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Orchard designing in fruit crops

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Abstract
An orchard design is a comprehensive strategy for the establishment and management of an orchard. Orchard design aims at efficient utilization of space and other resources, minimizing competition between trees for nutrients and moisture, maximizing light interception and to have compatibility with various management practices. There are five components that must be considered while orchard designing viz, tree density, rootstock, training system, row direction and orchard layout. Plant density greatly affects orchard efficiency, productivity and intensity of management needed to run the orchard. The different plant density systems are: (1) Low density system, (2) Medium density system and (3) High density system. Nowadays orchardists are switching to ultra-high density system since agricultural land is shrinking day by day due to urbanisation. Ideal plant density will depend on rootstock, training system, orchard layout etc. Rootstocks which offer maximum size control are used for high density planting while those which offer less size control are used for low density planting. Moreover, proper training helps in the development of strong tree framework and increases canopy porosity to light. For low-density orchards, the training systems used include open-centre, central leader and modified central leader. For high-density orchards, the training systems used are : perpendicular-V-system, parallel-V, Quad-V, vertical axis, slender spindle, Hytec, tatura trellis etc. Recently new training system (centrifugal system) has been developed in apple for better colour development due to its maximum light interception. Orchard layout is also an important component and it should aim at providing maximum number of trees per hectare, adequate space for proper development of trees and ensuring convenience in orchard cultural practices. There are two main systems of orchard layout: (1) Vertical row planting pattern (square, rectangular) and (2) Alternate row planting pattern (hexagonal, triangular and quincunx). Hexagonal system is considered best. North-South row direction is best for maximum solar radiation interception. Effectiveness of each component of orchard system viz, tree density, rootstock, training system, layout etc is measured by its influence on light interception and light distribution. Introduction of optimum strength of honey bee colonies in an orchard at proper location and distance from fruit trees is critically important due to their pivotal role in pollination, thus fruit set and production of orchard depends on honeybees. Proper and careful combination of the best components will result in best orchard design and thus higher productivity of quality fruit.

Keywords: Orchard design, plant density, training system, row direction

Introduction
An orchard design is a comprehensive programme for the establishment and management of an orchard (Barritt. B.H, 2000) [7]. In selecting a particular orchard design there are many factors to consider. All these factors are not equally important, the importance of any one factor depends on the grower's goal (Barritt *et al*., 1997) [11]. A goal to maximize yield by sacrificing some management convenience will call for one kind of planting system. A goal to maximize management efficiency, fruit quality, or early returns on investment will require another another system. Goals for an orchard are not always mutually compatible. Many orchard systems have been developed over the years to meet special climate, equipment, labour and market needs at specific locations. Orchard systems developed in fruit districts around the world include the freestanding central leader, vertical axis, slender spindle, super spindle, tatura trellis, V-spindle and HYTEC. Each of these systems is made up of five building blocks (components). These are the five pieces of the orchard system puzzle that must be integrated to achieve a successful orchard. Each orchard system is a unique combination of these factors (Barritt., 1992) [8]. For example, the freestanding central leader system is a non-supported medium density of pyramid-shaped trees planted in single rows on a semi-vigorous rootstock with a central leader trained vertically up to a height of 4 to 5m (13-16 ft). In contrast, the slender spindle system, also a pyramid tree form is planted at much higher densities, often in multi-row arrangements, uses a dwarfing rootstock, is supported and is trained to a height of approximately 2m (6.5 ft). Orchard design affects economic strategies, such as intial investment costs, coming to first returns, and expected life span of the orchard

(Day *et al*., 2003). For example, one grower may choose to increase orchard establishment costs to obtain early high yields. Another may minimize establishment costs for a slower return on initial investment. The choice could be to emphasize premium price fruit (high quality, large sizes) or to emphasize volume at the expense of quality and size. Of the numerous orchard designs available, no one is best for all situations. Selecting the "best" depends on the goals previously mentioned and on such limitations as soil fertility, water supply, variety vigour, variety growth and bearing habit and the availability of size controlling rootstocks.

Objectives

The main objectives of orchard designing are:

1) To have efficient utilization of orchard space and other resources.
2) To have maximum solar radiation interception and distribution within the orchard canopies in order to achieve maximum fruit quality and yield.
3) To minimize competition between trees for nutrients and moisture by having proper tree spacing.
4) To have compatibility with various management practices such as pruning, thinning, harvesting, pest control etc.

- **Important considerations in orchard designing**

Following points should be considered during orchard designing or setting an orchard:

1) Leave adequate room at the ends of rows for equipment to turn. At least 30 feet will be needed.
2) Long rows allow for greater efficiency in maintaining the orchard than many short rows. Less time is spent in turning at the ends of the rows.
3) Planting across a slope is preferable to planting up and down. This makes installation and operation of irrigation systems simpler, increases precission of pesticide application.
4) Uniform-shaped fields mean fewer short rows.
5) Leave open spaces in low areas of rows planted across slopes, to enhance air drainage out of the orchard, which lessens frost and disease pressure and provides an area to turn equipment.

