Tall Spindle-
A promising high density orchard planting system for apple

K.L. Kumawat

W.H. Raja

D.B. Singh

O.C. Sharma

J.I. Mir

A. Sharma

Sajad Un Nabi

S.N. Kirmani

ICAR-Central Institute of Temperate Horticulture

CITH Technical Bulletin
02/2020

Citation: K.L. Kumawat, W.H. Raja, D.B. Singh, O.C. Sharma, J.I. Mir, A. Sharma, Sajad Un Nabi and S.N. Kirmani. 2020. Tall Spindle- A promising high density orchard planting system for apple. Technical Bulletin. ICAR-CITH, Srinagar

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First Edition
2020

Published by
Director,
ICAR-Central Institute of Temperate Horticulture
Old Air Field, Rangreth, Srinagar, J&K
Tel. No.: 0194-2305044
Fax: 0194-2305045
E-mail: dircithsgr@icar.org.in
Website: www.cith.ernet.in

Compiled & Edited by
K.L. Kumawat
W.H. Raja
D.B. Singh
O.C. Sharma
J.I. Mir
A. Sharma
Sajad Un Nabi
S.N. Kirmani

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Introduction

The agro climatic conditions of Himalayan region in India are highly suitable for growing temperate fruits. Among the temperate fruit crops apple is the major crop in India, producing 2.33 million MT from 3.01 Lakh hectare areas. During 2017-18 India has exported 12.53 thousand MT apples and earned 391.66 million rupees. Jammu and Kashmir is the largest apple producing state in India, producing 1.81 million MT, which accounts for 77.78 per cent of national production Whereas, Himachal Pradesh produce 19.21 per cent apple of India. In India apple was first introduced in Kullu valley of Himachal Pradesh by Captain R.C. Scot of British army in the 1870. Later it was introduced in Kashmir and due to suitable climate and other agro-ecological factors, it emerged as a major contributor to Kashmir's Gross State Domestic Production (GSDP), with more than Rs 9000 crore turnover annually. The state is known for its best quality apple not only in India but in bordering country too. Other apple growing states in country are Uttarakhand (2.54% production), Arunachal Pradesh (0.32% production) and Nagaland (0.09% production) (Source- Horticulture Statistics at a glance, 2018).

The apple industry in India has changed significantly over the last 30 years. During the late 80's apple orchards were characterized by standard type 'Red Delicious' plantings on seedling rootstocks trained on open vase system pollinized mainly with 'Golden Delicious'. In early 90's with the introduction of spur type 'Red Delicious' varieties and semi-dwarf rootstocks such as MM.106 and MM.111 apple planting density has increased from 156 (8 x 8 m) to 800 trees/ha using Open Centre, Delayed Open Centre and Central Leader training system mainly in square design at a spacing of 5 x 5 (400 tree/ha) and 4 x 4 (625 tree/ha), whereas, some grower's adopted rectangular design with spacing of 6 x 4m (416 trees/ha) or 5 x 3 m (666 trees/ha) and 5 x 2.5 m (800 trees/ha). However, after 12-15 years of orchard life many of these orchards had excessive vigor with permanent upper tier branches that were too strong resulting in shading of the lower and inner canopy which compromise fruit quality and in some cases return bloom. By the introduction of dwarfing rootstocks (M-9), there is a strong trend towards denser orchards (2200 or more trees/ha) by adopting flat planner orchard planting system like Espalier and vertical planner orchard planting system like Vertical Axis and modified form of Vertical Axis. Now from last 4-5 years, Tall Spindle orchard planting system is gaining popularity among the Indian apple growers.

Research advancement which lead to change in apple orchard planting systems

Evolution towards more competitive apple orchard systems has taken place

to improve orchard efficiency in term of yield, quality and profitability with efficient use of inputs. Until the mid-1900's the most common tree form in traditional apple orchards was large globe-shaped tree planted on seedling rootstock with a height of 6-8 m and density of 70-100 trees/ha. However, over the last 70 years planting density of apple has been increased from 70-100 trees/ha to some cases more than 6,000 trees/ha after development of dwarf rootstock and improved management approaches, which resulted in development of several orchards planting systems for apple, each with their own merits. Even though the systems differ in specific management practices, many of the modern apple orchard planting systems have similarities and are based on the same underlying principles. They all have the common goals of early yield, high sustained yield and better fruit quality with maximum use of available resources (land, light, water, labour, energy etc.). Efforts to modify tree form and develop new apple orchard planning systems began in the middle of the 20th century. The journey has been started with Spherical-shaped canopy form and reached to vertical planner canopy system via conic, flat and V-shaped canopies. Both researchers and apple growers began to search for more efficient shapes and system.

Training systems are designed to manage trees for optimum yield of quality produce with efficient input use. In continuous development of apple orchard planting system, many principles have been discovered which have lead to present change.

- Development of dwarf rootstocks
- Light interception studies
- Light distribution and tree form studies
- Pruning studies
- Better understanding to bearing habit of cultivar
- More understanding to the management of branching
- Limb angle studies
- Introduction of feathered plants
- Development of new cultivar with high market price
- Shrinkage of available cultivable land

Development of dwarf rootstocks

Dwarf rootstocks played a key role in development of new orchard planting systems. They induce dwarfness in scion cultivar, consequently increased tree density and labour efficiency. Further, they induce precocity in trees thus

provide early return on investment. Moreover, they influenced the partitioning of resources between vegetative growths and fruiting, thus affect fruit quality and yield. They also provide resistance against biotic and abiotic stress, and in turn improve orchard profitability. In 1950's and 1960's with the use of semi-dwarf rootstocks tree density increased from 70-100 to 250-350 tress/ha. In the early 1970's with the use of fully dwarf rootstocks, new orchard planting system developed at densities of 1000-2000 trees/ha. Since then, tree density has been increased towards higher side in most of apple growing countries. The significant control in tree size with the use of dwarf rootstock led to development of many new orchard planting system in apple. Most successful high density orchards are established using dwarfing rootstock like M.9, M.26 and B.9. However M.9, became the dominant dwarfing rootstock for high density planting in the world. In recent years, B.9 has become an important dwarfing rootstock where fire blight is serious problem in apple production.

