Modern Production Technologies in

Horticultural Crops

Innovations and Practices for Optimum Growth

B. S. Tomar | A K Singh | P. K. Singh | Prabhat Kumar
Gograj Singh Jat | Prawal P. Singh Verma | Som Dutt

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HORTICULTURAL CROPS

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HORTICULTURAL CROPS
INNOVATIONS, PRACTICES AND OPTIMAL GROWTH

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सत्यमेव जयते

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Chairperson
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Ministry of Agriculture and Farmers Welfare
Government of India

FOREWORD

The Horticultural crops comprising of a wide range of species belonging to fruits, vegetables, flowers and ornamentals species, plantation crops, medicinal and aromatic plants etc. constitute an important component of our food system. These crops provide the much-needed nutrition to the consumers and income security for the farmers. India is the second-largest producer of fruits and vegetables in the world, which is a testament to the Horticulture sector's growing prominence. This sector contributes approximately 33% to the country's total agricultural GDP that reveals its relevance and importance for the country's well-being.

Research efforts in horticulture have resulted in the development of high-yielding varieties, valuable genetic resources, and innovative technological interventions. Despite these advancements, there remains an urgent need to develop new hybrids, explore underutilized crops, and expand the horticultural frontier through sustainable technologies. The vast pool of knowledge generated across institutions remains scattered, and its effective compilation and dissemination are essential. In the light of these imperatives, the Society for Horticultural Research and Development (SHRD) successfully organized the **3rd Indian Horticulture Summit-cum-International Conference -2024** on *"Technological Intervention for Boosting Horticultural Production"*, held during February 1-3, 2024 at Rajasthan Agricultural Research Institute, S.K.N. Agriculture University, Jobner, Durgapura Campus, Jaipur, Rajasthan. The summit witnessed the participation of leading scientists, researchers, and specialists who presented insightful lectures and contributed expert chapters. The outcome of this international meet is the present book, ***Modern Production Technologies in Horticultural Crops: Innovations, Practices, and Optimal Growth.*** It is a comprehensive compilation of 32 rigorously reviewed chapters, contributed by subject-matter specialists across various horticultural domains. The book highlights production technologies for major horticultural crops, and invites attention to lesser-known crops with high nutritional and economic potential. Topics such as plant health management, pest control, and region-specific industrial opportunities have been thoughtfully integrated. Written in an accessible and readerfriendly style, this book is designed to serve a wide audience including students, scientists, educators, policy-makers, and practitioners in the field of horticulture. It reflects the dedicated efforts of its editors and contributors, especially Dr. B. S. Tomar, Dr. AK. Singh, Dr. P. K. Singh, Dr. Prabhat Kumar, Dr Gograj Jat, Dr P.P. Singh Verma and Dr Som Dutt. Their commitment to presenting cutting-edge information in a practical and usable format is truly commendable.

I congratulate the editors for their painstaking efforts. It is expected that this book will serve as a valuable resource and inspiration for continued innovation and development in Horticultural Science.

Date: 24th October, 2025

(Trilochan Mahapatra)

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PREFACE

The horticultural science has emerged as the leading discipline in total agricultural development In India. Now-a-days, horticultural science plays a very significant role as its total production has surpassed total food grain production in our country. Besides, horticultural science has also proven facts of protecting mankind from so many dreaded diseases and making hunger free in the crisis of food scarcity.

A number of ICAR institutes and State Agricultural Universities are devoted in the field of research and development of horticultural crops. There is a large network consisting of huge manpower working on research and developmental activities across the country. Since horticultural production has surpassed our food grain production, still we need further research. A number of new varieties, genetic resources, technological interventions and certain breakthroughs need to be updated, compiled and disseminated to the target audience and stakeholders. Still there are so many crops which have enormous potential to be tapped. A number of challenges and problems are also emerging in our day-to-day field of research. Biotic and abiotic stresses have also challenged our research system. To overcome all these problems, collection of adequate scientific information and its timely dissemination has become the need of the hour.

The Society for Horticultural Research and Development (SHRD), Ghaziabad, Uttar Pradesh, India, convened the Indian Horticulture Summit on Mitigating Climate Change and Doubling Farmers Income through Crop Diversification, and Webinar on Boosting Immunity through Horticulture during the year 2020. The researchers belonging to all streams of horticultural science participated with their pieces of research information. Besides, we have invited some relevant chapters from other innovative scientists. And all such information has been compiled in the book. A number of lead lectures belonging to very senior research workers have been compiled in this publication. The publication consists of recent information. All the contributors have tried their best to give their valuable information in their lead lectures and chapters. The Society compliments all researchers who have shared their information for publication in the form of a book.

The book comprises chapters on genetic resources, varietal wealth, crop improvement, plant health management, management of insect, pests and diseases, and value-addition of horticultural crops. Besides, some chapters dealing general horticulture have also been dealt at length.

