Effects of Planting Density on Tropical Fruit Crops

Subjects: Horticulture
Contributor: Mohammad Amdadul Haque, Siti Zaharah Sakimin

Plant density refers to the number of individual plants per unit of ground area. In an ideal plant population, the capability of the plant canopy to collect environmental resources, including radiation energy, water, and inorganic nutrients, can be improved. A dense plant population increases the competition between plants for resources, which results in limited resources being depleted. Additionally, improved canopy construction can lead to an optimal leaf area index that can boost photosynthetic ability through efficient solar radiation interception. High densities of plants encourage better productivity; lower densities, in general, allow for the harvesting of more large fruits, resulting in higher pricing on the fresh fruit market. Higher planting density is used for higher yields without increasing production costs.

Keywords: planting arrangement ; planting density ; fruit crops

1. Introduction

The selection of the appropriate density is critical for optimizing the yield potential. The optimal plant density should be kept for the maximum possible yields of good quality fruit. Increased plant population density improves the interception of solar radiation and water use efficiency [1], which helps to boost canopy photosynthetic capacity and biomass production [2], thus increasing yield and water productivity [3]. As a result of the optimal planting density, crop yield and quality are improved, while the need for fertilizer and labour is reduced [4]. However, when planting density exceeds a certain threshold, the yield tends to be reduced [5] due to an inadequate supply of carbon and nitrogen, because of intense interplant competition for sunlight, soil nutrients, and water. In modern cropping systems, high plant density in planting is one of the most important agronomic approaches [6]. Maximum yield occurs when the spatial plant density allows for the maximum leaf area index to be given by the rapid growth of the leaf canopy, enabling maximum solar radiation interception as early as possible in the growing season [7]. Plant population density has been a vital variable in yield enhancement studies [8]. As plant density increases, the distribution of resources on the plant scale (soil water, fertility of the soil, light interception) decreases, increasing competition between plants and, in turn, reducing the potential of individual plant yield [9]. The probability of negative effects increases when the density reaches the optimal level for a given area [10]. One of the best management practices to increase yield is the selection of sufficient planting density to maximize light interception, as crop productivity is highly influenced by the total solar radiation intercepted by the crop. Generally, with rising planting density, and solar radiation obtained by the crop increases, the higher planting density is also found to have higher total yields [3]. High plant density associated with shading may lead to disease infestation, the shedding of fruit, reduced fruit size, delayed maturity, and decreased individual plant growth and light interception [11].

Crop spatial arrangement is another agronomic component that might affect the yield [12] and crop competition against weeds [13]. This pattern can also affect plant growth, and development [14]. Uniform planting patterns reduce mutual shade and hasten canopy closure in increasing the leaf area index (LAI). All of these factors contribute to the canopy's improved radiation interception [15], which boosts crop growth and production [16]. The equal spacing of crops, on the other hand, may restrict light penetration or change the illumination quality under the crop canopy. Some weed seeds may not germinate, weed seedlings may not flourish, and weed seed production may be reduced [16]. When there is a uniform distribution, intraspecific competition within a crop is prolonged, but interspecific competition with weeds begins sooner. This permits the crop population to shade out the weeds and prevent them from re-emerging in large numbers [17]. Planting arrangement, or planting pattern, might be an important determining factor for individual plant performance [18]. The planting arrangement of the crop is the most important management aspect that determines the crop structure and can alter crop yield–density relationships [19].

2. Planting Arrangement of Fruit Crops

2.1. Vertical Row Planting Pattern

This pattern of planting is divided into two methods: square and rectangular. The square pattern of planting is the most common method, and it's simple to set up in the field. Plant–plant and row–row distances are the same in this method (**Figure 1**). The plants are at right angles to each other, forming a square with each unit of four plants. After the orchard is planted, this system facilitates interculture in two directions. The main flaw in the system is that the space in the centre of the square is left unutilized [20].