Light interception studies

Light interception is the amount of available light intercepted by the tree canopy and not striking the orchard floor. Therefore the interception is a function of orchard planting system, rootstock (particularly in early age of orchard), tree density, tree form, tree height, tree arrangement/row orientation, canopy size, alley width, leaf area index within the canopy and length of the growing season. To achieve high mature yield of quality fruits, orchard canopies must intercept a high proportion of available light (70-75%). The studies of canopy light interception and its optimization played a key role in development of new orchard planting systems.

Light distribution and tree form studies

Generally shaded areas of the canopy produce fruit of smaller size, poor fruit color, less return bloom and weak fruiting spurs. In an ideal orchard, light should be evenly distributed under tree rows & alley's and should be around 60-70 per cent. Light penetration into the tree is usually determined by the size and shape of the tree. Tree shape and light distribution was extensively studies and the findings lead to development of various orchard planting systems to improve light interception and distribution in trees.

Pruning studies

Pruning of apple trees has been studied from very long time. Over the last 40 years, a number of studies have focused on the natural growth habit of the apple tree to develop improved pruning techniques and as a result the concept of minimal pruning at planting and renewal pruning has developed. Pruning of young tree through heading cut at the time of planting is a most

common practice with the central leader system to encourage vegetative growth to form canopy as soon as possible which fill the allotted space in the orchard, whereas the vertical planner orchard planting systems, utilize more natural tree form and trees are planted very close within row thus requires a minimum growth to fill allotted space. Moreover, pruning at the time of planting leads to delay in fruiting. The concept of renewal pruning with bevel cut to replace big branches with new one, lead to development of vertical axis system which utilizes the natural growth habit of tree and minimize the shading problem of upper tier of branches. With the passage of time many orchard planting systems has developed which utilizes renewal pruning concept. Further the concept of minimum pruning at the time of planting and training of tree by branch positioning lead to increase the profitability of vertical planner orchard planting systems. Thus the better understanding of negative effects of pruning on tree vigor and new pruning concept has lead to development of new orchard planting systems.

More understanding to growth and bearing habit of cultivar

According to type of fruiting the apple cultivars has been classified in four groups as

Columnar- It is presented by upright growing cylindrical trees with a terminal and fruiting spur along the main leader which bear fruits. It is controlled by a dominant gene and was previously discovered in 'Wijcik McIntosh'. It hardly needs any pruning and tends to bear biannually.

Goldlane

Redlane

Columnar type cultivars of apple introduced by ICAR-CITH, Srinagar

Spur type - It is mainly characterized by short shoots in the scaffold limbs. The trees tend to be upright with numerous spurs close to the trunk. Most of the fruiting spurs are produced on two year or older wood. But due to less autonomous nature of the laterals, cultivars comes under this group tends to be biannual bearing i.e. Starkrimson

Oregon spur

Silver spur

Spur bearing varieties of apple

Spindle - Varieties belonging to this group tend to be spreading with wide crotches and frequent branching. They bear both on spurs and shoots that are generally 1–3 years old. The fruiting zone tends to move away from the trunk to the outer sides of the tree. Spindle is presented by ('standard') 'Golden Delicious'.

Tip bearing- Varieties belonging to this group tend to have upright main scaffold limbs with narrow crotches and frequent branching. These varieties rarely develop lateral shoots in the lower portion of their wood. The fruiting zone moves towards the outside of the trees (more rapidly than spindle). These trees have longer branches with the weeping habit and bear a large part of the crop terminally on the previous year's brindle length shoots. Weeping habit may be partly due to the weight of the fruit on these longer shoots. This kind of cultivar i.e. Granny Simth has a shorter production time and due to more autonomous nature of the laterals cultivars fall under this group show regular bearing pattern than Spur and Spindle type.

Granny Smith

Rome Beauty

Tip bearing varieties of apple

Better understanding to the fruiting nature of apple trees led to development of group specific branch management concept which results in development of bearing habit specific orchard planting system i.e. SolAxe system (modification of vertical axis system) which was developed to achieve more weeping canopy by more branch bending and by avoiding renewal pruning. This system is developed to utilize natural balance between vegetative growth and fruiting on tip bearing cultivars.

Limb angle studies

With the development of Central Leader and Slender Spindle systems branch manipulation become an important part of tree management in formative stage of orchards. In central leader branches in each tier are spread manually to an angle of around 30º above horizontal in bottom tier and to horizontal in the upper tiers. Likewise in Slender Spindle branches are tied down to horizontal or below horizontal in the second year. Lespinasse (1977) studied branch angle and its effect on flowering, fruiting and fruit size and concluded that branch angles above 45º produced vigorous growth and little flowering and fruiting. Further, branch angle of 45º to horizontal position produced less growth, heavy flowering and larger fruits. Whereas, angles below horizontal produced minimal growth but often produced small spurs and small sized fruits. After further studies on branch angle Lespinasse and Delort (1986) identified three fruiting zones in fruiting limbs. 'Zone A' (0-30º from the vertical) is characterized by the development of strong vegetative shoots, which are able to produce good quality fruits after one or two year. 'Zone B' which is below the former between 30º and 120º from the vertical, is the prime fruiting zone, with good light distribution and moderate shoot growth. 'Zone C' which is below 120º, produces smaller inferior fruits because of the deleterious effects of within-tree shading on fruit size and quality. These studies lead to development of orchard planting system with the aim to

develop branches in 'Zone B', which produce the best quality fruits.

Feathered Plants

Before 1970, almost all the nurseries were producing one year old and maiden nursery plants. However, with the development of high density orchard systems many researchers began to study alternate approaches to nursery plant management as these one year old whip nursery plants were not found suitable for establishment of most of the high density apple orchard planting systems, as they considerably delay fruiting thus devastate the potential returns and negate the benefit of the high density planting for profitability. From many studies it has been established that feathered plant has many benefits over maiden nursery plant. These studies led to development of two year old feathered nursery plant with various techniques. Two years old highly feathered nursery plants with more than 1.7 m height and 12-14 mm caliper are the critical component of most of the vertical planner orchard planting system.

Development of new varieties with high market price

Many new apple varieties have been developed during the last three decades. Some varieties were quickly discarded but many others have become very important. Generally the fruit price was very high when the variety was introduced but as production increased the price decrease. Generally modern high density orchard planting system have 15 year economic life or up to 20 years economic life with better management practices. Therefore, such high density orchard planting system provides better opportunity to replace their orchard with new cultivars with high market price.

