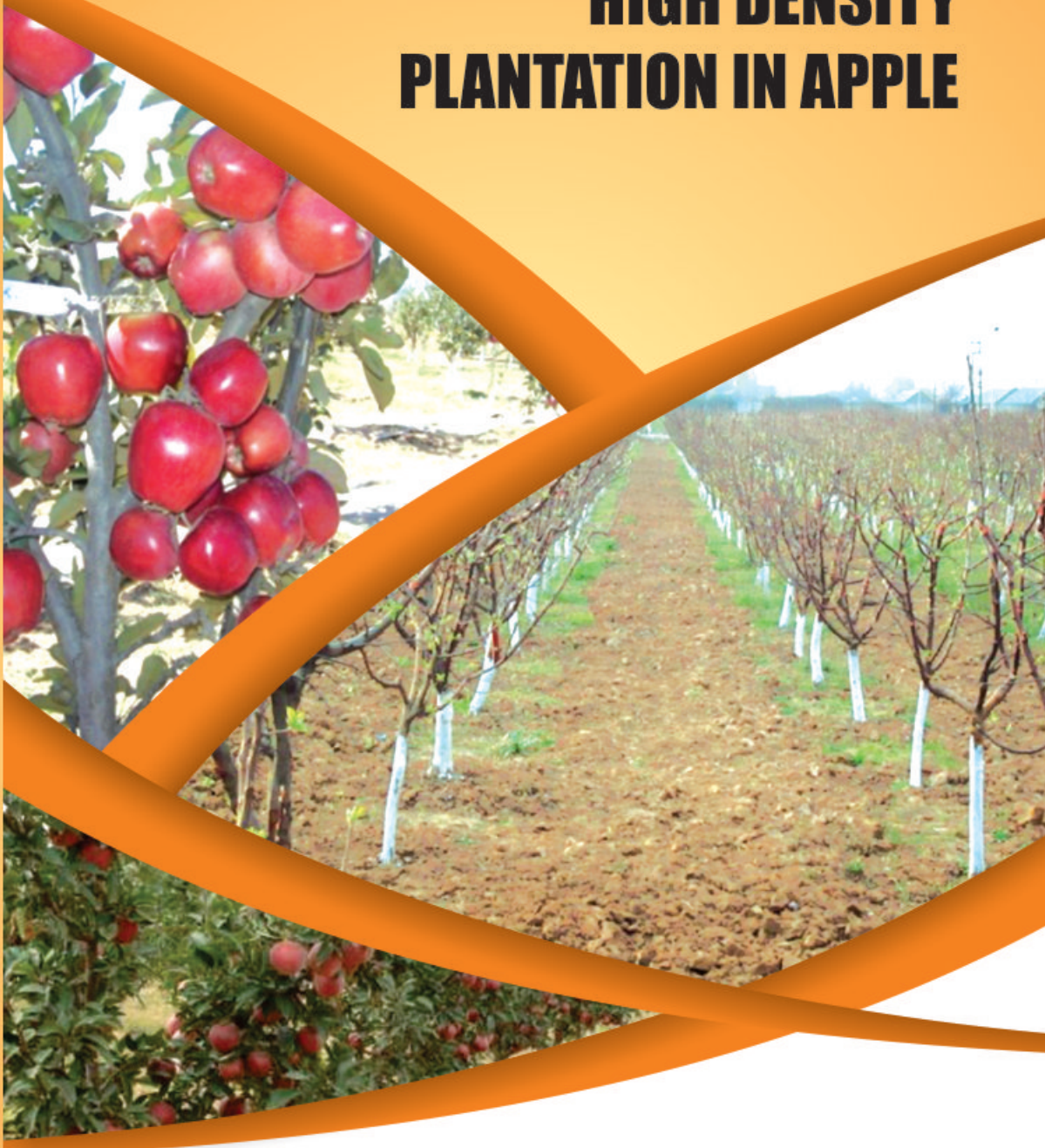
HIGH DENSITY PLANTATION IN APPLE



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First Edition

2017

Lasertypeset & Printed at

M/s Royal Offset Printers, A-89/1, Naraina Industrial Area, Phase-I, New Delhi 110 028