- **Components of orchard designing**

There are five important components while selecting or designing an orchard, viz tree density, rootstock, training system, orchard layout and row direction. These components are permanent and cannot be changed during mature stages of orchard, so orchardists have to be very careful while selecting these components as they have direct impact on solar radiation interception which inturn affects productivity of an orchard since plant is actually the collector of solar radiation and converts it into chemical energy (Barritt *et al*., 1997) [11] These components are strongly related to each other and they need to be assembled properly to ensure good economic results (Hoying and Robinson, 2000) [25]. Provided that techniques are compatible, a large range of combinations is possible (Costes *et al*., 2006) [12]. These components are discussed below:

A) Tree density

One of the crucial decisions that the orchardist has to take is the tree density. It is defined as the number of trees per acre and it greatly affects orchard productivity, efficiency and intensity of management required to run the orchard (Tustin *et al*., 1997) [40]. Higher density orchards (500+ trees/acre) maximize productivity per acre and thus minimize land wastage. Low density orchards (100-300 trees/acre) tend to produce less, but also minimize intensity of management, as water management, tree training and pruning etc (Perry and Fernandez., 1993) [36]. Today majority of the mature orchards have densities between 200-500 trees per acre, but many growers are switching to higher density planting due to increased production and precocity. Increasing the no. of trees per unit area increases yield upto certain limit in young orchards, but as the trees mature too many trees cause crowding and shading, which change the microclimate of the tree as a result tree invites many diseases and pests which result in decline of yield and quality of fruit (Annandale *et al*., 2004) [3]. Ideal tree density will vary depending on soil type and topography, varieties, rootstocks, training systems, presence of irrigation and the grower's management capabilities. There are three types of density systems: 1) Low density, 2) Medium density and 3) High density system. Potential advantages of planting at higher densities are to : 1) increase early yields, 2) increase efficiency of orchard operations (ladderwork,spray coverage, weed control, etc.) through altered canopy configurations and reduced size, and 3) increase fruit yield relative to vegetative growth. Since the land is shrinking day by day due to urbanisation, and people are moving towards mechanization i.e. using mechanical harvesters and other machinery for carrying out various orchard cultural practices another system of planting has been developed known as ultra-high density system and farmers are nowadays switching over to this system (Barden and Marini., 1998) [5]. It is also known as bed system, because the beds of 10-15 rows is closely planted (30cm× 45cm) and seperated by alleys having 2.5m width between beds. Another name for ultra-high density is meadow tree orchard system, since the no. of trees is very large about 40,000-50,000 trees/ha. This system is used in Northern Europe for apples on ultradwarf rootstocks, but are unsuitable on non-dwarfing rootstocks. The meadow-orchard system involves annual mowing of shoots at harvest time similar to using a commercial tomato harvester. Barritt (2000) [7] has conducted an experiment on Fuji and Braeburn apple cultivars, in which he compared three tree density systems in relation to yield and found that yield was higher in high density system in both the cultivars. This was due to higher canopy volume/ha. in case of higher density system resulting in maximum solar radiation interception, thus higher photosynthetic efficiency as depicted in table below:

System/rootstock	Tree density (no./ha)	Yield (MT/ha)	Canopy volume/ha (m^3/ha)
Fuji			
Vertical axis/M.26	1,502	31.4	11,471
Central leader/M.26	1,111	22.4	9,088
Braeburn			
Vertical axis/M.26	1,502	35.1	5,514
Central leader/M.26	1,111	24.9	3,149

In another experiment conducted by Barritt (2000) [7] on the same apple cultivars, Fuji and Braeburn, he found that mean annual production for the three orchard systems at a density of 2,500 trees/ha was very similar with both Fuji as well as Braeburn cultivars. The HYTEC system with lower tree density had significantly lower production/ha than the other three systems with both the cultivars. The reduction in yield in HYTEC was proportional to its reduced tree density. Thus it is apparent from these data (shown in table below) that tree density has significant effect on fruit yield.

Treatments	Yield (MT/ha)	Yield (MT/ha)
Orchard system	Fuji/M.9	Braeburn/M.26
Tatura trellis at 2500 trees/ha.	45.3	42.7
'V'spindle at 2500 trees/ha.	44.7	41.3
Double row at 2500 trees/ha.	43.5	39.0
HYTEC at 1667 trees/ha.	31.2	28.9

At whatever planting density is finally decided upon, the basic rule is to plant trees so that at maturity they touch each other but donot crowd each other. Also ensure that space is available for machinery to move freely through the orchard.

B) Rootstocks

In order to obtain ideal tree size for the tree density used, proper rootstock combination is necessary. Rootstocks which offer maximum size control are used for high density planting, where as those offer less size control are used for low density planting (Hirst and Ferre., 1995) [24]. Accordingly rootstocks have been categorised as: dwarfing, semidwarfing, ultradwarfing and vigorous. When selecting a rootstock to use for a cultivar, consider what effect the rootstock is going to have over the aerial portion of the tree. The genetic control of rootstock on cultivar include:

- Size: The overall size of the tree will be greatly determined by the rootstock, but the cultivar that will be grafted onto the rootstock must be considered. Low vigour cultivar must not be grafted on very dwarfing rootstock, because result may be a very runted tree.
- Date of bloom and amount of bloom: Some rootstocks may delay or hasten bloom.
- Precocity: Precocity or ability to bear fruit early is one of the advantages associated with some rootstocks, particularly the dwarfing rootstocks.
- Winter hardiness: Winter hardiness of rootstock is important to consider. Some rootstocks are slower at 'hardening' for winter and might be killed if an early frost occurs.
- Resistance: Rootstocks must be resistant to diseases such as collar rot, fire blight etc.

The list of dwarfing, semidwarfing, ultradwarfing and vigorous rootstocks of various fruit crops is given in the table below:

Fruit tree	Dwarfing	Semidwarfing	Ultradwarfing	Vigorous
Apple	M.9, G.65.	M.7, M. 26, MM.106, P.1, B.9.	M.27, P.2, P.16 P.22, B.469.	MM.104, MM.109, MM.111.
Pear	OH×F51.	OH×F.34, OH×F.69, OH×F.87, OH×F.230.	Quince C.	P.communis, P.ussuriensis, P.calleryana, P.beutifolia, OH×F.18.
Peach, plum and apricot	Prune GF.43, P. basseyi (sand cherry), pixy	EM.478, Damas GF.1869, St. JulieA,St. Julie Hybrid-2.	St. Julie K, P. maritime,P. tomentosa.	Mariana, Myrobalan, Buck plum, St. Julie Hybrid-1.