Need of precociousness and regular high yield

The need of early yield as well as mature high yield leads to development of new orchard planting systems. To compensate high orchard establishment cost, the new systems were developed with the aim of early yield. Early yield is largely a function of tree density, rootstock, type of nursery tree (whip vs feathered), branch orientation, pruning intensity at planting and growth of tree after planting. Higher tree density utilizing dwarf rootstock, feathered nursery tree, branch bending, minimum pruning at planting and maximum tree growth after planting can result in significant yield during second year. Further, branch management with renewal pruning concept results in regular mature high yield.

Need of Mechanization

Manual labour cost is increasing day by day. Therefore, it is important to

increase labour use efficiency to increase orchard efficiency and this led to development of system which suit to partial mechanization. Most of the modern high density orchard planting systems are ideally suit to partial or complete mechanization in planting, fruit thinning, harvesting, pruning etc.

Shrinkage of available cultivable land

The availability of cultivable land is declining day by day and the cost of land is rising. Meanwhile, the demand of apple is rising but, the productivity of apple is less due to small land holding and apple production from small land holding with traditional orchard planting system remained unprofitable for farmers. Therefore need of increasing land productivity by accommodating more number of plants per unit area lead to development of new orchard planting system.

Tall Spindle orchard planting system

Tall spindle is ideally suitable for apple fruit growers in India, particularly in Kashmir region where most of the apple orchard are on plain land with assured irrigation facilities. Instead of relying on strong trunk and big scaffold branches, Tall Spindle trees depends on a trellis system for support. Tall in the name of system denote height of the tree which is about 10-12 feet whereas spindle (thin) is natural growth habit of standard 'Golden Delicious' cultivar which tend to be spreading with wide crotches and frequent branching. The Tall Spindle incorporates aspects of the Slender Spindle (high tree density), Vertical Axis (tree height, limb renewal pruning), Solaxe (pendant limb angle) and Super Spindle (simpler and narrow canopy, small diameter fruiting branches, no large scaffold) orchard planting system. The Tall Spindle orchard planting system achieves the goals of early cropping, regular high yield and good fruit quality. In addition to this it also maximizes the profitability by utilizing the optimum tree density, moderate investment and simplified management technique. Therefore if done properly it will be the most profitable system for apple growers of Kashmir valley.

Basic Principle and merits of Tall Spindle orchard planting system

Tree management in Tall Spindle orchard planting system is relatively very simple than other systems and very easy to manage by growers. The basic elements of mature Tall Spindle system is a single dominant trunk with height limited to 90 per cent of the distance between the rows which result in maximum light interception (70-75 cm). The second principle is that it has no large diameter branches from the base of the tree up to the top. Only those branches are allowed to remain which are smaller than 2.5 cm in diameter.

This system have majority of branches which are smaller in diameter with 7-10 fruits and hang due to fruits load and produce very narrow conical tree. A Tall Spindle trees generally have 15-20 small fruiting branches which produce about 150 high quality fruits. The third principle of the Tall Spindle system is that it maintains a very narrow canopy. The top is narrower compare to base of the tree that allows good light exposure on both sides of the tree. Trees in north to south oriented row receives morning sun shine on one side of the tree and in the afternoon other side of the tree. Since it is very narrow (less than 3 feet deep canopy) almost all fruits receive direct sunlight exposure leading to develop uniform colour and size. Further, this system not only have very narrow tree wall but is also very tall thus it provide an opportunity for partial mechanization for pruning, hand fruit thinning and harvesting in upper part of trees by positioning worker at 6 feet by using platform. Due to possibility of partial mechanization labour reduction can contribute to the potential positive ability of Tall Spindle. Thus Tall Spindle system not only has a lot of advantages that combine high economic productivity but also tree management is very easy under this system.

Essential component of Tall Spindle orchard planting system

1. High tree density

Planting density is single most important factor which determines the yield of orchard particularly in early years. The closer tree density results in more competition and less growth for individual trees. However, proper selection of tree density for Tall Spindle system depends on consideration of vigor of rootstock and variety, bearing habit of variety, soil fertility (determine in row spacing) and land slope (determine between row spacing). The proper tree density can vary from as many as 3700 trees/ha (0.9 x 3 m) to 2300 trees/ha (1.2 x 3.6 m). For weak or moderate growing cultivars like Delicious, Golden Delicious, Gala, Braeburn, Empire, Jonamac, Macoun, Idared, Honeycrisp etc. the recommended row spacing is 0.9 m whereas for vigorous cultivar like Spartan, Fuji, Jonagold, McIntosh, Mutsu etc. and tip bearing cultivar like Granny Smith, Rome Beauty, Gingergold, Cortland etc. the recommended in row spacing is 1.2 m. For plain land recommended spacing between rows is 3 m whereas for sloppy land recommended spacing between rows is 3.6 m.

Tree density for Tall Spindle at different spacing

Tree spacing (m)	Row spacing (m)	
	3.0	3.6
0.9	3700 plants/ha	3080 plants/ha
1.2	2770 plants/ha	2300 plants/ha

2. Selection of rootstocks

The success of a high density orchard largely depends on the selection of rootstock and selection of rootstock depends on tree spacing, vigor, climatic and soil conditions. Wrong combination of rootstock, spacing, soil and climatic conditions results in excessive vigor, consequently the trees will quickly outgrow their assigned space and will require excessive pruning to manage it within allotted space. In contrast if the trees do not fill their allotted space in expected time, then fruit yields will be compromised.

Dwarfing rootstocks are essential for early cropping as well as to manage vegetative vigor of scion cultivars. The trees in Tall Spindle orchard planting system should be dwarfing and precocious. Till date most successful Tall Spindle orchards were established on M.9 and B.9 rootstocks. Within rootstock, however, there are vigor differences. Weaker clones (M.9-T337, B.9, G.11 and G.41etc.) are recommended for vigorous cultivars or virgin soils, whereas, more vigorous clones (M.9 Pajam 1&2, M.9 Nic29, M.9 EMLA G.16 etc.) should be used with weak scion cultivars or weak soils.