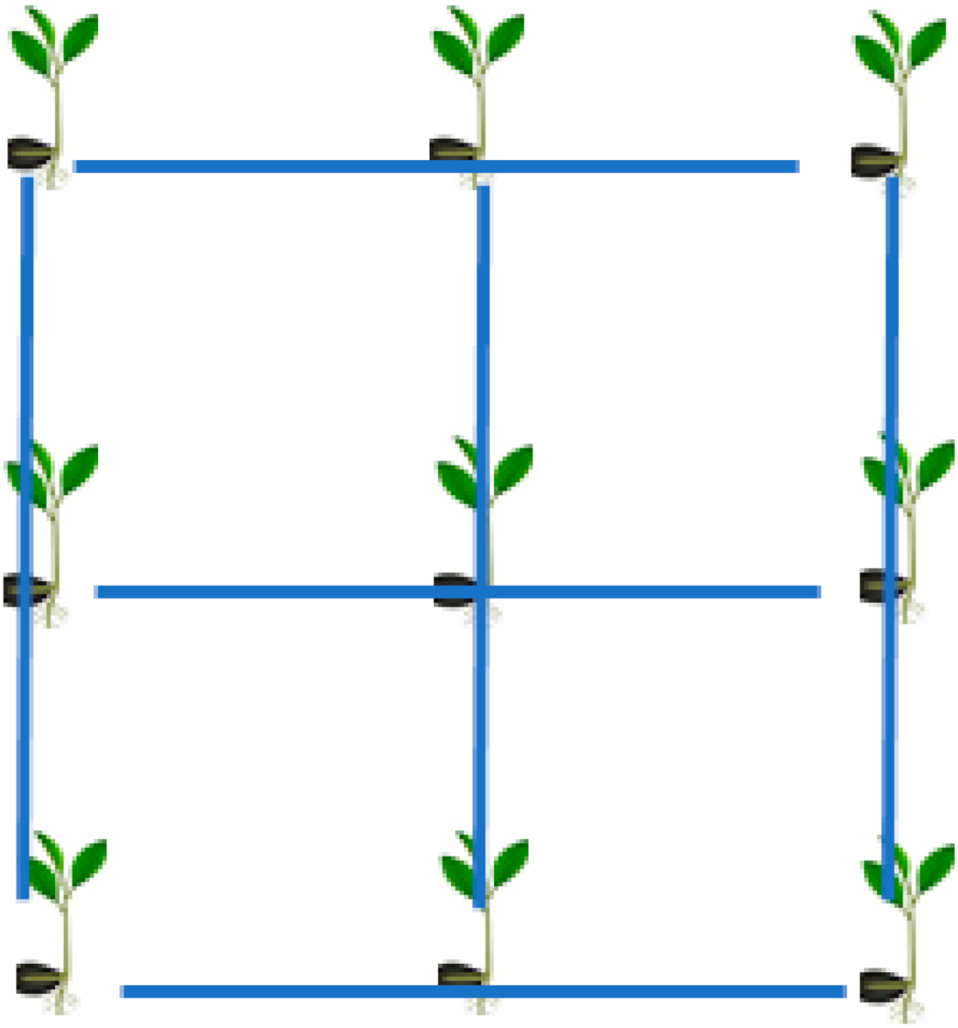

Figure 1. Square pattern of planting.

As opposed to squares, the plot is divided into rectangles, and trees are planted in straight rows running at right angles to each corner of the rectangle (**Figure 2**). Similar to the square system of planting, this system also allows intercropping in two directions. Because the distance between any two rows is higher than the distance between any two trees in a row, there is no equal distribution of space per tree. The main disadvantage of this system is that it results in a greater loss of income when intercropping isn't used [21]. Weed growth is higher than in the square arrangement [22].