Introduction

Traditional orcharding system in apple give poor yield due to low density plantations and also the quality of fruit is poor due to improper canopy management. High density planting is a planting system in which the maximum numbers of plants are accommodated within a unit area to obtain maximum output by optimum utilization of solar radiation, land, water and nutrient from soil. The principle of HDP system is to make the best use of vertical and horizontal space per unit time and to harness maximum possible return per unit of inputs. In other words, it is the planting of more number of plants than optimum through manipulation of tree size. The successful management of apple trees in any high-density planting system depends on maintaining a balance between vegetative growth and fruiting. The successful balance of vegetative vigor and fruiting results in ideal trees that produce heavy annual crops and require only a light annual pruning. It is cultivation of fruits using dwarf rootstocks with modified canopies. Proper light distribution within tree canopy increases the number of illuminated leaves. Fertilizer dose, spacing, growth regulation by the training and pruning, use of the mechanical devices etc. may also be tried either singly or coupled with other crop management practices for a successful adaptation of this concept. It also promotes rate of photosynthesis that leads to high yield per unit area. Basically, the availability of a dwarf plant is the first and foremost prerequisite for establishing any high density orchard. There has been a steady increase in planting density over the last few decades from 270 trees/ha at 6m x 6m spacing to 2222 trees/ha at 3m x 1.5m spacing.

Advantages of HDP

- High density planting facilitates better utilization of available resources i.e. solar radiation, land, water, labour, dwarf rootstocks, spur cultivars, human skill etc.
- High density orchards are more precocious thus result in earlier return on investment which is key for investment.
- High density planting results in higher productivity and harvest index due to increase in bearing surface per unit area.
- High density planting produce better quality fruits due to high light interception and distribution of light within plant canopy.
- High density planting facilitate easy picking with less injury to fruit which result in better post-harvest life during storage.
- High density orchards have better acceptance to modern input saving fruit production technique such as drip irrigation, fertigation, mechanical harvesting, mechanical pruning etc.

- High density orchards increase effectiveness and reduce cost involved in horticultural operation like inter-cultural operation, pruning, plant protection measures etc.

Limitation/Constraints

- High initial establishment costs, mainly due to the increased tree cost per unit area and tree support structure.
- Need more professional and scientific approach in management.

Table 1: Comparison of high density plantation with traditional orcharding system in apple

Parameter	Traditional orcharding	HDP
Planting density	100-250 plants	400-8888 plants
Training system	Centre leader, open centre, modified central leader system	Tall Spindle, Espalier, Vertical Axis, Bi-axis, HYTEC, SolAxe etc.
Root stocks	Seedling (Crab, Maharaji etc.)	Clonal rootstocks (M-9, MM-106, Bud-9 etc.)
Varieties	Non Spur type (Red Delicious, Golden Delicious, American Apirouge etc.)	High yielding mainly spur type varieties like Oregon Spur, Red Chief, Well Spur, Super Chief, Silver Spur etc.
Precocity	Bearing starts after 6-8 years of plantation	Highly precocious (Bearing starts after second years of plantation)
Productivity	Low (<30 t/ha)	High (>40 t/ha)
Yield potential	Low	High
Fruit quality	Low; due to low photosynthetic photon flux density (PPFD) and less penetration and diffusion of photosynthetically active radiation (PAR).	High; due to high photosynthetic photon flux density (PPFD) and more penetration and diffusion of photosynthetically active radiation (PAR).
Input use efficiency	Low	High
Disease incidence	High; this is due to dense canopy and low air circulation through canopy.	Low; which is due to sparse canopy and more LAI
Mechanization	Difficult	Easy and cost effective

Components of HDP system

High density plantation in apple involves the interaction of multiple factors which are contributing significantly in productivity and quality enhancement. Many factors which contribute to the performance of apple crop under high density plantation i.e. rootstock; variety, planting density, quality of nursery tree and canopy management, irrigation and fertigation, weed control and fumigation, crop load management etc. The role of these factors is discussed below:

1. Rootstocks

In order to obtain ideal tree size for the tree density used, proper rootstock combination is necessary. Seedling (standard) rootstock has been the most commonly used in traditional orchards. This vigorous rootstock often provides a tree that occupies huge space and attains large size. Trees on this rootstock often take 8 to 10 years to begin significant bearing. In contrast, the promising apple rootstocks offer varying degrees of size control and frequently induce early bearing (precocity). Rootstock MM-111 usually produces a tree about 80 per cent the size of that on seedling. This stock is quite tolerant to varying soil and climatic conditions, particularly drought, and may be very useful where summer irrigation cannot be provided. Rootstock MM-106 produces a tree 65 to 75 per cent the size of that on seedling and provides more precocity than MM-111 apple rootstocks. It also provides good anchorage, is easily propagated, and is resistant to woolly apple aphid. M-7 produces about a half-size tree and is tolerant to high arsenic levels in the soil but it produces large number of suckers and need high degree of maintenance. M-26, one of the newer clonal apple rootstocks, provides a tree 40 to 50 per cent of the size of that on seedling and is quite precocious. Individual trees on this stock may require support under some conditions. M-9 is more dwarfing than M-26, giving a tree about one-third the size of that on seedling. It has a brittle root system with poor anchorage and usually requires support by stakes or trellis. It is very precocious. M-27 and P-22 are ultra dwarfing rootstocks and are generally used for meadow orcharding system which is not been practiced in India at present. Bud-9 is precocious and freeze tolerant rootstock and thus suitable to high chill areas.

When selecting a rootstock to use for a particular cultivar, consider what effect the rootstock is going to have over the aerial portion of the tree. Different vigour controlling rootstocks along with resistance to biotic and abiotic stress are available (Table 2, Fig. 1).

Table 2: Apple rootstocks and their characteristics

Character	Rootstocks	Character	Rootstocks
Ultra dwarf	M-27 , P-22 , P-16, P-2 , B-469,G-65	Cold hardy	B-491, B-490, B-9, O-3, P-2, P-18, P-22, K-14, Novole, Alnarp 2, Robusta 5
Dwarf	M-9,G-11,G-41, G-16,G-935, G-214	High temperature tolerant	M-7, MM-109.
Semi dwarf	M-7,MM-106, M-26, B-9,P-1,G-202,G-69,G.-30, G-210, G-890	Drought tolerant	MM-111, KC-1, KC-1-48-41
Vigorous	MM-104, MM-109, MM-111	High soil moisture tolerant	MM-116, M-7, MM-104
Tolerant to high soil pH	M-9, MM-106	Resistant to powdery mildew	P series (P-1, P-2, P-16, P-18
Resistant to crown and root rot:	B-9, B-491, MAC-9, O-3, P-2, Novole, G-30, G-65.	Resistant to latent viruses: OH series,	B-9, MAC-9, C-6, Novole