We are also thankful to Dr A. K. Singh, DDG, Horticultural Science (ICAR) and Drs G. Kalloo, T. Janakiram, J. P .Sharma, U. S. Gautam, R. C. Agrawal, S. Rajan, P. L. Saroj, D. B. Singh, Vishal Nath, S. Uma, B. K. Pandey and V. Pandey and Shiv Shankar Singh for their inspiration and encouragement during compilation of the book. Our sincere thanks are due to Astral International Pvt Ltd, New Delhi, for timely publishing of the book.

The book will serve the purpose of all students, scientists, researchers, policy-makers and related stakeholders engaged in the field of horticultural science. The editors of the book have taken utmost care while editing and making the book in a very easy-to-understandable language.

Dr B. S. Tomar

Dr A. K. Singh

Dr. Praveen Kumar Singh

Dr. Prabhat Kumar

Dr Gograj Singh Jat

Prawal Pratap Singh Verma

Dr Som Dutt

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THE EDITORS

Dr B. S. Tomar has been actively involved in development of seed production technology of vegetable crops under open field condition as well as hybrid seed production under protected conditions. Besides, he worked on genetic improvement of brinjal, onion, okra and cucumber (under protected condition) from last two-and- a half decade. He is associated with the development of 30 vegetable varieties [brinjal (6), onion (3), okra(1), cucumber (3), musk melon (2), garden pea (1), bitter gourd (2), velayti palak(1), cow pea(1), dolichous bean (1) etc.].Most of them have been commercialized through MoU, National Seeds Corporation and NHRDF, IARI and its regional station Karnal. He has also organized live vegetable demonstrations on vegetable technologies at UVRD farm and *mela* site. He has been associated with the teaching in Seed Science and Technology and Division of Vegetable Science since last 24 years and guided 8 Ph.D. students and 6 M.Sc. students, and Dr R Y Vishwanath, one of his students, won the IARI gold medal for his outstanding contribution in his Ph.D. programme. Dr. Tomar has published 101 peer-reviewed research publications in vegetable crops and more than 100 popular articles in *Indian Horticulture/Phal-Phool/Khad Patrika* etc.

Dr Tomar has published 11 training manuals, 2 practical manuals and more than 30 book chapters. He has organized one each short training course and winter school sponsored by Agricultural Education Division of the ICAR, two Model Trainings sponsored by Directorate of Agricultural Extension, MoA&FW and other sponsored farmers training programme in vegetable and seed production. He has also organized *Sabzi Pathshala* at All India Radio sponsored by M/s. Dayal Seed, Meerut and delivered more than 500 talks on All India Radio, Delhi Doordarshan and DD Kisan programme for the benefit of farming community. Dr B. S. Tomar served as an expert member in UPSC, ASRB, NFL, NSC, CCSHAU-Hisar, PAU-Ludhiana, CSHPKV-Palampur, NDUAT-Faizabad, ICFR &E-Dehradun. He has served as Incharge Seed production Unit, 2011-13. He is Fellow of Indian Society of Seed Technology, Indian Society of Seed Spices, Indian Society of Vegetable Science and National Academy of Horticulture Sciences and got best teacher Award-2014 at IARI, New Delhi, and Dr G. Kallo Outstanding Horticulture Scientist Award-2018 by SHRD, Ghaziabad, Uttar Pradesh.

Dr A. K. Singh, Principal Scientist (Fruit Science) at Central Horticultural Experiment Station (ICAR-CIAH), Godhra, Gujarat, put in over 21 years for furtherance of dryland fruits of major and minor significance being grown in hot semi-arid and arid conditions, and proved mettle in *ex-situ* establishment and conservation of genetic diversity of dryland underutilized fruits in field gene bank, especially bael, 213 clonal and 121 seedling and have developed 8 varieties of bael (Goma Yashi, Thar Divya, Thar Neelkanth, Thar Srishti, Thar Prakriti, Thar Shivangi, Thar Gauri and Thar Bhavya) and 12 varieties of other fruit crops, viz. jamun (Goma Priyanka and Thar Kranti), tamarind (Goma Prateek and Thar Rashmi), chironji (Thar Priya), khirni (Thar Rituraj), phalsa (Thar Pragati), karonda (Thar Kamal), wood apple (Thar Gaurav and Thar Prabha) custard apple (Thar Amrit) and mahua (Thar Madhu) as co developer. Dr. Singh, specialized in dryland fruit culture, published 128 full length research papers (50 articles >6 NAAS rating), 13 review paper, 13 short notes, 133 popular articles, 57 book chapters, 29 leaflets, 16 technical bulletins, 3 training manuals, 57 full length papers and 151 Abstracts in Conference Proceedings and 14 books in his credit including '*The bael in India*'. Valuable scientific information was generated from 12 in-house and 9 externally funded projects. He has been rewarded several times by best oral and poster presentation and research paper awards, and recipient of awards from scientific professional societies, viz. *Young Scientist* (HTHS), *H. S. Mehta Memorial Best Young Scientist* (Mehta Foundation), *Distinguished Scientist* (AIASA), *Distinguished Horticultural Scientist* (SHRD), *Scientist of the Year* (AIASA), *Outstanding Research Scientist of Noni* (ISNS) *and Research Excellence Awards (*Global Research Foundation). He is recipient of national fellowships of CHAI, HSI and ISNS. He is member of various scientific societies and editor of *Indian Horticulture*, ICAR, New Delhi. He also organized many national and international conferences, symposiums, national horticulture fair and bael day as organizing secretary and convener. Dr Singh is a life member of many professional societies in the field of Horticulture and Agriculture.