Thus before deciding plant density, the proper rootstock selection is very important and should be done with utmost care.

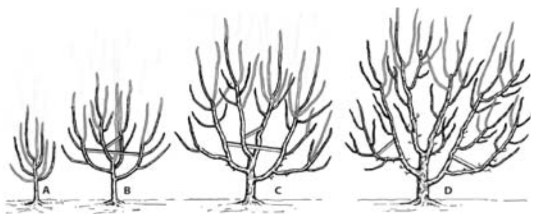
C) Training systems

Fruit growers often neglect annual training of fruit trees. Without proper training, however, fruit trees will not develop proper shape and form (Barritt, 1992) [10]. Properly trained trees will yield high quality fruit much sooner and live significantly longer (Forshey *et al*, 1992) [23]. Primary objective of training is to develop a strong framework that will support fruit production (Flore *et al*, 1996) [22]. Improperly trained fruit trees generally have very upright branch angles, which result in serious limb breakage under a heavy fruit load (Almeras *et al*., 2002). This significantly reduces the tree's productivity and may greatly reduce tree's life. Proper tree training also opens up the tree canopy to maximize light penetration (Almeras *et al.,* 2004). Light penetration is essential for strong flower development and optimal fruit set, flavour and quality (Myers, 1994) [35]. Opening the tree canopy also permits air movement through the tree, which promotes rapid drying to minimize disease infection and allows thorough spray penetration (Lauri and Lespinasse, 2000) [33]. Additionally, a well-shaped fruit tree is aesthetically pleasing, whether in a landscaped yard, garden or commercial orchard. Once the tree structure is established, the main focus of all the training systems is to annually balance the fruit number and weight with vegetative growth. In many perennial crops, an excess of fruit at the expense of vegetative growth may lead to irregular cropping, alternating between large and small crops in consecutive years. Thus training methods at tree scale aim at directing vegetative growth towards fruiting sinks through precocious growth cessation that optimizes the carbon budget of tree with regard to fruiting (Sansavini and Corelli Grappadelli, 1992; Lauri and Kelner, 2001) [38, 30] and reduces heterogeneity between shoots (Lespinasse, 1996) [32]. The main benefits of training are summarised below:

- To promote development of strong framework.
- Enhance early productivity.
- Aid in the development and maintenance of tree size and shape.
- Promote flower bud development throughout the canopy.
- Increase fruit size and enhance fruit quality.
- Reduce tendency for biennial bearing.
- Reduce the incidence and spread of certain diseases.
- Facilitate other horticultural practices like, spraying, thinning, harvesting etc.

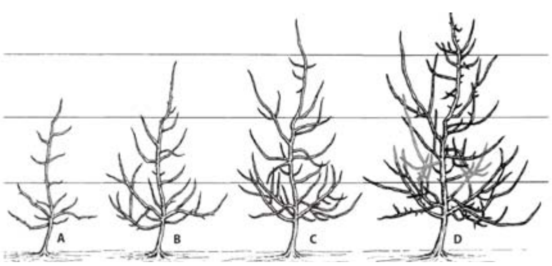
Different types of training systems for various fruit crops are as given below:

1) **Open-centre system**: This is the traditional low density training system almost exclusively used for peaches, plums and nectarines. With open-centre system, the leader is removed leaving a 'vase-shaped' tree with upright growth removed from the centre. Instead of having central leader, the open-centre tree has three to major limbs called 'scaffolds', coming out from the trunk (as shown in Fig. below). This training system allows for adequate light penetration into the tree, which minimizes shading problem prevalent in higher-vigour trees such as peach trees.



Open-centre training system.

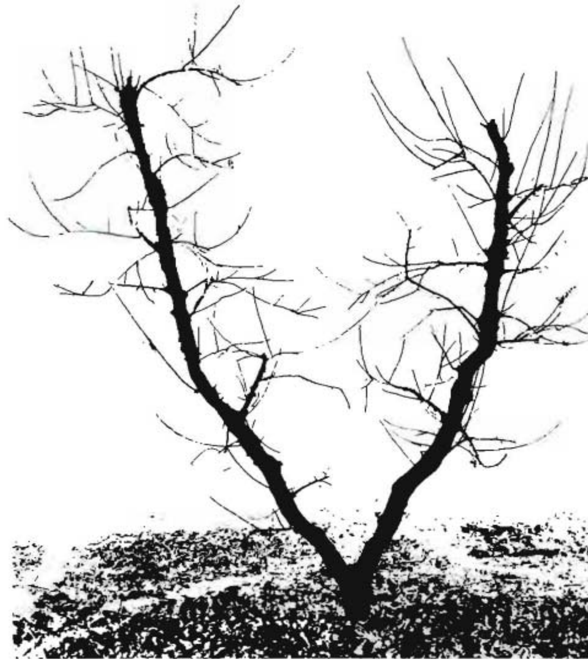
2) **Central leader system:** A central leader tree is characterized by one main upright trunk, referred to as leader. Branching generally begin on the leader 24-36 inches above the soil surface to allow management practices under the tree. Fruiting branches arise from the central leader directly or from the lateral branches arising from the main scaffold (as shown in Fig below). Since the tree's top is exposed to direct sunlight, it results in excessive vegetative growth at the top creating an umbrella effect, which, as the season progresses, shades lower portions for greater lengths of time, causing decreased fruit yields and colour in lower portion of tree (Dejong and Grossman., 1995) [17].