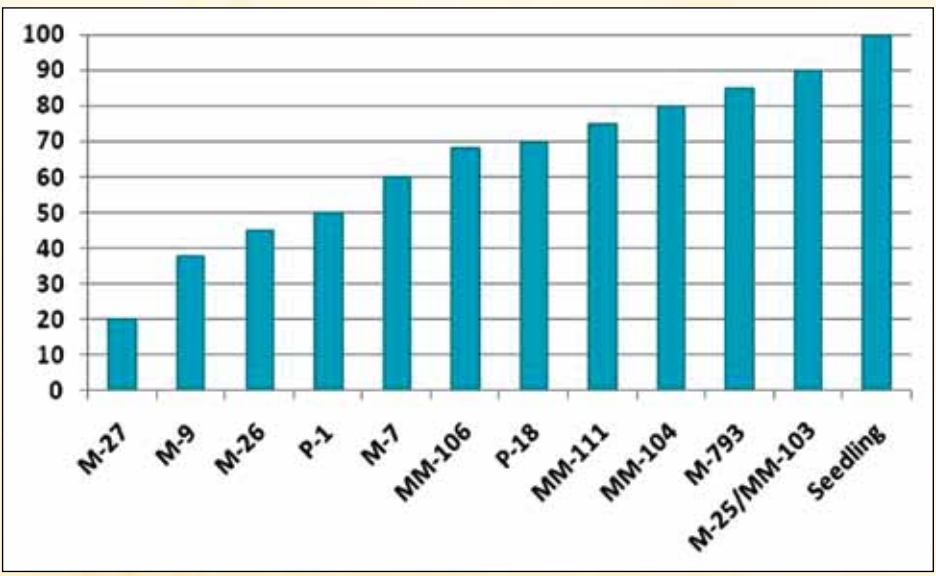

Fig. 1: Comparison of size of different clonal rootstock with seedling rootstock

2. Varieties

Apples are available in a great array of colours, sizes, and flavours. The growth habits and characteristics of various varieties can also influence high density plantings. Most adopted apple cultivars for high density apple cultivation are spur type varieties. These are strains that have compact growth habits with more spur and less shoot formation than standard strains of the same variety. Spur bearing varieties of apple have shown improvement in yield and quality under HDP system.

Table 3: Apple varieties on the basis of bearing habit

Standard (Tip bearer)	Mixed (tip and spur bearers)	Spur type
Cornish Gilliflower, Cortland, Cox Stone, Empire, Fuji, Golden Russet, Granny Smith, Irish Peach, Red Free, Rome Red, Scarlet, Summer Red, McIntosh, Maharaji, Rome Beauty, Honey crisp	Ginger Gold, Golden Noble, Gravenstein, Green Sleeves, Lord Lambourne, Northern Spy, Pink Lady, Vista Bella, Wealthy, Yellow Newton Tydeman's Early Worcester	Red Chief, Oregon Spur, Golden Spur, Starkrimson, Silver Spur, Well Spur, Cox's Orange Pippin,

3. Planting 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 hectare and it greatly affects orchard productivity, efficiency and intensity of management required to run the orchard. Higher density orchards (500 + trees/acre) maximize productivity per acre and thus minimize land wastage. Low density orchards (100-300 trees/ha) tend to produce less, but also minimize intensity of management, as water management, tree training and pruning etc. Today majority of the mature orchards have densities between 200-500 trees per ha, 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 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. 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:

- **Low density**: The trees are planted at wide spacing accommodating 100-250 plants/ha. It is an age old planting system and trees acquire commercial yield after 8-10 years of planting.

Oregon spur

Silver spur

a. Spur bearing varieties

Tydeman's E. Worcester

Vista Bella

b. Mixed bearing varieties

Granny Smith

Rome Beauty

c. Tip bearing varieties

Plate-1 Bearing habit of different apple varieties

- **Medium density**: This system accommodates 250-500 plants/ha, proper training and pruning is done to manage trees in desirable shape.
- **High density**: This system accommodates maximum number of plants per unit area. Very condensing planting with 500-10000 plants/ ha, medium high density: 500-1500 plants/ ha, optimum high density: 1500-10000 plants/ ha and ultra high density: 10000-100000 plants/ ha.

Potential advantages of planting at higher densities are to

- Increase early yields
- Increase efficiency of orchard operations (ladder work, spray coverage, weed control, etc.) through altered canopy configurations and reduced size, and
- Increase fruit yield relative to vegetative growth.

Since the land is shrinking day by day due to urbanization, 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. 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 ultra dwarf rootstocks, but is unsuitable on non-dwarfing rootstocks. The meadow-orchard system involves annual mowing of shoots at harvest time similar to using a commercial tomato harvester.

Plate 2: High density apple plantation at ICAR-CITH, Srinagar

4. Quality of nursery tree

A successful HDP orchard should start cropping early and give annually a high yield of good quality fruit in an economically justified way. High quality tree should be used for establishment of high density apple orchard, form which farmers can expect some yield in the second year and full production by the fourth or fifth year. With the use of high quality tree canopy management will be easy and cost effective. Moreover, early cropping control vegetative growth of

Plate 3: Production of high quality apple nursery plants in nursery at ICAR-CITH, Srinagar

trees. High quality nursery tree should be at least 1.7 to 2 m tall, with dominant central leader, 12-15 mm trunk caliper and abundance of healthy roots. It also should have enough well distributed feather (6-10) which are developed at desirable height (above 70cm), achieving appropriate length (10-25 cm) and crotch angle (more than 45°). Feathered nursery trees are a critical component of most high-density planting systems including the Tall Spindle. But most apple varieties do not produce satisfactory lateral branching in the nursery without some form of intervention to stimulate branching. Traditionally nurserymen/ growers have obtained feathered nursery tree through the removal of small undeveloped leaves, called "leaf pinching" or "plucking". But unfortunately, it is inconsistent and most of the nursery apple cultivars require more than one "leaf pinching". This labor-intensive practice substantially increases the costs in an apple nursery. The use of plant growth regulator chemicals has been seen as a more consistent and less expensive method to induce lateral branching than manual "leaf pinching". In most apple varieties 3-4 spray of 6-benzyladenine (500-700 ppm) induce desirable feather when applied to apical section of the main shoot (10-15 cm) of one-year-old apple tree during second vegetative period when the growth of main shoot reaches 75-80cm.