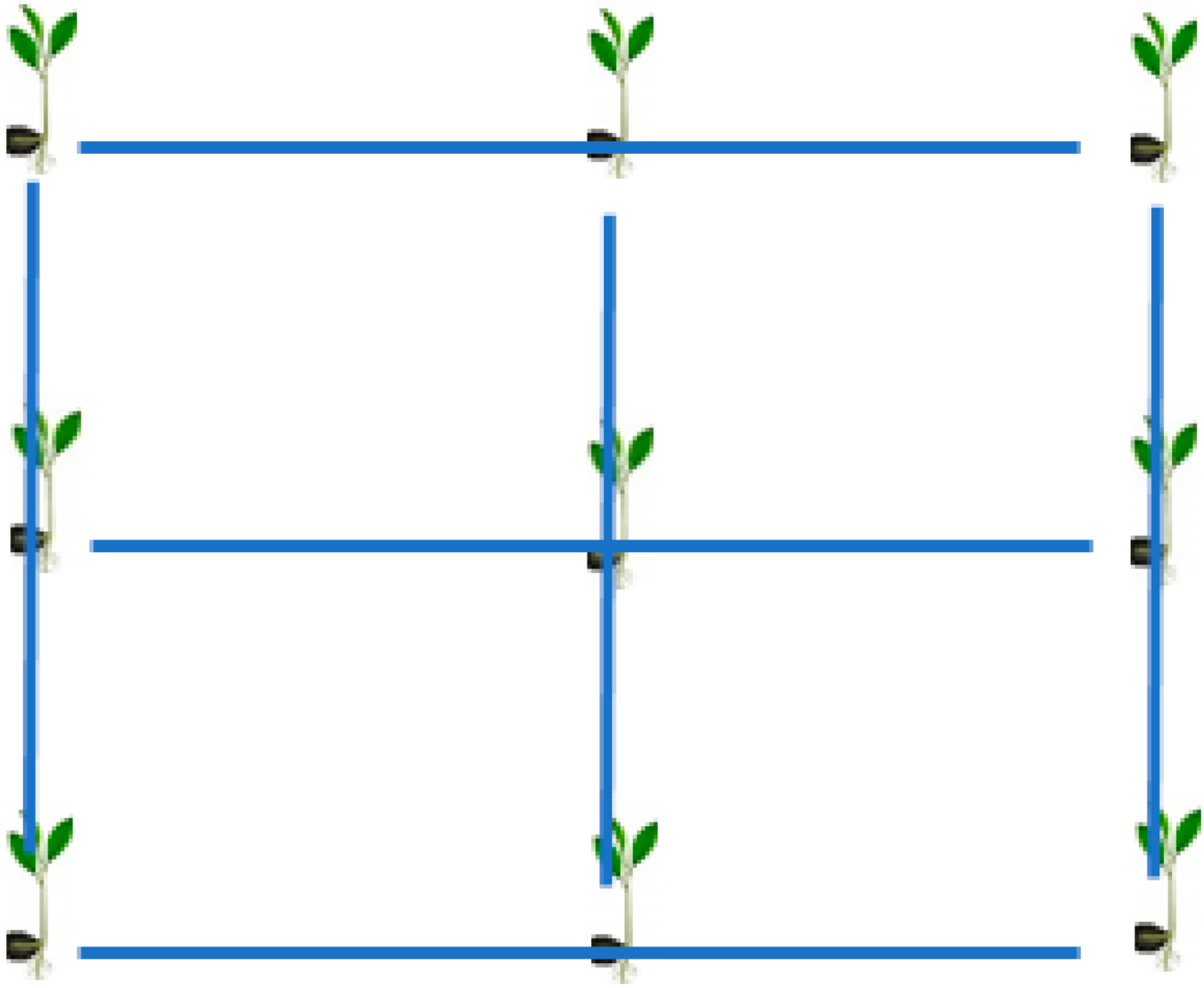

Figure 2. Rectangular pattern of planting.

2.2. Alternate Row Planting Pattern

2.2.1. Hexagonal Pattern of Planting

Within this system, trees are planted in equilateral triangle corners. Six trees are arranged in a hexagon, with another tree in the centre of the hexagon (**Figure 3**). Though it is a bit difficult to implement, it allows for 15% more plants. With this system, it is possible to cultivate land in three directions between the plant rows. In general, this system is used when the land is expensive, fertile, and irrigation water is abundant. If the distance between rows and plants remains the same, the hexagonal system could accommodate 15% more plants than the square system [23].

