Int.J.Curr.Res.Aca.Rev.2022; 10(05): 107-111

International Journal of Current Research and Academic Review

ISSN: 2347-3215 (Online) Volume 10 Number 05 (May-2022)

Journal homepage: http://www.ijcrar.com

doi: https://doi.org/10.20546/ijcrar.2022.1005.008

Effect of Population Density on Morphophysiological Parameters and Yield of Arabica Coffee: A Review

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Abstract

High planting density is an important strategy for better vegetative growth and higher coffee yield. In high population density, coffee plants undergo competition for growth factors. Plants adapt such constructing environments by bringing certain morphological modifications and physiological adaptations for increase photosynthetic rate. It increases plant height, root length, leaf area index, and specific leaf area while decrease net assimilation rate and increase coffee yield to the cretin level. In general, too closer spacing affects different morph-physiological parameters and yield of coffee. Therefore, optimization of population density is very critical to increase productivity of coffee.

Article Info

Received: 04 April 2022
Accepted: 26 April 2022
Available Online: 20 May 2022

Keywords

Arabica Coffee, Coffee Yield, Morphology, Physiology, Population Density.

Introduction

Coffee plant is more suited for a high planting system and the productivity is generally much greater than low planting systems. High planting density is an important strategy for better vegetative growth performances and higher coffee productivity. It has been also reported that a closely planting favors the individual coffee plant to utilize the environmental resources such as light, moisture, and nutrients throughout the growing period (DaMatta, 2004a).

Different light intensities promote changes in both the physiology and morphology of the plants. Plants adapt to such constructing environment by bringing in some morphological and physiological changes. High population density undergoes competition for sunlight and other growth factors, resulting in an increase in height. Moreover, in dense planting, coffee roots develop deeper so that they take up water and nutrients from lower soil horizons (Carr, 2012; Righi *et al.*, 2007). It increases leaf area index (LAI) and specific leaf area (SLA) while it affects net assimilation rate (NAR) due to mutual shading of leaves (Amanullah *et al.*, 2008; Adugna *et al.*, 2011; Wubishet *et al.*, 2020; Wubishet *et al.*, 2021). Increase in coffee yield with increasing population density has been attributed to efficient utilization of environmental inputs. In addition, too narrow spacing affects growth and yield of coffee through competition for resources (Taye *et al.*, 2001; Singh, 2002).

Optimal planting density is efficiently utilized growth and yield limiting variables such as light, water and plant nutrients. It depends on several factors including cultivars, availability of water and nutrients, spacing and canopy structure of coffee genotype (Singh, 2002; Van der Vossen, 2005; Ashenafi *et al.,* 2017). In general, maximum crop yield is achieved when crop produce sufficient leaf area to provide maximum light interception during reproductive growth and equidistant plant spacing. Therefore, the objective is to review the effect of population density on morphophysiological parameters and yield on Arabica coffee.

Effect of Planting Density on Morphological Parameters of Arabica Coffee

Shoot Height

In high planting density the intensity of light available to the individual plants is lower especially to lower leaves in the canopy due to shading. As the intensity of shading increased due to high population densities, the plant tended to grow taller due to competition. The tendency of increasing height by shade adapted species is important for better use of light (Biruk, 2018).

Densely shaded coffee plants undergo competition for sunlight and other growth factors, resulting in an increase in height. The pervious results have been reported, where the highest plant height was obtained from under shade conditions, due to adaptation mechanism to maximization of light interception by individual leaves (Biruk, 2018). Similar findings reported that Arabica coffee plants grown under shade level (70%, 50%, and 30%) including control, where 70% shade level was given highest plant height (Bote *et al.,* 2018b). Similar result has been reported for fababean, high population density increased plant height due to competition among each other. The highest plant height was obtained from shade, due to adaptation mechanism to maximization of light interception by individual leaves (Thalji, 2010; Biruk, 2018).

Root

Typical root system of a mature Arabica coffee tree consists of a taproot, axial vertical roots, lateral roots, some of which are more or less parallel to the soil surface and other deeper roots that ramify evenly in the soil. The horizontal and vertical growth of coffee roots can be influenced by plant, environmental and soil factors (Wintgens, 2004).

The coffee roots systems are affected by different factors among population density is one of the factors. Coffee roots develop deeper in dense planting systems and they take up nutrients and water from lower soil horizons. Similarly it has also been reported that coffee root length is varying with plant density, genotype, and cultural practices. In another study closely planted coffee results in better uptake of available soil nutrients by denser rooting (Van der Vossen, 2005; Cavatte *et al.,* 2008).

Effect of Population Density on Physiological Parameters of Arabica Coffee

Leaf Area Index

Leaf area index (LAI) refers to leaf area per unit area of land. The importance of this unit of measure is in relation to interception of light for maximum growth. High planting density increase LAI due to mutual shading of leaves and negatively affects on absolute growth rate, relative growth rate and net assimilation rate due the decrease in light interception and had positive effects on LAI. Increase in LAI with increase in plant density is important for better utilization of solar energy (Amanullah *et al.,* 2008; Amanullah *et al.,* 2010).

The higher LAI observed for coffee plants growing under shade indicated that those plants have higher potential for CO_2 assimilation and dry matter production, because of leaves adjust to the light environment under which they expand and develop. Genotype, plant population, water and nutrient had also makes difference on LAI, this difference also a determinant factor in radiation interception, photosynthesis, biomass accumulation, transpiration and energy transfer by crop canopies (Sobrado, 2005; Mohammed *et al.,* 2015; Wubishet *et al.,* 2020). Leaves adjust (anatomically, morphologically, and physiologically) to the light environment under which they expand and develop. However, knowing how plant species respond morphologically and physiologically to contrasting light conditions can be critical in helping to explain and predict their occurrence and abundance patterns under specific environmental conditions. Optimum LAI is very important, as both below and above the critical level may not allowed maximum light interception by plants and yield may even tend to decline due to shading and competition for water, nutrients and light (Taye and Burkhardt, 2015).