Central-leader system.

3) **Multi-leader system:** A multi-leader system is a modification of traditional central leader tree and is the option for pear varieties that are susceptible to fire blight. With a multi- leader tree if one leader is infected with fire blight, it may be removed without loss of major portion of tree. The multi-leader tree uses the same concept as that of the central leader tree except there are several leaders in the centre of the tree. Each leader is maintained the same as an individual central leader tree.

4) **California-V-system:** In this system, tree is trained to two scaffolds oriented at an angle (Fig. below). This is to overcome the shading problem caused in central leader system. This is a high density training system having less distance between rows compared to open-centre and central leader system which causes difficulty in moving and turning the equipment. Since the angle is less than in conventional, open-centre trees, particular care must be taken not to let the centre of V fill in or an umbrella effect occur.



California-V-system.

5) Perpendicular-V-system: This system is similar to the California-V-system, except that the two scaffolds are oriented perpendicular to the row(Fig below).Trees are planted 5-7 feet apart in the row(high density system) and is used to obtain early high yield (Dejong *et al*, 1991) [15]. Here row widths are similar to conventional open-centre system, thus the equipment can freely move between the rows, so there is no need of modification of an equipment. The primary disadvantage of this training system was tree cost, because three to four times more trees are initially planted.

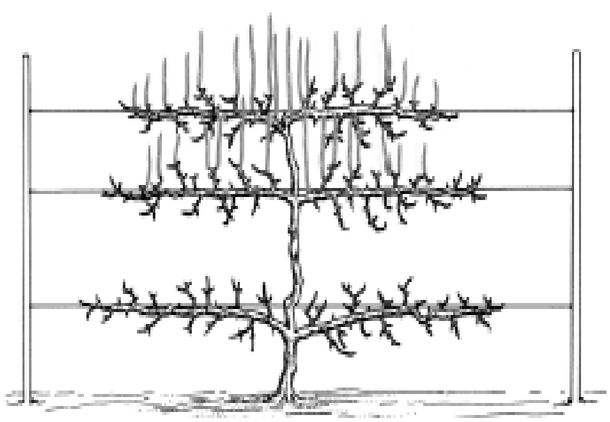
Perpendicular-V-system

6) Quad-V-system: To overcome the problem encountered in perpendicular-V-system, a variation of Perpendicular-V-system, called as Quad-V-system was developed. In this system, trees are planted slightly farther apart down the row and has four scaffolds instead of two. The Quad-V- system retains the uniformity aspects of Perpendicular-V-system, but allows for third fewer trees per acre, which means a significant savings (Day *et al*, 2005).

The main advantage of these 'V, systems is the uniformity among the trees. Since the tree is trained to two or four scaffolds, this improves the labour efficiency. Uniformity also allows growers to better estimate, plan and develop the crop in an orchard; at the same time, every scaffold projects in the row middle, improving equipment usage and spray efficiency. These 'V' systems have been developed to accommodate mechanical harvesters.

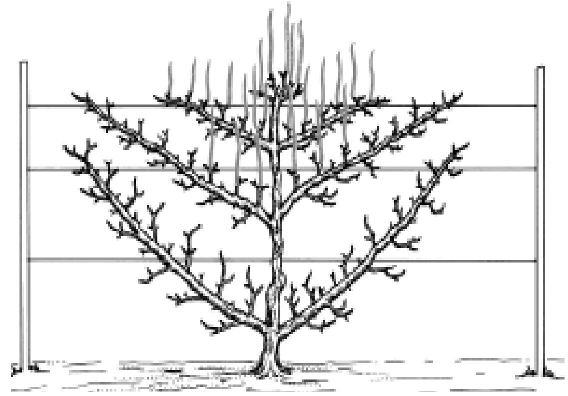
Quad-V-system.

7) **Espalier system:** In this system, trees are trained to a central leader and horizontal fruiting branches tied to trellis wires (Fig. below). Since forcing to grow more horizontally can stimulate spurs to form and increase fruitfulness, this system offers greater potential for extensive manipulation of tree canopy. However, successful manipulation is costly and requires considerable knowledge of tree responses to manipulation. Also tying branches horizontally to wires stimulate water sprout development and reducing shoot productivity (Dejong and Grossman, 1994) [16]. Vertical espalier system offer potential for rapid canopy developement, more uniform sunlight distribution throughout the canopy and maintenance of a narrow fruiting wall.



Vertical espalier

8) **Palmette system:** This is a special pattern of vertical espalier system. In this system, tree is trained to a central leader with fruiting branches tied at an angle of 45 to 60 from vertical instead of 90 as in espalier system(Fig below). This is to minimize water sprout development as in Vertical espalier system and thus increase fruitfulness.



Palmette system.

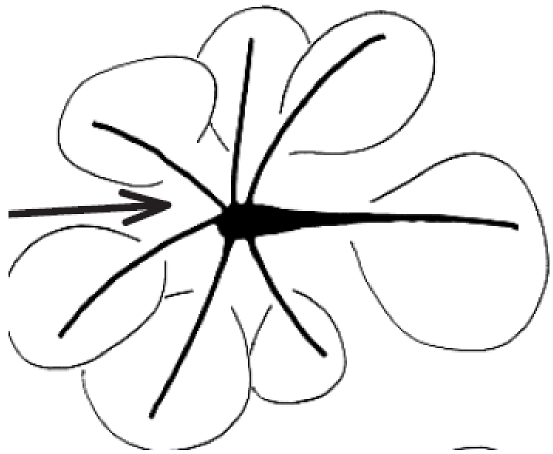
9) **Tatura-trellis system** This is similar to Prependicular-V-system except that the trees are planted more closely together and fruiting scaffolds are tied by the trellis(Fig. below). This system offers the rapid canopy development and was initially intended to accommodate mechanical hedging and harvesting of the processing fruits. This system has potential of high yields because sunlight is distributed efficiently over the entire system and the wide canopy angles tend to stimulate fruitwood development.