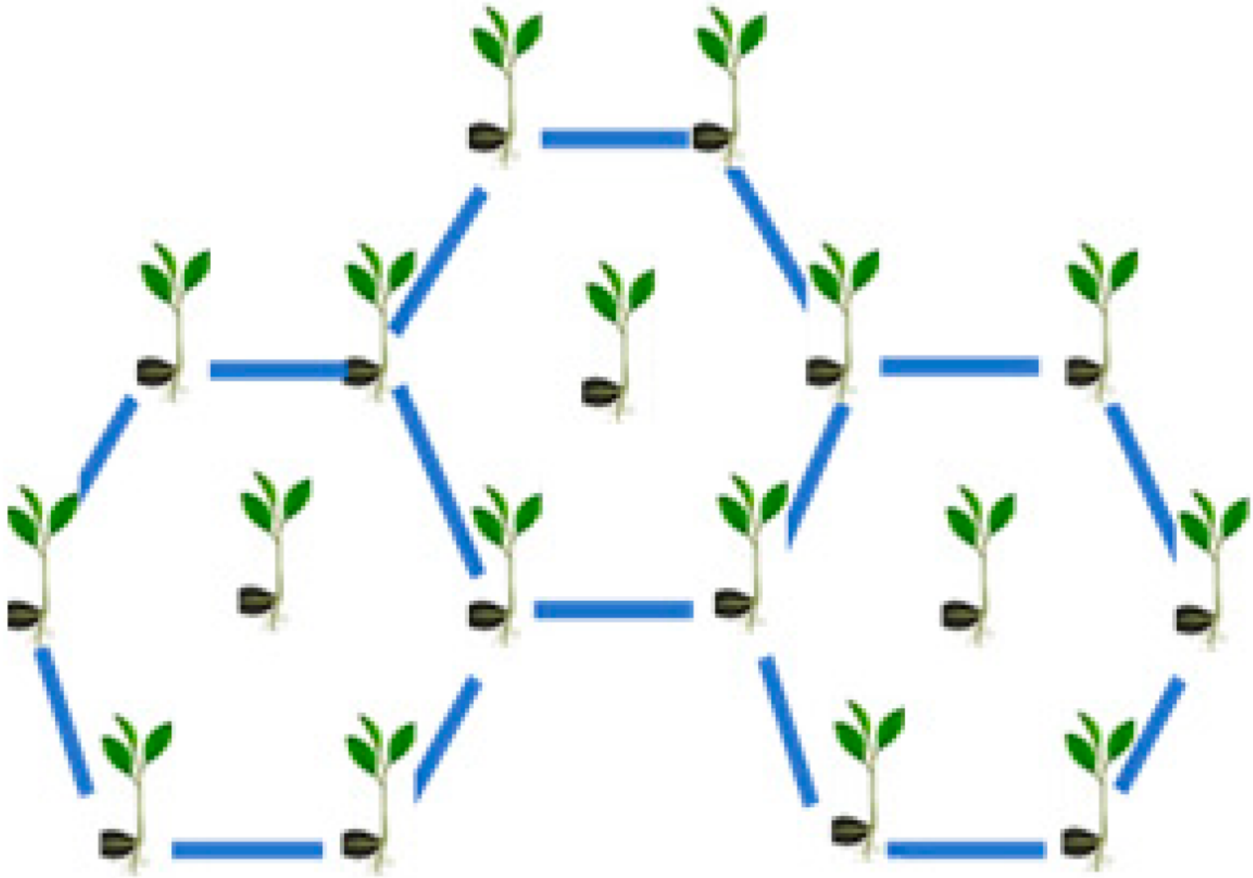

Figure 3. Hexagonal pattern of planting.

2.2.2. Triangular Pattern of Planting

The trees are laid out in a square pattern. The trees in even-numbered rows are situated halfway between those in odd-numbered rows, rather than being opposite to each other. The perpendicular distance between any two consecutive rows is equal to the distance between any two trees in a row (**Figure 4**). This system allows more open space for plants and intercrops, which is beneficial to both. The six plants are planted at each corner of the hexagon, with a seventh plant placed in the middle. There is a slight (11%) reduction in plant accommodation when compared to the square system [23].