3. Cultivar selection:

Certain cultivar perform better in some areas than others therefore, care should be taken to ensure suitability of cultivars to the particular growing region. Further, when choosing cultivar to grow, it is important to consider the market price of the cultivar, because market price has the greatest effect on the potential profit of orchard planting system. In most cases the market price is very high when the new variety is introduced in market but as production increased the price drops. The high density planting systems are more sensitive to price fluctuation than the low density planting systems. This means that when the market prices are less, they suffer the most and when the market prices are more they benefit the most.

4. High quality well feathered nursery plants for planting

A high density apple orchard should be precocious to overcome the high early investment costs. Therefore, whip or small caliper plants are not suitable for establishment of the Tall Spindle orchard planting systems. If apple grower's

use such type of nursery plants, the plants do not bear fruits until 4 or 5 year. To achieve bearing in the second year after planting, high quality well feathered nursery plants must be planted. Therefore, high quality feathered nursery plant is essential component of this system.

An ideal nursery plant should have following characteristics-

I. An ideal nursery plant should be at least 6 feet tall with dominant straight central leader. Tall nursery plant is beneficial for obtaining high yield efficiency during the initial years. Well-developed flower buds on the upper parts of the leader promote yield in the second year and sustain autonomous branching with bourse shoots in the subsequent years. Additionally, tall nursery plant help in acquiring targeted tree height (10 feet at the end of second year) in Tall Spindle orchard planting system.

II. The initial large caliper of the nursery plants at planting leads to greater growth and yield in initial 4 to 5 years. At early age of tree, crop load is generally determined by trunk diameter, hence ideal nursery plant should have at least 14 mm trunk diameter at 10 cm above bud/graft union to produce significant yield during second year.

III. A dominant straight central leader is prerequisite for Tall Spindle orchard planting system to achieve targeted height.

IV. Tall Spindle orchard planting system generally requires 10-12 feathered nursery plants.

V. Once lateral develop on nursery plant they need to grow a desirable length since feather length and orchard tree productivity are linked positively. Generally feathers less than 10 cm in length are not considered as ideal feathers. For high density planting the feather length of apple nursery plant should be less than 40 cm to reduce branch manipulation after planting.

VI. Nursery plants should have feathers with moderate vigor to avoid renewal pruning in early years of orchard establishment. To preserve a hierarchy of branch and leader diameter, at lower part of plants feather diameter should not be more than 50 per cent of leader diameter whereas; at upper part of plants it should not be more than 33 per cent of the leader diameter.

VII. The height of first feather from ground is important to determine the quality of nursery plant. VPOPS in which tying down of lower branches (to manage vigor and induce early high yield) is essential component of system, optimum height of starting feathers is 75-80 cm.

VIII. Feathers should be distributed along the central leader at regular interval.

IX. Ideal nursery plants should have feathers with > 45º crotch angle from central leader. Feathers with wide angle form strong union and result in early bloom, higher productivity, balanced vegetative growth, and are easily positioned after planting.

X. Ideal nursery plants should have abundance of healthy roots to support tree canopy during first year.

Advantage of feathered nursery plants-

Feathered plants are critical component of Tall Spindle orchard planting system.

I. Feathered plants with large caliper will quickly establish, grow to desired height and fill their allotted space in orchard thus improve total light interception in early life of orchard.

II. Feathers form flower buds in the second year of nursery cycle as well as during first year in orchard and will produce significant yield during second year, which will help to cover the initial cost of establishment.

III. Early cropping controls vegetative vigour of apple trees and consequently resulted in optimum growth for flowering and fruiting

IV. With the use of well-feathered nursery plants, canopy management after planting will become easy and cost effective.

Technique for feathered plant production

Vigorous and healthy one year old grafted apple nursery plants of 60-80 cm height should be planted during the end of December at 90 (within row) x 60 (in row) cm spacing. Lateral branches if any should be removed at the time of planting. Spray 600 ppm 6-benzyladenine to produce 6-8 feathers nursery plant and higher concentration of BA (1000 ppm) to produce 10-14 feathers nursery plant during the second vegetative growth on the apical portion of

the central shoot when it has 12-15 cm new growth in standard type varieties and on 15-20 cm new apical growth in spur type varieties using hand sprayer until run-off. Apply 3-4 sprays at one week interval in standard/vigorous growing varieties and 4-5 sprays at two weeks interval in spur/slow growing varieties. Follow routine nursery management like nutrient, water, weed, pest and disease management. In addition to this, two foliar applications of urea at 15 days interval starting from first week of September should be applied.

Preparation of benzyladenine (BA) solution: Dissolve required quantity of BA in small quantity of IN NaOH (40 g NaOH in one litre water) and then add required amount of water.

Preparation of ppm (part per million) solution

- ✓ 600 mg in I litre = 600 ppm,
- ✓ 1 g in 1 litre = 1000 ppm

Some basic consideration-

- ✓ Spray under slow drying conditions i.e. late evening or early morning (best temperature- 18-28ºC).
- ✓ Do not spray on wet foliage.
- ✓ Do not spray on un-healthy and stressed plants.
- ✓ Ideally there should be no rain at least 6 hr after BA spray.
- ✓ Add 400 µL per litre silicon based adjuvant in spray solution if rainfall predicted.
- ✓ Rewetting- within 1-2 days of spray application can increase effectiveness.

One year old nursery plant

First application of BA at 15 cm new growth

Bud swelling- 15-20 days after spray

Initiation of feathers- 20-25 days after first spray

Initial feathers growth

Advancement in feathers growth

Advancement in feathers growth

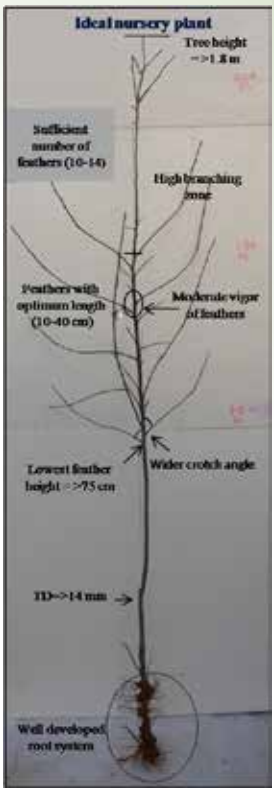
Fully developed feathers

Second year nursery cycle- dormant 2 years old feathered nursery plants

Evenly distributed feathers with wide crotch angle

Flowering – during second year

Fruiting - during second year



Ideal nursery plant for tall spindle orchard planting system

High planting depth

Deep planting always comes with a risk and can hurt the tree. Keep the nursery soil line above the ground and just cover roots with soil. This provides proper

oxygen to roots and roots work better. Graft/bud union needs to be 10 to 15 cm above ground to avoid scion rooting, graft union rot and to regulate the stionic effect.