The primary disadvantages of this system are the high cost of establishment and replanting, and the necessary commitment of extensive, detailed canopy manipulations.

Tatura trellis

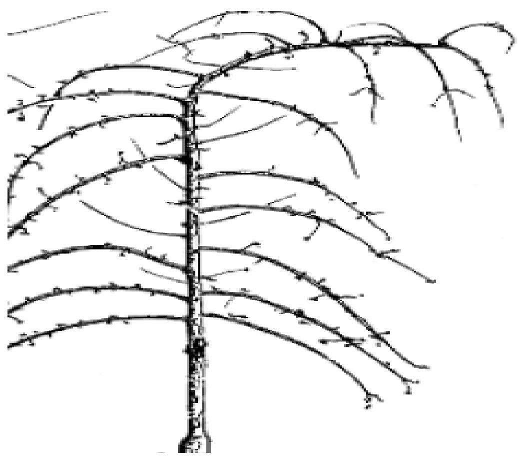
10) **Centrifugal system**: In this system, artificial extinction is carried out more specifically on underside as well as proximal part of the fruiting branch and around the vertical trunk, where shaded laterals have poor fruit set, size, colour and soluble solids (Tustin *et al*, 1988; Rom. 1992) [39, 37]. This favours fruiting in the peripheral zone of the canopy and significantly improves light interception by fruiting shoots (Fig. below), as well as canopy porosity (Willaume *et al*. 2004) [31]. From a biological point of view centrifugal training doesnot act only as a fruit load-regulating technique since some photosynthate sources (leaves) and sinks (fruits) are removed at same time. It is therefore not fully comparable to hand thinning or chemical thinning of flowers and fruitlets during which only generative organs are removed, while leaves are kept.

Results on 'Gala' and 'Braeburn' in an experiment conducted by Lauri *et al*. 2004 [42]; Ferre *et al*. 2002 [43]; Larrive *et al*. 2001 [28]; Crete *et al*. 2002 have shown that centrifugal training improved and homogenized fruit size and return bloom as compared to vertical axis and Solaxe systems.



Centrifugal system

11) **Solaxe system:** In this system tree is trained to a central leader, but limb positioning is done towards horizontal, so as to overcome apical dominance and thus to ensure development of lateral branches, resulting in increased fruitfulness (Fig. below). Developed for apple (Lauri and Claverie. 2005) [29].



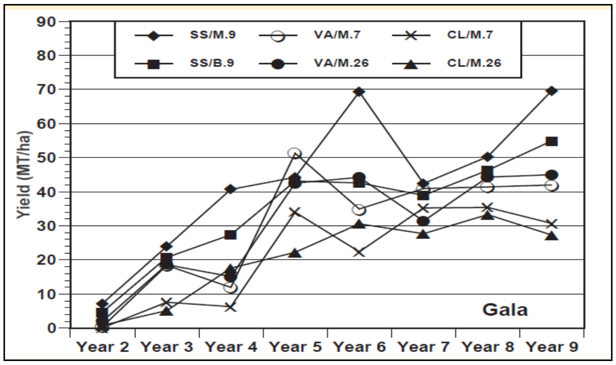
Solaxe

12) **High density central leader system**: Nowadays apples are being grown and sold on size controlling or dwarfing rootstocks. Since many more trees are planted per acre, the term high-density planting is used. The use of size controlling rootstocks and need to maximize fruit production have led a shift in training systems. High density trees are trained differently, but basically they are modified central leader trees with branches continually along the central leader to the top of the tree. The different high-density central leader training systems are: 1) vertical axis system 2) slender spindle system3) free standing central leader and 4) HYTEC (Hybrid tree cone). The important characteristics of these high-density systems are illustrated in the table below:

Characteristic	Free standing central leader	Vertical axis	HYTEC (hybrid tree cone)	Slender spindle
Tree height (feet)	12-14	10-14	9-11	7-8
Tree spread at base (feet)	9-11	5-7	5-7	3-5
In-row spacing (feet)	10-15	5-6	5-6	4-5
Between-row spacing (feet)	15-22	13-15	11-14	10-12
Density(trees/acre)	132 – 290	500 – 700	500 – 900	700 – 1,000
Rootstocks	M.7, MM.106, MM.111	M.9, M.26, M.7	M.9, M.26	M.9
Support systems required	No	Yes	Yes	Yes

Wunsche *et al*., 1996 [26] conducted an experiment on ‘Empire’ apple trees in which three training systems (‘Y’, ‘SS’, ‘CL’) were compared with respect to no. of fruits/tree, yield (kg/tree), yield (t/ha.) and it was found that no. of fruits/tree and yield (kg/tree) was higher in Central leader system and lower in ‘Y’ system and ‘SS’ system, but yield(t/ha.) was highest in ‘Y’ system and lower in ‘CL’ system. The reason for this being the maximum leaf area index in ‘Y’ system resulting in maximum light interception and highest yield in ‘Y’ system and in case of central leader system most of the light is being lost in between the rows of the trees and less light is intercepted by the trees and thus results in lower yields in this system.