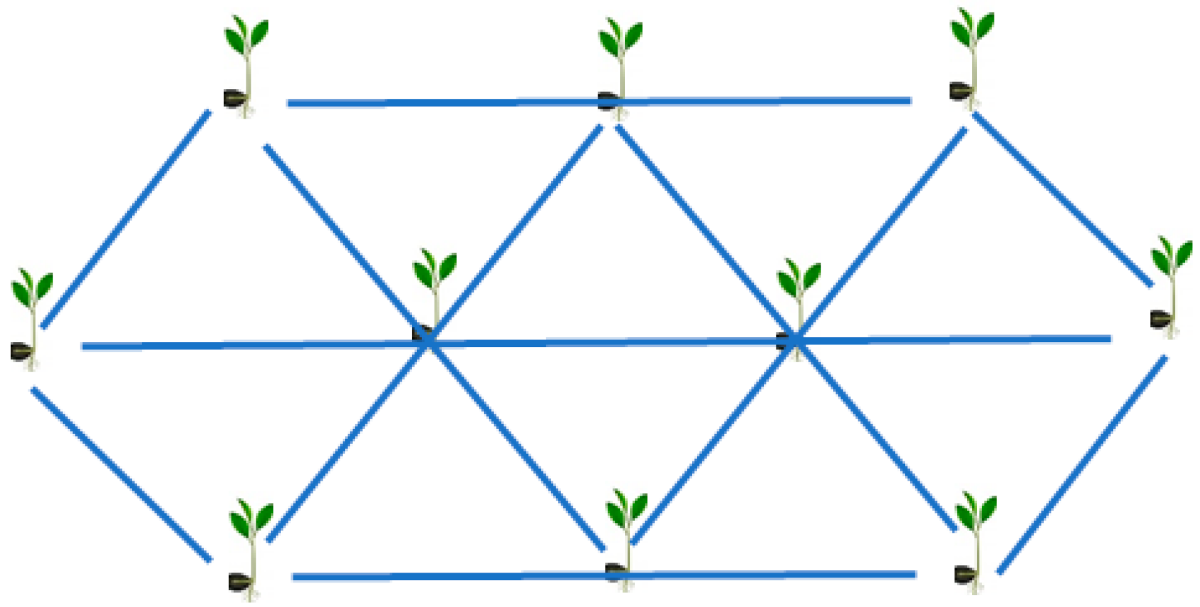

Figure 4. Triangular pattern of planting.

2.2.3. Diagonal or Quincunx Pattern of Planting

There are no differences between this system and the square system, except that each square has an additional tree planted in the middle (**Figure 5**) [24]. This system doubles the number of plants ha^{-1} when compared to the square system.

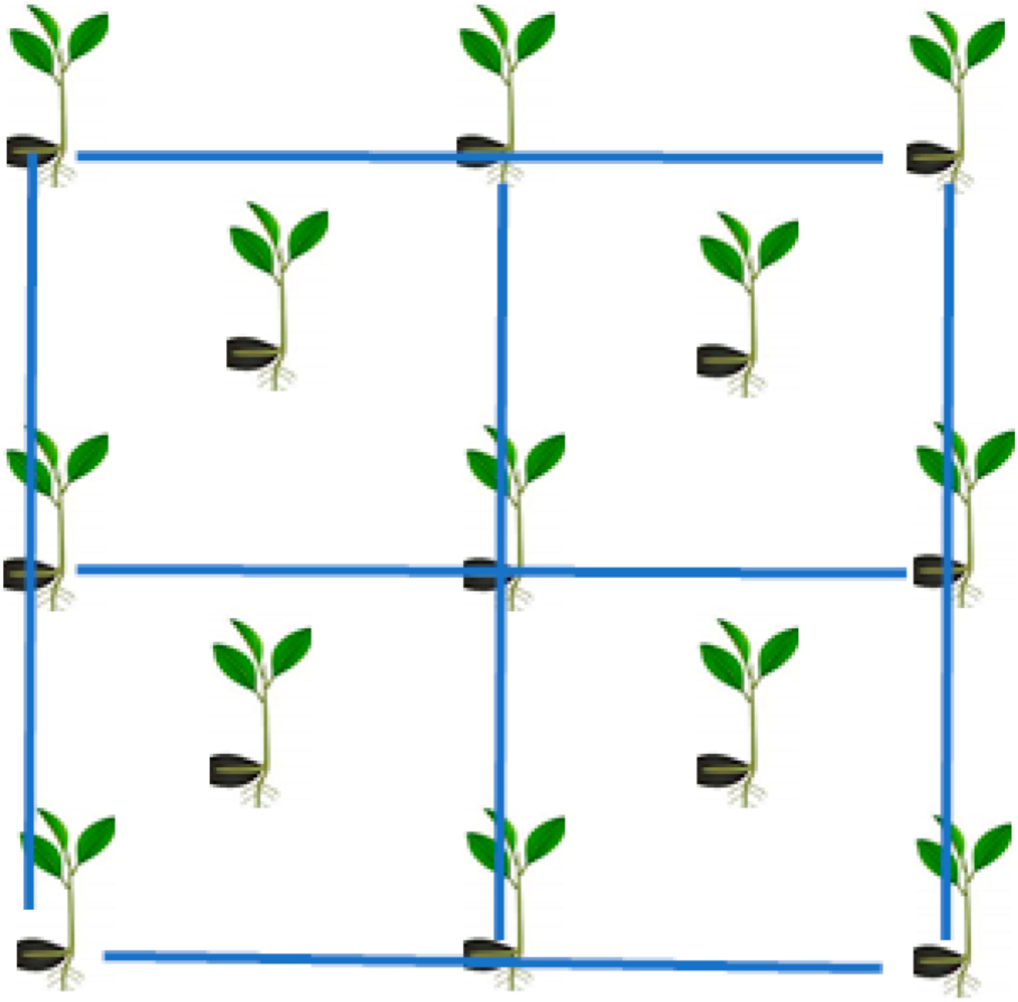

Figure 5. Quincunx pattern of planting.