Ideal planting depth - just covers roots with soil

Graft/bud union should be 10-15 cm above ground

5. Minimal/no pruning at planting

Pruning of tree at the time of planting is a most common practice with most orchard planting systems to maintain shoot to root ratio and to encourage vegetative growth to form canopy as soon as possible to fill allotted space in orchard. However, under Tall Spindle system, plants are planted at closer spacing. Therefore very little space is needed to fill and very little pruning is needed. In this system leader as well as feather is not pruned at planting to achieve targeted height and to get crop in second year. Even if a whip is planted, the leader is not pruned at planting. Research studies have shown that any pruning of young trees will delay fruit production in early life of orchard. Moreover, minimally pruned tree show some transplant shock during first year which help to manage vigor of tree. In the Tall Spindle orchard planting system, following precaution should be taken:

- Do not head back tree at the time of planting
- Remove low branches (below knee height) and any feather/s that are larger than 2/3 of the diameter of the leader.
- Leave as many feathers as possible without compromising growth of leader

Remove branch/es below knee height at the time of planting

Remove feather/s competing with central leader at the time planting

Remove dead or damaged end of feather's or remove copletely at the time of planting

Remove larger feather/s that is/are larger than 2/3 of the diameter of the leader where they insert with bevel cut at the time of planting

6. Bending feathers and branches below horizontal at planting

The most important method of inducing early cropping and reducing vigor of vertical branches is tying branches below horizontal. The shoot in vertical position favours the development of strong vegetative growth which tends to remain unfruitful. A shoot in horizontal or pendant position grows less vigorously and therefore crop heavily in the next year and bend with the

weight of fruit. Moreover, the fruit compete for resources and limit tree growth further. If a vertical shoot is bend below by tying them or by putting weight, lateral buds are released from dormancy. If the branch has excessive vigor these buds may grow into vigorous upright shoots and remain unfruitful. On the other hand, if the branch has more moderate vigor the lateral buds grow into short shoots which become fruitful.

In the Tall Spindle system instead of very high vegetative growth (desired in moderate and low density orchard to quickly fill allotted space) only optimum growth is needed. Moreover, this system utilizes highly feathered plant, therefore no lateral growth is needed but only central leader growth is needed to attain anticipated tree height as soon as possible. This lead to management of branch angle soon after planting to limit extension growth. The extent to which branches should be managed to limit extension growth depends on the in-row tree spacing and with 90-120 cm spacing, branches should be tied down below horizontal in a pendant position at planting so that they produce almost no extension growth and ready to begin fruits in second year. This also prevents them from developing into large lower scaffolds and prevent severe limb removal pruning in early age. Thus this simple method of branch management in early age allows for long-term fruiting in many branches and little intensive pruning for first 4-8 years at very close in-row tree spacing. After the initial tying or weighing down of branches at planting, new lateral branches that arise along the central leader do not need to be tied down. In most climates, if moderate vigor shoots are not headed back, often fruit load in the third year will bend them down below horizontal and a natural balance between growth and fruiting will be established without additional branch management. Thus with the Tall Spindle branch tying is needed only at the time of planting. However, in vigorous climates or where winter chilling is insufficient, branches often become too large before they set sufficient crop loads to bend the branches down. In these climates, tying down to all vigorous branches must be done annually for the first 3-5 years until the tree settle down or began to crop heavily.

- Bend feathers below horizontal at planting
- Bending of feathers needed in 1st year only in most climates
- Use wire or string or bend by weighing down

Bending of feathers at the time of planting

- Important to get 2nd year yield and to suppress vigor

Note: The best time of tying of feathers is within one month after planting. But bending can also be done in June, July, or up to August however, late tying is more difficult due to the presence of new growth and foliage. It takes more time in tying and to fix angle as it do at the time of planting furthermore, it also disturb branch growth pattern. During, second year if some branches show vigorous growth tying can be done after completion of vegetative growth.

Bending of branches due to crop load during second year

7. Limb renewal /no permanent scaffold branches

In Tall Spindle orchard planting system, plants are spaced very close within the row thus there should be no permanent limbs within the tree. Therefore, when scaffolds grow too large they should be renewed by complete removal for available space. Renewal cuts are made using the "bevel cut" method (removal of large branch at the point of origin leaving about 2-2.5 cm long beveled stub) which encourages new shoots to form as replacement fruiting limbs.

Renewal pruning using bevel cut

Sub cut can also be used for renewal pruning but it often end with many branches

8. Leader management

Maximum leader growth during first 2-3 years is critical in a Tall Spindle apple orchard planting system to obtained desired yield. The tree should reach the top wire (10 feet) by the end of the second or third year. To achieve targeted growth of leader in expected time, maintaining good leader growth is critical. With a weak growing cultivar such as Honeycrisp the lack of sufficient leader growth to reach the top of the trellis (10 feet) by the end of the 3rd year is a serious problem that limits yield in future years. With more vigorous cultivars such as Gala, Fuji or Mclntosh reaching the top of the trellis by the end of the 3rd season is usually not a problem. However, with weak growing cultivars, growers need to intensively manage the trees in the first 3 years to achieve desired growth.

1. Use suggested combination of cultivar and rootstock (weak cultivar plus vigorous M.9 clones)
2. In the Tall Spindle system, the leader is promoted, and is not pruned. Even if planting a whip tree, the leader should not be cut back, which not promote the growth pattern needed for the Tall Spindle.
3. Remove the buds around the leader and cut back top shoots competing with leader at the time of planting.
4. Quickly install the trellis and irrigation lines after planting
5. Water (when needed) should be supplied by drip irrigation with low doses per tree (8-10 litre) but frequently (2-3 times per week)
6. The best tree growth response can be achieved by injecting liquid nitrogen fertilizer (fertigation) with each irrigation (100 ppm = 0.1 g / liter of irrigation water)
7. The new trees should grow healthy, without weed competition, and biotic and abiotic stress
8. The leader should be attached to the trellis with a rubber band or a wire loop as soon as it reaches successive wire
9. In first 2-3 years, remove branches that compete with central leader (early growing season or during dormant season) or rub off the second and third shoots below the central leader at 5-8 cm of growth.