Barritt. 2000 [7] conducted an experiment on ‘Gala’ apple cultivar in which he compared different training systems and rootstocks with respect to yield and found that yield was highest in 'SS/M.9' followed by 'SS/B.9 and lowest in 'CL/M.26(shown in graph below).This is because of the fact that no. of trees/ha. is highest in 'SS/M.9' resulting in maximum light interception as well as maximum light distribution between trees, thus highest yield compared to other systems, where as no. of trees/ha is lowest in case of 'CL/M.26 resulting in less light interception and thus lowest yield in 'CL/M.26'.



Day *et al.,* 2005 conducted an experiment on three peach and one nectarine cultivar where three training systems(Parallel-V, Open-centre and Central leader) were compared with respect to yield and it was found that highest yield was obtained from Parallel-V system and lowest yield was obtained from Open-centre system. The reason being the more no. of trees/ha. in Parallel-V system, thus resulting in maximum light interception and hence maximum rate of photosynthesis and thus higher yield, but in Open-centre system tree density is lowest thus considerable light is lost due to extensive, unproductive alleys between the rows, and thus less light is being intercepted by the trees resulting in low yield.

In another experiment conducted by Day *et al*. 2005 on peach and nectarine in which comparision of four training systems (Cordon, KAC-V, HiD KAC-V and Open vase) was made with respect to crop value, cost and profit and it was observed that crop value was highest in HiD KAC-V but profit was highest in KAC-V. This is because the cost incurred in HiD KAC-V was more than in KAC-V system.

Barone *et al*., 1995 [6] compared the two training systems(Fussetto and 'Y') of peach with respect to quality parameters like flesh firmness, SSC, TA etc and it was observed that quality parameters were better in case of 'Y' system than Fussetto system. This is due to better exposure of fruit to direct sunlight during last stage of fruit development.

Thus in order to obtain higher yield of quality fruit and to have maximum profit, training systems should be selected carefully.

D) **Orchard Layout**: Any method of layout should aim at providing maximum no. of trees per hectare, adequate space for proper development of trees and ensuring conveniance in orchard cultural practices. The system of layout can be grouped under two broad categories viz, (a) vertical row planting pattern and (b) alternate row planting pattern. In the former planting pattern (e.g, square system, rectangular system), the trees set in a row is exactly perpendicular to the trees set in their adjacent rows. In the latter planting S pattern (hexagonal, quincunx and triangular system), the trees set in the adjacent rows are not exactly vertical, instead the trees in the even rows are midway between the odd rows.

The various layout systems used are the following:

a) Vertical row planting pattern

1. Square system: In this system, trees are planted on each comer of a square whatever may be the planting distance. This is the most commonly followed system and is very easy to layout. The central place between four trees may be advantageously used to raise short lived filler trees. This system permits inter cropping and cultivation in two directions.

2. Rectangular system: In this system, trees are planted on each corner of a rectangle. As the distance between any two rows is more than the distance between any two trees in a row, there is no equal distribution of space per tree. The wider alley spaces available between rows of trees permit easy intercultural operations and even the use of mechanical operations.

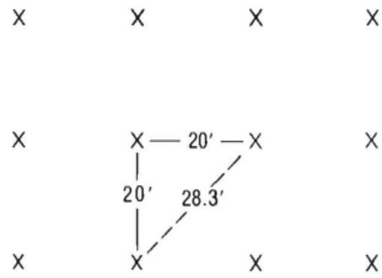
b) Altrernate row planting

3. Hexagonal System: In this method, the trees are planted in each comer of an equilateral triangle. This way six trees form a hexagon with the seventh tree in the centre. Therefore this system is also called as 'septule' as a seventh tree is accommodated in the centre of hexagon. This system provides equal spacing but it is difficult to layout. The perpendicular distance between any two adjacent rows is equal to the product of 0.866 x the distance between any two trees. As the perpendicular distance between any two row is less than unity, this system accommodates 15% more trees than the square system. The limitations of this system are that it is difficult to layout and the cultivation is not so easily done as in the square system.

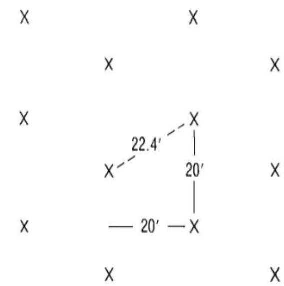
4. Diagonal or quincunx system: This is the square method but with one more plant in the centre of the square. This will accommodate double the number of plants, but does not provide equal spacing. The central (filler) tree chosen may be a short lived one. This system can be followed when the distance between the permanent trees is more than 10m. As there will be competition between permanent and filler trees, the filler trees should be removed after a few years when main trees come to bearing.

5. Triangular system: The trees are planted as in square system but the difference being that those in the even numbered rows are midway between those in the odd rows instead of opposite to them. Triangular system is based on the principle of isolateral triangle. The distance between any two adjacent trees in a row is equal to the perpendicular distance between any two adjacent rows. However, the vertical distance, between immediate two trees in the adjacent rows, is equal to the product of (1.118 x distance between two trees in a row). When compared to square system, each tree occupies more area and hence it accommodates few trees per hectare than the square system.

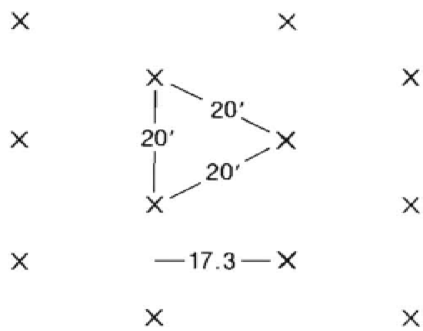
6. Contour system: It is generally followed on the hills where the plants are planted along the contour across the slope. It particularly suits to land with undulated topography, where there is greater danger of erosion and irrigation of the orchard is difficult. The main purpose of this system is to minimize land erosion and to conserve soil moisture so as to make the slope fit for growing fruits and plantation crops. The contour line is so designed and graded in such a way that the flow of water in the irrigation channel becomes slow and thus finds time to penetrate into the, soil without causing erosion. Terrace system on the other hand refers to planting in flat strip of land formed across a sloping side of a hill, lying level along the contours. Terraced fields rise in steps one above the other and help to bring more area into productive use and also to prevent soil erosion. The width of the contour terrace varies according to the nature of the slope. If the slope becomes stiff, the width of terrace is narrower and vice-versa. The planting distance under the contour system may not be uniform.