5. Canopy management

Trees in high density apple orchards usually require a different training system than those in standard orchards. Modern canopy management systems like tall spindle, espalier, cordon, single axis, spindle bush, head and spread, two scaffold etc help in accommodating more plants per unit area and enhance yield and quality of fruits by providing more fruiting area and improving the penetration and diffusion of photosynthetically active radiation and PPFD. Some rootstocks like M-9 have brittle root system and thus need support or trellis. The wire trellis aids in tree support, training limbs to the desired angle, and limb support during early bearing. The high cost of materials and labor may preclude many trellis systems. It includes:

a) Training

Fruit growers often neglect early training of fruit trees. Without proper training, fruit trees will not develop proper shape and form. Properly trained trees will yield high quality fruit much sooner. Primary objective of training is to develop a strong framework that will support fruit production. Improperly trained fruit trees generally have very upright branch angles, which result in serious limb breakage under a heavy fruit load. 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. Light penetration is essential for strong flower development and optimal fruit set, flavour and quality. Opening the tree canopy also permits air movement through the tree, which

promotes rapid drying to minimize disease infection and allows thorough spray penetration. 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 and reduces heterogeneity between shoots.

- The main benefits of training are summarized 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 apple are given below (plate.3):

- **Espalier:** Espalier training system is a type of kniffin training system of grape in which 10 scaffold branches (5 scaffolds on each side) are trained on galvanized wire. The fruiting spurs develop on the primary scaffold branch. The planting is done at 3.0 x 1.5 m plant to plant and row to row spacing. The first scaffold branches on both directions of the trees should be encouraged by giving incision on the main trunk at 45 -50 cm height. The central leader should be allowed to grow up to 1.5 -1.6 m height and on both sides, 10 scaffold (5 primary branches each side) branches are encouraged. The scaffold branches are trained at 90^{o} angle on the erected wire. The central leaders should be removed leaving 5-10 cm main trunk after 5th (top most) wire trellis. The laterals should be cut back in dormancy leaving 10-15 buds. Proper balance between leaves and fruits should be maintained and the intermingling branches /shoots should be removed from its origin.
- **Cordon:** In this system, trees are planted at 0.75 x 1.5 m spacing on M-9 rootstock at inclined position (45^{o}angle). The trees are supported by 5 wires erected on 8 feet height iron angle fixed at 8 m interval. On the main scaffold

branch, 6-9 branches are encouraged straight to fill the allotted space. It is very precocious training system. The intercultural operations like pruning, fertilizer, irrigation, spraying have been found very easy.

- **Tall spindle:** It maximizes profitability through early yield, improved fruit quality, reduced spraying, pruning, and training costs, and the ability to rapidly turn over apple varieties from those less profitable to those more profitable. Proper selection of density for this system depends on consideration of the vigor of the variety and rootstock and the soil strength. The optimum spacing for an average vigorous variety and soil is 3 feet by 11 feet. Fully dwarfing rootstocks should be selected for this system (M-9 and B-9). Nursery stock ideally having 10-15 feathers per tree should be used. Significant pruning at planting is a common practice with most planting systems to provide balance between the scion and root to encourage growth to fill the allotted tree space. Since the tall spindle system is planted with very little growth needed to fill the available space, very little pruning is needed. Transplanting shock is actually one of the objectives in this system which is caused by a high scion to root ratio which helps in keeping trees well within alotted spacing.
- **Slender spindle**: This was developed by Weitheim (1968) and was designed to improve early yield and management efficiency by planting higher tree densities and reducing tree height to allow all management to be done from the ground. The tree is a narrow, fully dwarf, conic shaped which allows planting of very high tree densities, ranging from 1500-4000 trees/ha in either single, double or, multi row beds. The tree is trained to a slender bell, or pear shape with the bottom whirl of branches acting as a permanent fruiting table. The leader and top of the tree is kept quite weak. Renewal pruning of mature trees consists mainly of removing 2-3 of the largest diameter branches on an annual basis during the dormant season. Tree height ranges from 2-3 m and width is less than 2m. Most common rootstocks M-9, B-9 and G-16 are used in this system and tree density above 4000 trees/ha. The feathers which develop during first year form a permanent tier of branches.
- **Super spindle:** This system is modification of slender spindle system that utilizes very high tree densities. The system suggests the planting compact, slim apple trees with the spurs along the central leader at very close spacing, in single rows and then pulling out every second tree after 4 or 5 years once canopy becomes too crowded. The goals of super spindle system are very early and high yields so that new cultivars can be introduced as quickly as possible to meet market demands, less manual work, less chemical and high picking output, resulting in low fruit cost per hour of labour. Super spindle

