

The productivity of a crop depends on the ability of plant cover to intercept the incident radiation, which is a function of the leaf area available, the architecture of vegetation cover and conversion efficiency of the energy captured by the plant in biomass. High density planting and training system has a bearing role in light interception. Light interception by plants are higher than plant will produced more yield and good quality production. Closer planting or high density planting with open centre increased light interception. High light distribution also promotes the higher yield per unit area. For successful farming there should be good light interception and good light distribution. High density planting technology is gaining popularity because of earlier production and net returns, increasing utilization of land and efficient use of available resources due to greater root densities efficient pesticidal application and easier weed control.

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