10. If leader gets damaged before reaching to top wire, choose replacement leader from the strong upright branch, tied to the trellis or stalk and remove competing branches.

During first 2-3 years, remove branch/es that compete with central leader

Choose replacement leader it leader get damaged before reaching to top wire

9. Superior support system

Support system is an essential component of modern high density orchard planting system because most of high density planting system utilizes dwarf rootstock to manage vigor and induce early cropping. The orchard support system is crucial factor for achieving targeted tree growth during the early age of orchard, early high yield and to support crop load on weak fruiting branches. The orchard support system signal tree to direct its energy to growing fruit spurs, buds and roots rather than structural wood. Moreover, many rootstocks have brittle graft union, which have tendency to snap under any type of stress induced by wind and fruit weight and snow. In addition tree support system also have influence on growth and fruiting by reducing movement of tree which results in less secondary trunk thickening thus fewer carbohydrates used in wood development and more available for fruit production. Research study revealed that the tree supported from planting time produced 30 per cent or more yield in first five years compared to the unsupported tree.

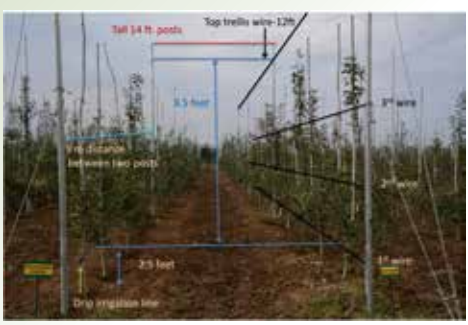
The Tall Spindle system is design to produce early high yield and the trellis need to support this crop load. With 10-12 feet tall trees, crop from bottom to top, the trellis design need to support at least 60 tonnes/ha in all kind of weather and soil conditions. There are two types of support systems available i.e. individual tree stakes and post & wire. However, post & wire trellis have several advantage over individual tree stakes i.e. the trellis is more economical

at higher tree density, the wire attachment allow less twisting in the wind with fever broken graft union. Further, wire gives more option for branch positioning and support fruit load on weak fruiting branches.

To avoid failure of orchard trellis under high wind, snow and heavy rain event, consider following critical area for proper construction of support system.

- Anchor shift should be screwed in the ground at least 3 or preferable 4 feet deep. Anchor pole should be at least 60° angle for maximum strength.
- In row pole should be 10-14 m apart.
- Post stalk should be 3-4 feet in the ground.
- Post installation should be based on pounding or vibration rather than augering.
- Wire should be 12.5 guage hi-tensile, joint with cripple and attached to post with carefully placed staples avoiding damage to the wire.
- Large size U-Hooks (8-10 cm) should be used to support trees.

Note: *Build the support system for trees as soon as possible. Consider providing temporary bamboo stakes to individual tree if establishing the support system is delayed.*



Post and four wire trellis support system for Tall Spindle orchard planting system.

Strong support system minimize damage to trees due to untimely snowfall.

10. Irrigation Management

Drip irrigation system is more suitable for Tall Spindle as it enhance water use efficiency and useful in providing optimum amounts of irrigation water (and fertilizer) consistently throughout the season for good fruit development. For establishing high density apple orchard large highly feathered nursery trees are planted and large trees sometimes do not grow well after planting as we

desired them to grow. Highly feathered nursery trees undergo water stress shortly after planting in spite of adequate soil moisture levels. This is because of the damaged root system of a transplanted trees and limited root to shoot ratio. Feathered nursery trees produce much more leaf area just after planting compared to whip trees which creates high water requirement before the root system can re-grow sufficiently to support the trees. Therefore the young feathered trees require frequent water supply to maximize first year tree growth. The growers should install drip irrigation soon after planting with high density orchards that use large feathered nursery trees.

The amount of water and when to apply depends on soil type, temperature (evapotranspiration), frequency and amount of rainfall. More frequent irrigations will be required on sandy soil and high temperature areas than clay and low temperature areas. Under the Tall Spindle orchard, developed on M-9 rootstock the area beneath the canopy of the tree should be wet to a depth of 45 cm at each irrigation.

In bearing or mature Tall Spindle orchard adequate soil moisture is critical during fruit set and fruit development but more critical period is early growing season. Since in most of the apple cultivars fruit cell division only take places during the 4-5 week after bloom. After that period, cell division do not occur and fruit growth for the rest season occur only by cell expansion and during the cell expansion period the similar amount of weight adds by fruit per day until harvest. However, in case of heavy crops or cold weather the growth may decline before harvest. The bigger fruit have higher growth than smaller fruit and this difference in growth rate is directly controlled by cell numbers, as each cell grow the same amount per day in all fruits as explained by many anatomical studies. The bottom line is that the final fruit size potential of apple fruit depends primarily on the number of cells in the fruit. Therefore, if the trees are under stress during the cell division period, the potential size will be reduced. Similarly, low soil moisture/water shortage prior to harvest (approximately 5-6 week before harvest) fruit size and quality will be affected. In contrast too much soil moisture in this period lead to reduce fruit quality.

Irrigation should be done through drip irrigation using 4 micro-tube type emitters (1.5 L per hour discharge capacity) per tree in every direction for equal distribution of water around the tree. It helps in proper root distribution and mineralization of nutrients.

11. Nutrient Management

Highly feathered nursery trees has limited ability to take up nutrients from soil just after planting due to damaged root system as well as during planting year due to limited root to shoot ratio. Therefore, increased nitrogen application to

support growth in feathered young trees may be needed during the first 1-2 years. After planting apply low doses of nitrogen at 3-4 days interval through fertigation during first 3-4 month to increase uptake of Nitrogen and achieve good tree growth during the first year. After first two years, low nitrogen application is desirable to keep the trees calm with a balance between vegetative growth and fruiting. Sometime, mature Tall Spindle orchards can result in excessive vegetative growth which can lead in severe canopy management problem especially in vigorous varieties. This can happen due to improper branch management and excess nitrogen fertilization. Therefore soil fertility also should be considered when calculating the amount of nitrogen fertilizer to be applied.

Under drip irrigation system only a portion of the soil volume around each plant is wetted and thus conventional method of fertilizer application is not so effective. 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 Tall Spindle orchard planting system.