trees are trained differently from slender spindle to reduce tree growth and maximize early fruiting, super spindle trees are not headed at planting and are often planted on top of the ground and a small amount of soil is pushed up to cover the roots. In the first year, the steep angled and strong lateral branches are removed by ripping them from the tree. Growth regulator sprays of NAA or ethephon can also be used to stimulate flower bud initiation. The orchard life of super spindle orchards can be as short as 7 years, but generally not longer than 12-15 years. This means that the economic success of super spindle orchard depends to a large extend on very early, high yields of high priced new cultivar, low priced trees from nursery, higher picking output and fewer management hours to maintain the system.

- **Vertical axis**: Developed originally by J.M. Lespinasse in France. The system relies on high density, dwarfing rootstocks, minimal pruning, limb renewal, and an effective support system. Advantages include early production, high quality fruit, lower tree cost than higher density systems, and lower management costs than free standing systems. The major disadvantage is that it is a tall system that requires working off the ground and the associated costs. Vigor control can also be a problem. Maintaining sufficient vigor in the bottoms and controlling excess vigor in the tops is a challenge on some varieties such as McIntosh and Gala. Excellent management in the tops and maintaining light distribution throughout the tree results in maintaining sufficient vigor in the bottoms. In this system spacing between rows is 12-14 feet, in-row is 5-7 feet, a tree height of 12-14 feet, a narrow canopy width along the axis of only 3-5 feet, tree density of 500-700 trees/acre, and arranged in single rows. M-9 is an excellent rootstock for this system. Trees should be minimally pruned at planting removing scaffold limbs more than ½ the size of the axis where they originate. All scaffolds should be shortened by 1/3 and the leader headed 18 inches above the top scaffold. The objective is to get fruits as early as possible so the trellis system should be established as soon as possible. Summer pruning is necessary to maintain tree shape and fruit color.
- **SolAxe:** Lepinasse (1996) developed a modification of the vertical axis called solaxe, by focusing even more on branch bending and avoiding renewal pruning in an attempt to gain more weeping canopy. The A, B, C zone concept does not fit the terminally bearing cultivars (type IV according to Lespinesse, 1977), such as Granny Smith or Rome Beauty. In these cultivars the growing shoot generally ends in a fruit bud and is able to develop a bourse shoot, which will fruit again in following year. This system combines the bending of the central axis and the fruiting branches from the solen system with the free growing fruiting branches and the removal of competing vegetative branches

from the vertical axis system. The tree is developed at planting by strongly bending the feathers along the trunk into an arc. Branches that are below 1.2m are removed. When the leader reaches the top of the support system, it is bent horizontal, either naturally by fruiting or artificially by bending. 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.