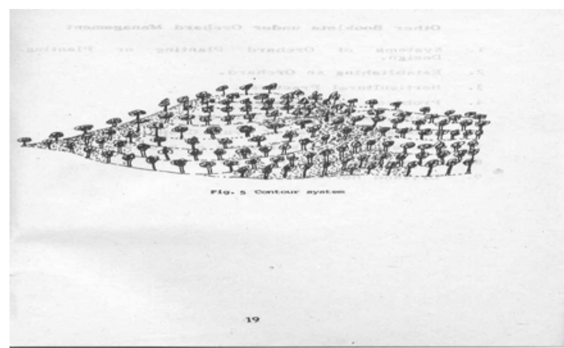
Square system



Offset Square



Hexagonal system



Contour system

E**) Row direction:** Another important component of orchard designing is row direction. Rows should be oriented in such a way that there is maximum solar radiation interception by the trees. For maximum light interception, trees should be oriented in North-South direction.

- **Light interception:** Effectiveness of each component of an orchard design, e.g, tree density, rootstock, tree training etc, can be measured by its influence on light interception and light distribution (Barritt., 2000) [7]. Given a common tree form (e.g., cone shape) and tree density, taller trees have higher light interception than short trees. However very tall trees tend to have poor light distribution in the lower parts of their canopy (Blanke and Notton., 1992) [10]. Trees planted at high densities tend to have high light interception but often have problems with tree-to-tree shading, resulting in poor light distribution within the canopies. Rootstocks that produce relatively large trees, e.g., M.7, MM.106, MM.111 and M.793, often have high light interception but unfortunately usually also have relatively poor light distribution throughout the canopy. On the other hand, trees with dwarfing rootstocks can have low light interception unless they are planted at sufficiently high tree densities and are trained to a reasonable height (Barritt., 1996) [9]. Optimal light interception and light distribution often occur in orchard systems when tree height is equal to approximately two times the clear alley width. The clear alley width ia the width required for equipment and bin movement down the row within the orchard. If a clear alley width of 1.5m is required for the tractor and bin, then a tree height of approximately 3m would be appropriate. It has been observed that trees which are approximately 3m tall, when compared to 2m trees with the same basal diameter, have 60% greater canopy volume per tree. Therefore, the trees should be trained to a height of 3m to improve light interception.

Productivity of an orchard is directly related to the amount of light intercepted by the orchard canopy. Light which affects flower bud formation, fruit quality and productivity is a major limiting factor in fruit production. Main aim of the orchard design should be to maximize light capture and distribution within tree canopy. Tree size along with tree density determines the percentage of light captured on a per area basis that can be utilized for fruit production. In general, effective light penetration into the tree canopy is approximately one metre. Based on this fact, the canopy of a large tree can be broken down into three zones with regard to light penetration (Fig below). Zone one located in the top portion of the tree recieves 100-60% full sunlight; zone two recieves 59-30% of full sunlight and zone three receives less than 30% full sunlight.

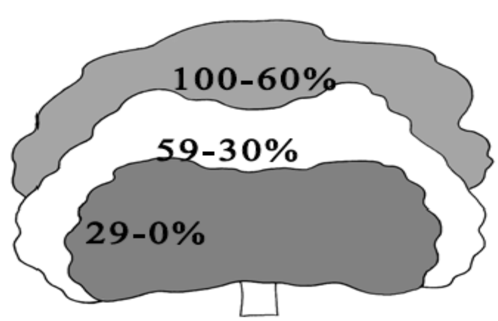


Fig 2: Light penetration

Once light level falls below 30% of full sunlight, flower bud formation is reduced, spur vigour is lost, fruit production in that zone is of poor quality. Zone three is non-productive zone and size of this zone is influenced by tree size, form and pruning. Tree size has significant influence on area of zone three withen tree canopy. The area of inadequate light can vary as much as 25% in large central leader trees to 1.6% in dwarf trees. The smaller area of non productive zone is one of the reasons why smaller trees can be more productive than large trees. With increasing height there is greater tendency for top of the tree to shade the bottom of the tree, the bottom of adjacent trees or bottom rows. In freestanding trees, the height of trees should not exceed the spread of the branches. In tree walls and trellis systems, height should not be greater than the distance between trees.

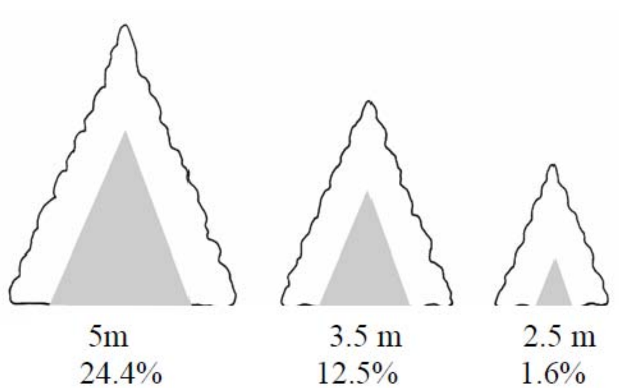


Fig 3: Effect of tree size on light penetration and the non productive zone

Tree shape also affects light distribution withen tree canopy and the areas of three zones. A conic or pyramidal shape such as a central leader, produces a much more favourable light distribution than that of globular form. The common apple tree shapes are: 1) Globular- is characteristic of large open centre trees where the most productive portion of the tree is top third where fruit is less accessible. 2) Conical or pyramidal- this would be characteristic of a Christmas tree shape with an open framework. The top of the tree does not shade the bottom branches and the major part of bearing surface is close to ground. The open framework will allow light to penetrate well into the canopy.3) Central leader and Spindle form. 4) Horizontal canopy- where thickness of canopy is limited to one metre, which allows for effective light penetration to the full canopy. The Lincoln canopy is a good example of this tree form. 5) Y or V form - allows for maximum light penetration while providing growth control and influencing productivity. The Tatura V trellis and the New York Y trellis are examples of this form.