2.2.4. Contour Pattern of Planting

Hilly areas with steep slopes typically use this system [24], but the system is very similar to the square/rectangular system in terms of its basic design. Planting the trees in lines that follow the contour of the soil with a slight slope may be the best option in such situations (**Figure 6**).

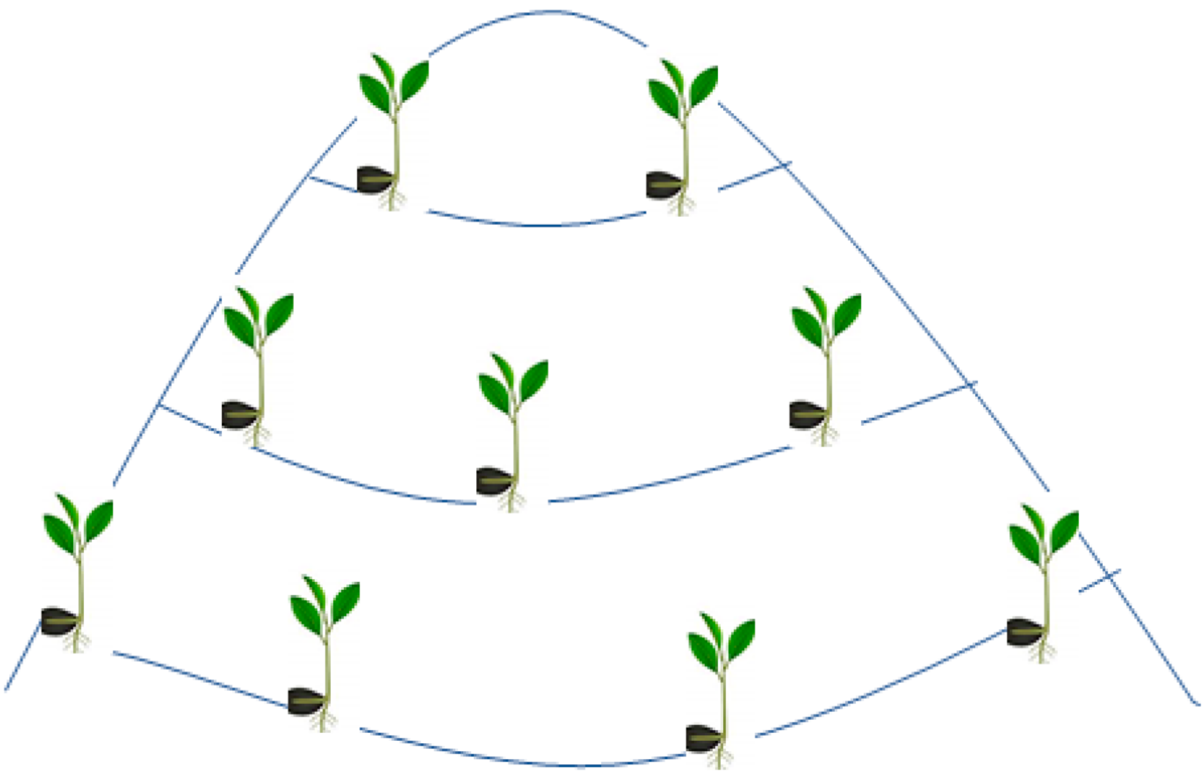

Figure 6. Contour pattern of planting.

3. The Benefit of Planting Density

Nutrients are required by plants. The sun, the soil, and any amendments or fertilizers applied to the soil during the season provide these nutrients. Plants that compete with their neighbours for soil nutrients and sunshine will not be as healthy as those that have all of the resources they require. Their roots will also have to compete for space, nutrients, and water. Too few plants can also be a problem. The shade from properly positioned plants can crowd out weeds as they grow and keep the soil moist, creating a favourable environmental condition that only works well if plants are spaced apart suitably [25]. Adequate space between plants will reduce competition for light, will conserve water, and will provide more soil nutrition to each plant [26]. Plant spacing is significant because it reduces disease risk in two ways: contagious disease and immune system improvement [26]. Plant diseases can easily spread from one plant to another when they grow too close together. Plants that grow too close together are less healthy than those that have enough separation [27]. Overcrowding also lowers air circulation and increases the likelihood of plants being sick. For many pathosystems, microclimatic changes resulting from higher plant densities usually create conditions that are more conducive to disease development [28]. Increased plant density is likely to increase the duration of wetness on host tissues.