Specific Leaf Area

Plants under take certain modification at high planting density to increase carbon fixation such as developing thinner and larger leaves with more thylakoids per granum, more grana per chloroplast, higher chlorophyll content and larger individual leaf area, which allow a more efficient capture of available light energy. At low light, plants enhance light interception by means of a high biomass allocation to leaves and the formation of thin leaves with a high specific leaf area (SLA).

SLA is the ratio of leaf area to leaf dry weight. In high planting density SLA are increased due to mutual shading. Coffee plants grown under shade develop thinner leaves, wider, a larger leaf area and higher SLA which allow more efficient capture of light energy. Plants in low light increase SLA and higher carbon storage; this reflects the adaptive phenotypic plastic plant structural characteristics of coffee seedlings, which enable them to tolerate shade environments. These modifications allow them to efficiently capture and utilize the available light energy in order to increase their dry matter production. In Coffee plants, higher SLA is contributes for the higher rate of photosynthesis (Adugna *et al.*, 2011; Wubishet *et al.*, 2020).

Net Assimilation Rate

Different factors decrease growth and productivity of the crop. Among, light is perhaps the most influential factor involved in the survival, growth and reproduction of tropical species. Light responses usually provoke physiological alterations, which are determinant for CO_2 assimilation and optimization of gas exchange. It can also influence other physiological processes both quantitatively and qualitatively. For this reason, environments that are either shaded or under high irradiance light can inhibit the photosynthesis processes simply because there is too little or too much light. Light is an essential prerequisite for plant life because of energy source for photosynthesis (Goncalves *et al.*, 2005).

Net assimilation rate (NAR) is determined primarily by the ratio of carbon gained through photosynthesis and carbon lost through respiration (Behnam *et al.*, 2014). Photosynthetic rate is the rate at which CO_2 is assimilated in order to increase biomass. Photosynthesis processes could be inhibited, due of the presence of too little or too much light which creates a stressful environment to the system. High population density is reduces photosynthetic active radiation due to mutual shading or low light interception. Plant photosynthesis, hence, NAR is affected by different factors; from this light intensity is one. Plants undertake certain morphological modifications and physiological adaptations for increase photosynthetic rate. Coffee yield is decreased in agroforestry systems, due to limitation of photosynthesis due to low light availability. Leaves are exposed to light have more net photosynthesis than shaded leaves (Araujo *et al.*, 2008; Wubishet *et al.*, 2021).

However, coffee is shade-loving plant with greater quantum utilization efficiency for photosynthesis; excessive shading by the upper two to three canopy strata of various tree species would decrease growth and productivity of the crop including coffee. In such conditions, the plants spent much of their photosynthesis activities for maintenance purposes and also achieve reduced whole-tree carbon assimilation (DaMatta, 2004a; DaMatta *et al.*, 2007; Taye, 2007; Franck and Vaast, 2009). Similar report showed that a low physiological plasticity to low light in coffee leaves located inside the canopy, resulting in reduced NAR as compared to exposed leaves (Araujo *et al.*, 2008).

Effect of Population Density on Yield of Arabica Coffee

High planting density is important for water conservations, soil fertility, soil structure, nutrient cycling and decreased soil acidification, organic matter mineralization, nutrient leaching and runoff.

Coffee is more suited for high-density plantings; indeed the productivity of dense plantings is generally much greater than that of traditional plantings (DaMatta, 2004a; Van der Vossen, 2005). High planting density systems is increases production per unit area along with population density up to a certain level. Previous report showed that production per unit area increased along with plant population density increased. In addition, better vegetative growth performances of coffee cultivars planted using a high density planting system (Taye *et al.*, 2001; Pereira *et al.*, 2011; Nigussie *et al.*, 2017).

Population density is also dependant on the moisture availability and nutrient status of the soil. Under conditions of sufficient soil moisture and nutrients, higher population is necessary to utilize all the growth factors efficiently. Besides spacing, canopy crop or a variety also determines the optimum plant population per unit area of land. However, the yield per unit area is increased due to efficient utilization of growth factors. Coffee yield increased with increasing population densities, though the magnitude varied across crop years and locations (Taye *et al.*, 2001).

Too narrow and wide spacing do affect yields through competition (for nutrients, moisture, air, radiation, etc) and in efficient utilization of the growth factors, respectively. Close spacing between rows and plants resulted in a coffee yield increment, but it depends on several factors such as climatic conditions, coffee variety, soil fertility, pruning systems, and cropping patterns and inputs to be applied. An impact of close spacing on coffee yield performance is largely associated with the prevailing climatic factors that determined the rate of vegetative growth and subsequent adverse mutual shading effects. Optimum population per unit area of the field is essential to get maximum yield (Taye *et al.*, 2001; Paulo *et al.*, 2005; Singh, 2002).

High planting density is an important strategy for better vegetative growth and higher coffee yield. In high planting density, plants undertake certain morphological modifications and physiological adaptations for increase photosynthetic rate. It increases coffee yield to the cretin level while too close spacing is decrease coffee yield due negatively affect net assimilation rate. Therefore, optimization of population density is very important for better vegetative growth and yield of Arabica coffee.

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How to cite this article:

Wubishet Tamirat. 2022. Effect of Population Density on Morphophysiological Parameters and Yield of Arabica Coffee: A Review. *Int.J.Curr.Res.Aca.Rev.* 10(05), 107-111. doi: https://doi.org/10.20546/ijcrar.2022.1005.008