12. Crop Load management

Early cropping is the main goal in high density planting and cropping must began in the second year with the Tall Spindle system. Early cropping is necessary to get early return on investment however, over-cropping can negate the vigor and profitability of orchard. Trees which are over-cropped in early age may take more time to fill allotted space and may not achieve higher yields. Moreover, over-cropping affects return bloom especially in apple cultivars which are prone to biennial bearing i.e. Honeycrisp, Fuji, Mutsu, Golden Delicious etc. Even over-cropping can push any regular cultivar to a biennial habit. Furthermore, trees with heavy crops often have poorly colored fruits. The reason of this is likely that sugar levels in the fruit are low.

Crop load management is best way to produce quality apples and to get good return bloom. Avoid over-cropping by removing excessive fruit load in early summer. In young tree hand thinning is preferable over chemical due to unpredictable response of chemical thinner. Thin fruit after early drop as un-pollinated fruit naturally fall down on ground at this time.

Cropping targets for the Tall Spindle (number of fruits) system

Year	Number of fruits	
	Regular bearer or vigorous	**Biennial bearing and Slow growing**
2nd	15-20	8-10
3rd	50-60	25-30
4th	100	50

The correct crop load can be determined by tree size and it is usually measured at trunk diameter 10 cm above graft union. Fruit should be well distributed along the canopy of the tree to attain potential fruit size. Fruits in cluster should be thinned properly to avoid excessive competition and fruit fall. Further, number of fruits to be retained on individual tree depends on the fruit size. Those varieties which have smaller fruits can retain more number of fruits per tree. Caliper test is also useful in management of crop load on branches of larger tree. Although the Tall Spindle orchard planting system target high early yield of 50-60 tonnes/ha in first 5 years but it is more important to limit the crop load based on the tree size to allow the tree to grow to its full potential and to prevent biennial bearing.

Optimum numbers of fruits to be retained on the tree at different caliper (mm-10 cm above graft/bud union) in Tall Spindle orchard planting system.

Caliper (mm)	No. of fruit
12	7
14	9
16	12
18	15
20	19
22	23
24	27
26	32
28	37

13. Maintain conic shape of the tree

Good light exposure is critical for fruiting and fruit quality in any orchard planting system. Therefore it is important to keep the tree narrower at the top than at the bottom for maintaining a conic shape to the tree. Maintaining a conic shape with the trees age, is critical for keeping good light exposure in the bottom of the tree and this can be achieved by annual removal of large one or two upper branches completely by “bevel cut” so that small stub of the

lower portion of branch remains which often result in flat, weak replacement branch. When such type of pruning is repeated annually, the top of the tree can be composed completely with young fruitful branches, thus maintaining the conic shape of the tree.

Simplified Training System for Tall Spindle

First year:

✓ At planting- Plant high quality feathered nursery tree (10-14 feathers) at a spacing of 0.9 to 1.2 m by 3.0 to 3.6 m. Keep graft union well above the soil line (at least 4 inches). Remove all feathers below knee height using a flush cut. Remove damaged or dead ends of the feathers or remove if they are small with bevel cut. Remove larger feather/s that is/are larger than 2/3 the diameter of the leader where they insert with bevel cut. Remove feather/s that is/are below than 20 cm from the top of tree and competing with central leader with bevel cut. Whereas, remove all competitive shoots with leader in upper 20 cm with flesh cut. Tie down all remaining feathers to below horizontal. Do not head back the leader or the healthy feathers.

✓ Pinch off the flower/s if any.

✓ Rub off the second and third buds below the central leader shoot at 5-8 cm growth to eliminate competitions to the central leader.

Second year:

✓ Dormant- Do not head back leader or prune trees unless there are branches that are more than 2/3 the diameter of the central leader where they insert using bevel cut. Remove damaged or dead ends of the feathers or remove if they are small with bevel cut. Single the central leader by removing any competitive shoots. Make sure the leader is securely fastened to the support wire. Columnarize branches by removing fork or upright shoots. Remove suckers and water sprouts.

✓ Remove flowers (manually) if any present on trees

✓ 10-15 cm growth- Pinch lateral shoots in top ¼ of last years leader growth removing about 5cm of growth (the terminal bud and 4-5 young leaves)

✓ Early June- Manage crop load- hand thin the crop to single fruit 10-15 cm apart and keep fruit on tree as per the caliper test. Second year crop is very important to ensure profitability of Tall Spindle and to manage vegetative vigor of trees and to achieve more natural equilibrium between fruiting and vegetative growth.

✓ Mid June- Re-pinch all lateral shoots in top ¼ of last year growth. Tie the

developing leader or erect growing lateral branches to the support system.

Third year:

✓ Dormant-Do not head back the leader. Remove all broken branches or vigorous branches which are more than 2/3 the diameter of the central leader by bevel cut. Single the central leader by removing any competitive shoots. Make sure the leader is securely fastened to the support wire. Columnarize branches by removing fork or upright shoots. Remove suckers and water sprouts. Tie tree to stakes or to the top wire with permanent tree tie at the top of the stake to help support fruit load on the central leader.

✓ Early June- Manage crop load- hand thin the crop to single fruit 10-15 cm apart and keep fruit on tree as per caliper test.

✓ Late June - Tie the developing leader or erect growing lateral branches to the support system.

✓ Late July or Early August (or when seasonal growth has stopped) - Light summer pruning (remove few shoots to open up tree) to encourage good light penetration.

Fourth year:

✓ Dormant-Do not head back the leader. Remove all broken branches or vigorous branches which are more than 2/3 the diameter of the central leader by bevel cut. Thin out braches on leaders to get sufficient space between two branches. Columnarize remaining branches by removing fork or upright shoots. Remove suckers and water sprouts. Tie tree to the top wire with permanent tree tie if not done during third year.

✓ Early June- Manage crop load- hand thin the crop to single fruit 10-15 cm apart and keep fruit on tree as per caliper test.

✓ Late June -Tie the developing leader to the support system.

✓ Late July or Early August (or when seasonal growth has stopped) - Light summer pruning to open canopy and optimize fruit quality.