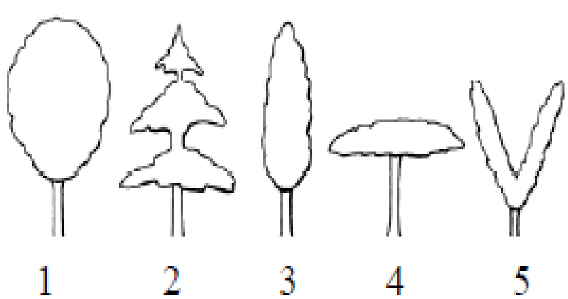


Fig 4: Common tree shapes

Thus for maximum light interception by the trees and its efficient distribution withen the orchard, proper tree training, proper tree density and selection of appropriate rootstocks are critically important.

F) Honey bees: Honey bees also constitute an important component of orchard designing, as they play an important role in pollination, thus fruit set and productivity of an orchard. The deciduous fruit industry is almost totally dependent on a healthy honeybee population and a viable beekeeping industry. These honeybees forage on flowers only for a reward of pollen and/or nectar; pollination is a fortuitous consequence of the foraging. Honeybees are able to detect minor differences in the sugar concentration present in nectar, and in the protein content in pollen, and for the most part will forage on the most rewarding resource available. Nectar in apples and plums is relatively poor in both sugar content and quantity, with normally only enough nectar to sustain colonies and not enough for a honey surplus. Apple and plum nectar levels are inferior to those of common weeds such as Cape Weed (Gousblom) andWild Radish (Ramenas). Pear flowers have extremely poor nectar, both in sugar content and quantity, and are not very attractive to foraging honeybees. All of apples, plums and pears have pollen that is readily collected by honeybees, but is not as attractive as that of common weeds. It is because the reward provided by deciduous fruit crops is less than that of common weeds that the practice of introducing naïve bees (colonies introduced during blossom) has become standard in commercial pollination. Following points are important while introducing honeybees into the orchard:

- Best practice is to introduce honeybee colonies at 20-30% blossom. However, because flowers are often most receptive on the day that they open and are often only receptive for 2-3 days, and because colonies require at least 24 hours to settle down and resume normal foraging after introduction, it is recommended that colonies be introduced at 10% blossom. There is also no value in keeping honeybee colonies in the orchard for longer than is needed, and colonies should be removed as soon as possible after full bloom, and by 30% petal fall at the latest.
- Honeybee colonies should be placed in the full sun or semi-shade, protected from the wind, and placed on stands of some sort to keep them off the damp ground. In extremely cold conditions, bees should be placed in the full sun; under very hot conditions, in the shade. Semi-shade is probably best for non-extreme conditions. The site should always be dry and out of the prevailing wind.
- It is recommended that colonies should be placed singly or in small groups of 2/3 colonies, and evenly distributed around the orchard. Where possible, colonies should be placed near pollinizers, to facilitate cross-pollination. Colonies should be placed at the end of rows of trees, particularly with hedgerow systems, as bees forage down rows and are 10-30 times more likely to move to the next tree in the row than to move between rows. Where possible, place colonies away from the immediate edge of the orchard, as this helps in the dispersal of foragers throughout the orchard. Colonies, however, should be placed no further than 100m of the target crop as the numbers of foragers decreases rapidly with distance, especially in bad weather, and there should not be windbreaks between the colonies and the target crop. If rows are greater than 100m in length, colonies should be

placed at both ends.

- Honeybee colonies should be introduced at night whenever possible, or in bad weather conditions when no or a minimum of bees are foraging, and with traveling screens or other means of adequate ventilation to prevent overheating and to allow colonies to settle down and resume foraging as quickly as possible. Each time a colony is moved there are forager losses and a decrease in the strength of the colony and it is recommended that colonies are used not more than three times for deciduous fruit pollination during a season.
- Numbers of foragers needed is influenced by the cultivar type, the age of the trees, by the weather and by local conditions. Standard recommendations regarding the numbers of colonies needed are presented in below:

Fruit crop	Coloney strength.
1. Almond.	5—8 colonies/ha.
2. Apple.	3-5 colonies/ha. HDP coloney strength more.
3. Apricot.	2-3 colonies/ha.
4. Cherries.	3 strong colonies/ha.
5. Pear.	3 strong colonies/ha.
6. Peach, plums and nectarines.	3 strong colonies/ha.

Conclusion

In the present world, land resources are shrinking day by day due to urbanisation & increasing population pressure resulting in less supply of fruit. So there is need to design orchards in such a way that the available resources are utilized efficiently in order to obtain higher, early and quality fruit production from these scarce resources. This can be achieved by the proper and careful combination of the above mentioned components. e.g, high density planting using dwarfing rootstocks, with rectangular layout and trained to such a system that tree height remains short and maximum solar radiation is being intercepted by the trees.

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