4. Factors to Be Considered for Planting Density

The optimal spacing for crops depends on several factors. The first factors to consider are environmental factors. The right establishment method, plant spacing, and planting configuration of crops depend on environmental conditions [29]. In a shady site, leafy plants may require more space than they do when grown in full sun. It is especially important to avoid overcrowding in shady conditions, where disease may be more likely to take hold. However, plants grown in full sun conditions will typically need more water, and so spacing may need to be increased to take into account the amount of water each plant will require and how much can be provided by the soil or growing medium. The planting density of a crop varies on the rainfall pattern of that area. Low rainfall areas should have wider tree spacing than high rainfall ones [30]. The planting density of the crop also depends on the harvesting stage of the crop. If the plants remain in the growing area to maturity, they will require a lot more space than crops that are to be harvested at an earlier stage in their development [31]. Wider spacing should be used for bigger or spreading canopies, while narrower spacing can be used for smaller or erect type canopy [32].

As root and shoot growth is restricted in heavy soils, less spacing should be used. Plant density varies considerably depending on the condition of the growing area and soil fertility status. Fertile soil can support a high plant population [33]. Therefore, closer spacing is possible. Trees trained on the head system require closer spacing than the other types of training systems [26]. On the other hand, the space between the rows should allow free passage for crop management practices. The spacing between rows should be greater for the operation of heavy machinery, while a narrow space is supposed to be used for small machinery [34]. Planting density also depends on the mechanization level of some cultural practices. High planting density can improve the adaptability of mechanized harvests by regulating plant structure [35]. The use of dwarf rootstock is another factor to be considered for planting density as most of the fruit crops are grown with the use of rootstocks. Robinson [36] stated that dwarfing rootstocks have been the key to the dramatic changes in tree size, spacing, early production, and quality of fruit crops.

5. Impact of Plant Density on the Use of Resources

Plants have extreme plasticity in terms of their size and shape that react remarkably to environmental conditions. The existence of competitive neighbours is one of the powers of such external forces and can contribute to a reduction in the size of a plant. Water, nutrients, light, oxygen, carbon dioxide, and pollinating agents during the reproductive process are the factors for which competition takes place between plants. The most common deficiencies are water, nutrients, and light. Competition depends on resource availability and starts when the immediate supply of a single essential factor is smaller than the plants' combined demand [37].

For a single species, the rise in density increases the return per unit area, and intraspecific competition increases as more plants compete for the same common resource constraints. At pure stands, the increase in competition is illustrated by a decrease in the output of individuals, e.g., average individual plant biomass and/or yield [38].

The planting arrangement changes the temporal and spatial pattern in which the limiting resource is intercepted, especially for crops in drylands, in which soil water is rarely sufficient during the growing season. In such circumstances, the spacing between and within the rows is usually a concern [39]. Closely spaced plants have an increased elongation of their roots and thus continue to extract moisture available between the rows for grain production later in the season [40]. The density of the plant must be adjusted to the moisture available, either within the rows or between the rows.

6. Planting Density on the Growth and Development of Fruit Crops

The plant growth can be visualized in terms of an increase in length, plant height, or stem diameter, an increase in fresh and dry biomass weight, an increase in leaf area and leaf weight, and so on [41]. The density of the plantation has a major influence on plant growth and development. The magnitude of the effect usually depends on whether plants compete with one another and on the pattern of growth and morphological characteristics of the competitor [42]. A high density causes certain changes in plant growth, e.g., plant height increases, leaf thickness decreases, leaf orientation changes, and the leaves become upright, thin, and spaced at longer intervals in a vertical order to intercept more sunlight [43].

Leaf area regulates the light interception capacity of a plant and is often used as a surrogate for its growth [44], which is very important parameter in determining plant productivity. Streck et al. [45] reported that green leaf area plant^{-1} was higher in treatments with larger spacing. The highest leaf area plant^{-1} from the treatment of wider spacing was due to the wider and higher number of the leaf. The index of leaf area (LAI) represents crop leafiness and is an important crop growth parameter [46]. All agricultural practices (planting spacing and population densities) lead to alterations of crop canopy and modification of leaf area index [46]. In general, highly populated plants tend to close the soil faster than smaller communities, and therefore, in densely populated plants, the optimum leaf area index is typically achieved more quickly when compared to sparsely populated plants. Planting density influences the leaf area index of crop plants [47]. Because of the larger density, the LAI per pit gradually increased. Although the size and number of leaves on individual plants reduced in high-density planting, the total number of plants and leaves per unit area increased dramatically, resulting in a considerably higher LAI [48].