- **HYTEC:** The hybrid tree cone orchard system was developed by Barritt (1991-92), specifically for apple producing regions that have significant fruit sunburn problem. The system also has the goals of high, early and sustained yield/ ha, high labour efficiency and high fruit quality. It is a blend of the slender spindle and vertical axis systems that combines nuances of both systems and is intermediate in canopy height between the two. To reduce vigorous growth high in the tree (often a feature of mature vertical axis tree), the central leader of HYTEC tree during the formative years is pruned and/ or bent annually in a manner similar to that of the slender spindle system. To achieve greater production at full canopy the slender spindle trees, the HYTEC tree is taller with greater canopy volume characteristic of vertical axis tree. Light distribution is maintained in the HYTEC tree by maintaining an open canopy structure, fruit sunburn is reduced by providing some limb to limb shading through stiffening lateral limbs with shortening pruning, a technique used in slender spindle, but not in training of vertical axis trees.
- **Bi Axis:** The bi axis was originally employed by growers by heading (topping) newly planted trees at planting to produce two leaders. To achieve well balanced trees with uniform axes, bench grafting has recently been replaced by double chip budding in the nursery. After planting, the two axis are grown as small independent spindle trees. The main difference with respect to a single tree is that distributing vegetation over two axis induces less vigour since the trees put most of their strength in forming two vertical axis instead of one. In the beginning, the main aim of bi axis training, which can be seen as a variant of the super spindle developed during the 1980s, was to achieve the advantages of the super spindle:
  - High early yield
  - Good exposure of fruit for high fruit quality, and
  - Simplification and speeding up of cultural practices, in particular winter pruning, limb bending in summer and harvesting, without the disadvantages of the super spindle
  - Very high capital outlays and
  - Excessive tree vigour in fertile areas

Espalier training system

Cordon System

Vertical axis

Tall Spindle

Slender Spindle

Super Spindle

SolAxe System

Bi-Axis System

Plate 4: Different training systems for HDP of apple

Thus the bi axis system turns the weak points into a positive asset. Another important advantage of the bi axis training system is that it is more suitable than spindle to mechanization of flower thinning and summer/winter pruning with newly developed machines. Other potential benefits related to the bi axis that need further investigation include less sunburn of fruit and longer orchard lifespan.

b) Pruning

After fruiting begins, only a minimum of pruning is necessary; heavy pruning only reduces or delays production and induces unnecessary shoot growth. Main aim of pruning is to develop plant form which is good in light distribution, small in size and easy to manage. Pruning may be done in winter (dormant), summer, or both. Winter pruning, if too heavy, stimulates excessive growth, which may cause tree crowding, shading out of lower fruitwood, and poor-colored fruits. Conversely, summer pruning reduces vigor and can be used to decrease excessive growth. All upright shoots should be removed from bearing, central leader trees. The central leader should be the only upright limb in the tree. Excess shoot growth should be removed to allow light throughout the tree and to balance fruiting and tree growth. Where trees lack sufficient vigor, limbs should be headed (cut) into last season's shoot growth to stimulate vigor. The central leader is normally headed into last season's growth each winter. If the tree becomes too tall, the central leader can be cut back to a weak lateral branch. Apple varieties respond differently to training and pruning mainly due to differences in growth and fruiting habits. Fruiting habit refers to the overall pattern of fruiting and includes fruit position on the ends of long or shoot shoots, age of spurs and location of crop on scaffold limbs. Base on fruiting habit there are four types of apple trees.

- **Type I:** This includes spur type varieties like Starkrimson and Delicious and other spur types that develop few laterals on main scaffold limbs. This type of trees bear fruits on short spurs that are long lived and is not necessary to prune this type to renew fruiting wood. The fruiting zone of this type remains close to trunk as long as this area is exposed to sufficient sunlight to induce flowering.
- **Type II:** The trees are characterized by most standard habit strains of Delicious. The fruiting zone is away from the trunk. This type of trees develops narrow crotches, so spreading technique is beneficial.
- **Type III:** The fruiting zone of this type of cultivars remains away from the trunk to the outside of the tree. Cultivars of this type bear early with most of the fruits on spurs and shoots that are about three year old. The branches are headed back for thickening in order to support early crops. The cultivars

of this type are characterized by standard habits and develop spreading branches with wide crotches.