Mature tree- (5th to 20th Year)

✓ Dormant- Limit tree height to 90 per cent of row spacing by cutting the leader back to a fruitful side branch. Annually remove 2-3 large branches which are more than 2/3 the diameter of the leader or more than 2.5 cm in diameter by using bevel cut. Shorten bottom tier branches where needed back to side branch to facilitate movement of equipment and preserve fruit quality in lower branches. Columnarize remaining branches by removing any side branches. In varieties like Delicious, Golden Delicious, Gala and McIntosh. If any shoots start to taper down to smaller than pencil size the diameter,

head back to where they are pencil size, preferably to a slightly growing shoot or spur. Remove all branches below knee height using a flush cut.

✓ Early June- Manage crop load to ensure annual bearing.

✓ Late July or Early August (or when seasonal growth has stopped) - Light summer pruning to open canopy and optimize fruit quality.

Winter pruning of mature Tall Spindle system

As Tall Spindle orchards mature, it becomes essential to allow sufficient sunlight penetration in trees. This will maintain high yields of good quality fruits. Excessive pruning is not needed in mature Tall Spindle orchards. Like formative stage after establishment, mature tree pruning is also minimal.

Rules of mature tree pruning

1. Limit tree height to no more than row width- Limit tree height to 90 per cent of row spacing by cutting the leader back to a fruitful side branch.

2. Remove 2-3 of larger branches- Mature Tall Spindle system follow "diameter based pruning" and leaving big branches will shut down the tree. In this system, the branches are not permanent. Therefore, annually remove 2-3 large branches which are more than 2/3 the diameter of the leader or more than 2.5 cm in diameter by using bevel cut.

Limb renewal pruning-Removal of large branch at the point of origin leaving a 2-2.25 cm long beveled stub

3. Simplify complex branches – Maintaining a columnar canopy, for best light penetration, is important. Therefore columnarize remaining branches (after removing big branches) by removing lateral secondary branches and leaving a column of fruiting spur. If we allow branches to make side branches than we have few branches along the trunk (6-10) as they take more space and moreover, they create shading. So by columnarizing we can able to keep more branches (15-16 on 8-9 feet) on trunk and meanwhile we can increase light distribution which is essential to produce good quality fruits with cultivar specific color. But when you perform the columnarizing you need to be careful to leave the fruiting spur rather than cutting it too close or you lose the potential for fruit at that location.

Columnization of branches by removing lateral secondary branches leaving a column of spurs

4. Cut back pendant or weak wood: In varieties like Delicious, Golden Delicious, Gala and McIntosh, if any shoots start to taper down to smaller than pencil size the diameter, head back to where they are pencil size, preferably to a slightly growing shoot or spur.

5. Shorten bottom tier branches (where needed) back to side branch to facilitate movement of equipment and preserve fruit quality in lower branches.

6. Corrective pruning: Remove all branches below knee height using a flush cut.

Removal of branch/branches below knee height with flush cut

Economics

- Target yields per hectare
  - 2nd year = 3.5 Tonnes
  - 3rd year = 9 Tonnes
  - 4th year = 18 Tonnes
  - 5th year = 25 Tonnes
- Total cumulative yield (first five year) = 55.5 Tonnes
- Return (first five year) 55.5 Tonnes X 30000 (Rs. 30/kg) = Rs. 16.65 Lakh

With the use of Tall Spindle orchard planting system grower can cover cost of establishment within five years.

Flowering during 2nd year

Fruiting during 2nd year

Flowering on columnarize branch during 3rd year

Flowering on central leader during 3rd year

Fruiting on central leader during 3rd year

Fruiting on central leader during 3rd year

Fruiting on columnarize branch during 3rd year

Advantage:

- Most profitable system (compared to other commercial orchard planting systems).
- High early yields (due to high tree density and feathered trees, bear fruit in second year, with a full harvest by 4th year).

- High mature yields (due to continuing renewal of fruiting area).
- High quality produce (due to increased light interception and distribution in the tall and thin tree's foliage).
- Highly efficient (minimum labour for training, pruning and harvesting).
- Simple and easy to establish and maintain.
- Use natural tree growth control (natural branch bending due fruit load).
- Better spray coverage (due to narrow canopy).
- Adaptable to partial mechanization (pruning, thinning and harvesting).
- Pedestrian orchard (70% of work from the ground).

Limitation

- Cost of establishment is high
- Irrigation is necessary
- Need lots of labour during early years of establishment
- Lack of availability of sufficient planting material

Conclusion

The Tall Spindle orchard planting system is gaining popularity around the world and is ideally suitable for Indian condition particularly for the Kashmir region. This system utilizes the concept of optimum tree density planting (2300-3700 tree/ha.) with high quality feathered nursery tree (10-14 feathers, 1.7-1.8 m height and >12 mm trunk diameter, 10-40 cm feather length), and minimal pruning at planting (removal of unwanted feathers) to get high early yield and sustained mature yield of high quality fruits while reducing and simplifying mature tree pruning and other management costs. The system achieves high light interception (70-75%) by growing tree to a height of 90 per cent of row spacing (3-3.5 m) and good light distribution throughout the canopy by keeping the tree canopy thin (1-1.5 m). Moreover, this system also provides opportunity of partial mechanization of training, pruning, fruit thinning and harvesting using platforms. Although, this systems have many advantages, but proper pruning must be conducted. It is not like traditional orchard planting system which can be corrected after a period of negligence. When Tall Spindle orchard planting system is neglected during the early year, tree canopy, precocity and potential orchard profitability is lost.

References:

Alan N. Lakso and Martin C. Goffinet. 2013. Apple fruit growth. *New York Fruit Quarterly*, **21**(11): 11-14.

Cain, J.C. 1970. Optimum tree density for apple orchards. *HortScience*, **5**: 232-234.

Lespinasse, J.M. 1977. La conduite du pommier. I. – Types de fructification. Incidence sur la conduite de l'arbre. INVUFLEC (Ed,), 80p. Paris

Lespinasse, J.M. and Delort, J.F. 1986. Apple tree management in Vertical Axis: appraisal after ten year of experiments. *Acta Hort.*, **160**: 139-155.

Robinson, T., Hoying, S.A., DeMaree, A., Lungerman, K. and Fargione, M. 2007. The evolution towards more competitive apple orchards system in New York. *New York Fruit Quarterly,* **15**(1): 3-9.

Robinson, T.L., Lakso, A.N. and Zhongbo, R. 1991. Modifying apple tree canopies for improved production efficiency. *HortScience*, **26**: 1005-1012.