7. Planting Density on Chlorophyll Content of Fruit Crops

Chlorophyll is essential for plant growth because it facilitates photosynthesis reactions that provide glucose to plants and release oxygen into the atmosphere with the presence of light energy [49]. The chlorophyll content is significantly influenced by planting density. Nagpur mandarin grown under high-density spacing recorded the lowest chlorophyll content, compared to the highest chlorophyll seen at a lower density [50]. Tripathi et al. [51] also observed that the highest chlorophyll content of guava leaf was registered in the widest spacing, whereas the lowest chlorophyll ‘a’ and ‘b’ content were found in the closest spacing. The reduction of leaf chlorophyll content at a higher density could be explained partially by the effects of shading of the lower canopy, causing poor canopy interception of the PAR (photosynthetically active radiation). Moreover, the strong interplant competition due to the crowding of the plants may have prevented the absorption of sufficient water and plant nutrients [52].

8. Planting Density on Fruit Yield

Crop productivity and optimal resource use are both affected by the spacing between plants [53][54]. Plant density is a key factor in optimizing the structure and increasing the photosynthetic capacity of the plant canopy. Agricultural factors such as crop geometry and plant density influence yield and profitability [55]. Sarrwy et al. [56] reported that the highest yield (13.80 t ha^{-1}) of banana was obtained from plants spaced at wider spacing (3 × 2 m) with two suckers per hole, while the lowest yield (12.28 t ha^{-1}) was recorded from 3 × 1 m, with one sucker per hole. The earliest flowering (12–13 days) with minimum days required for harvest was also recorded at the widest spacing (3 × 4 m) with three plants per hole, compared to that of the lowest spacing (3 × 1 m), with one plant per hole. Additionally, the heaviest bunches and fingers with the longest fruit were also harvested from the plants that were spaced at 3 × 4 m, with three plants per hole. They mentioned that the highest yield with the wider spacing of three suckers per hole could be attributed mainly to the increased number of plants in a unit area. According to Chaudhuri and Baruah [57], the plant population has a significant impact on both the yield and the yield-related characteristics. The largest bunches (18.50 kg) were found in those with the lowest plant population (4444 plants ha^{-1}) and this gradually dropped as the plant density increased. This drop in bunch weight with increasing plant density could be attributed to greater canopy light interception, which may have aided in improving the vegetative characteristics but not bunch weight. In contrast, when the plant population density was low, more leaf surface was exposed to sunlight and, indirectly, a larger amount of assimilates gathered in different organs of the plant owing to the increased bunch weight. Marketable yield was observed to show a tremendous increase per unit area with the increasing plant population density.

9. Planting Density on Fruit Quality

Measures of fruit quality include both internal and external properties. The internal quality is mainly determined by aroma, flavor, taste, texture, and nutritional quality (e.g., soluble sugar content, starch, organic acids, soluble solids content, carotenoids, total flavonoids, total phenolics, antioxidant activity, etc.), flesh firmness, diseases, and chemical residues. The external quality mainly concerns appearance, size, color, and bruises. Fruit quality depends on the distance of planting. Sarrwy et al. [56] confirmed that soluble solids concentration (% Brix) and total sugars (%) were measured from the highest plant spacing (3 × 4 m) with three plants at every hole. Another study by Chaudhury and Baruah [57] reported that the plants that are raised under low density exhibited superior fruit quality in terms of SSC, total sugar, and sugar-to-acid ratio. These parameters tended to decrease as plant density increased. In contrast, titratable acidity and non-reducing sugar showed the opposite trend. The higher acidity in a higher plant population may be due to the shade effect, where sugar conversion from organic acid is hampered due to a lack of sufficient light. Moreover, lower reducing sugar and higher non-reducing sugar in the high-density plot may be due to a lower conversion of sugar from starch.

10. Conclusions

High-density orcharding is one of the recent novel concepts of fruit cultivation, involving the planting of fruit trees densely for better light interception and distribution to increase yield as well as to increase mechanization level. Several studies have been conducted to standardize the planting density of different fruit crops for higher yields with superior quality. A very limited number of studies have focused on an integrated approach of higher planting density with other factors of agronomic management that can improve the quality of fruits. In summary, a lower planting density improved fruit size and fruit quality. However, a higher density of plantings increased yields but reduced the fruit quality. Hence, it is recommended that integrating plant spacing with other cultural practices should be investigated to improve fruit quality.

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