- **Type IV:** These are tip bearers and have upright main scaffold limbs with narrow crotches and frequent branching. There is strong tendency of fruiting wood to move towards the extremities of the branches. In order to insure high percentage of fruiting spurs it is important to use many small thinning cuts at the branch extremities. This type of cultivars should not be pruned from trunk outward as it would result in large amounts of blind wood.

c) Control excessive vegetative growth with the use of PGRs

Proper tree growth management is a major concern in apple production. Avoiding excessive shoot growth will induce earlier flowering and fruiting in young trees. In apple typically, tree growth management is performed by physical measures, particularly by dormant and summer pruning. In extreme cases, root pruning, girdling or even stem sawing is being used. Any of these methods is cost-intensive and/or bears a high risk of failure. Furthermore, part of the trees assimilates or potential assimilates are lost. Alternatively, an improved balance between vegetative growth and fruit formation may also be achieved by employing plant growth retardants. Many growth regulators i.e. CCC, SADH, paclobutrazol, ethephon etc. have been used in apple to control vegetative vigour but more recently, prohexadione-calcium has been introduced to control vegetative growth of apple and found promising. It can be applied 4 times sequentially at 50 ppm, as single applications, or repeated at 125 to 200 ppm when shoot growth reaches 5 to 10 cm. However, multiple applications provide better growth control than a single application.

d) Irrigation and Fertigation

Drip irrigation systems are more suitable for HDP in apple for enhancing water and nutrient use efficiencies. For establishing high density apple orchard highly feathered trees are planted which require adequate water supply. Such type of plants show water stress after planting as the root system of transplanted gets damaged and cannot supply adequate water to top of plant without frequent irrigation. Leaf area of highly feathered trees is more as compared to un-feathered trees which causes high water demand before the root system is established properly. Frequent and early trickle irrigation can help these trees produce good growth in the first year. The growers should install drip irrigation soon after planting with high density orchards that use feathered trees to prevent water stress and maximize first year tree growth. Under drip irrigation system of irrigation only a portion of the soil volume around each plant is wetted and thus conventional method of fertilizer application is ineffective. The limited root zone and the reduced amount of mineralization in the restricted wetted

zone are the main reasons for the reduced nutrient availability to the plant with traditional method of fertilizer application under drip irrigation. With drip irrigation both water and fertilizer can be applied more precisely in controlled quantity and at appropriate time directly to the root zone as per the tree needs at different growth stages. Fertilizer use efficiency can be improved by adopting fertigation systems under HDP. Supply of frequent low doses of nitrogen at least twice weekly through fertigation will greatly improve tree growth during the first 2 years. In case of tall spindle where trees are highly feathered, density is high and only vertical extension growth is needed fertigation for 2 years is essential to avoid water stress as well as for nitrogen which is rapidly moved to the root zone and is readily available to the tree as soon as it starts growing. For moderate tree densities such as with the vertical axis, slender pyramid or Y-trellis, trees must be grown vigorously for several years to fill the allotted space with canopy and relatively high nitrogen fertilization is desirable for 2-3 years after planting. After the first few years, low nitrogen fertilization is desirable to keep the trees calm with a balance between fruiting and cropping. Many mature high density orchards receive excessive nitrogen fertilizer rates which cause severe canopy management problems.

e) Fumigation and Weed Control

Most of the new orchards are planted on old orchard land that can be improved by soil fumigation. Before establishing an orchard on an old orchard site growers should conduct a bioassay to check the severity of replant problem and determine the value of soil fumigation. With fumigation almost all old orchard sites produce less tree growth than virgin sites. Thus, tree planting density should be increased on old orchard sites compared to virgin sites by 20-30%. Weed competition can reduce the tree growth during early years but can cause a failure of orchard. Critical time period of weed control in apple is first 3-4 months of growing season.

f) Crop load Management:

In high density apple orchards management of cropping during initial four years is important in order to prevent biennial bearing and to maintain a balance between vegetative and reproductive growth. Apple trees on dwarfing rootstocks set fruit 2nd or 3rd year after planting which results in alternate bearing. Moreover it results in increase in vigour in the 4th year. Biennial bearing tendency of each variety varies and it should be incorporated into the crop loads allowed on young trees. Recommended crop load of 6 fruits/ cm^2 TCA (25-40 apples/ tree in the second year, 40-60 apples/ tree in third year and 100-200 apples in fourth year) for varieties like Gala and 4 fruits/ cm^2 TCA (15-20 fruits/ tree in second year, 25-40 apples/tree in third year and 50-70 apples/ tree in fourth year) for slow growing and biennial bearing varieties like Honey Crisp.

NOTE