Dr Singh has a distinction of being Nodal Officer for 'DUS testing Centre on bael and Co- Nodal Officer of DUS testing center of aonla, Nodal Officer chironji and tamarind as recognized by PPV&FRA, New Delhi. He is well recognized scientist of his area for furtherance of dryland fruits which is prized for health and economic security. Dr Singh is the person with a scientific attitude and trying to bring out the best in dryland horticultural research and development by dedicated and sincere efforts for economic, nutritional and health security to the stakeholders of country.

Dr Praveen Kumar Singh born in a farming family in District Hardoi, UP. Presently he is serving as Head, Division of Plant Exploration & Germplasm Collection, ICAR- National Bureau of Plant Genetic Resources, New Delhi. He has received his graduation from C.S. Azad University of Agriculture & Technology, Kanpur. He obtained his post graduation from Punjab Agricultural University, Ludhiana. Dr. Singh's journey has been marked by academic excellence and noteworthy contributions to the field of Horticulture (Vegetable Science).

Dr Singh started his early career in the seed industry before transitioning to academia. He served as an Assistant Professor (Horticulture) at Rajasthan Agricultural University, Bikaner and later joined as Senior Scientist (Hort: Vegetable Science) at Indian Institute of Vegetable Research, Varanasi, in 2008, where he contributed till 2015. He moved to the Center for Protected Cultivation Technology (CPCT), Indian Agricultural Research Institute, Pusa, New Delhi and served as the Principal Scientist (Hort: Vegetable Science) until May 2023. He is a recognized Vegetable Breeder and seed production expert, Dr. Singh has made significant contributions to the field of Vegetable Science. He had taught several courses of Vegetable Science, Seed Production, Plant Biotechnology, Tissue Culture, Protected Cultivation and Plant Genetic Resources to UG and PG students. He developed, standardized & registered petaloid-type of male sterile system in Asiatic carrot in 2008. He conducted several Plant Explorations in difficult land locked and border areas and acknowledged as a Certified Intellectual Property Manager by the Institute of Intellectual Property development & FICCI, New Delhi. Dr. Singh has developed several tomato varieties, including Tomat Pusa Protected-1, Pusa Golden Cherry no.2, Pusa Prasanskrit, Pusa Cocktail tomato, Pusa Cherry Hyb.-1 and Pusa Tomato hybrid-6. He has also contributed to the development of the Pak Choi variety (Pusa PakChoi-1), Capsicum (Pusa Preet) and Longmelon variety (Kashi Santushti).

Dr. Singh's involvement extents to the development of tomato varieties like Pusa Rakshit and H-81, Ridge gourd (Kashi Shivani), Satputia (Kashi Khushi), watermelon (Kashi Mohini) and Roundmelon (Kashi Hari). His extensive body of work includes three edited books, 16 book Chapters, 70 research papers and numerous other publications.

Dr Prabhat Kumar, Horticulture Commissioner, GOI &Ex-National Coordinator ICAR-National Agricultural Higher Education Project was born on 1st July 1973 in Basti(UP). He obtained his B. Sc. Degree from C. S. A. Univ.of Ag. & Tech. Kanpur (U.P.) and M. Sc. degree (Floriculture and Landscaping) from Punjab Agril. University, Ludhiana, Punjab. He completed his Ph. D degree (Floriculture and Landscaping) in the year 2002 from IARI New Delhi. He started his professional career as Assistant Professor at G.B.P.U.A.&T. Pantnagar in April 2003. He was selected to the post of Associate Professor at HNBGU, Srinagar, Garhwal (A Central University School of Agriculture) in 2012. Further, he was selected to the post of Senior Scientist at IARI, New Delhi in 2013 and become Principal Scientist in 2015. Dr. Prabhat Kumar was actively engaged in teaching, research, extension and managerial assignments at all the places. He has guided 10 M.Sc. and 01 Ph.D. students as Major Advisor in the discipline of Floriculture and Landscaping & taught various courses at UG&PG level.

He has handled more than 04 externally funded and 6 institute research projects and published 112 research papers in various national and international journals, 35 popular articles, 15 book chapters, 11 technical bulletins and 10 books. He is associated in the development of 7 varieties namely; Pusa Deep, Pusa Bahar, Pusa Parv, Pusa Utsav(Marigold) &Pusa Sinduri, Pusa Shanti and Pusa Rajat. Established Model Floriculture Centre (MFC) under Horticulture Technology Mission at Pantnagar. In capacity of National Coordinator developed Monitoring and Evaluation cell to coordinate with all partners and facilitated to establish CAAST (Centre for Advanced Agriculture Science and Technology) centers (16) in cut edge areas like genomics, climate smart agriculture, digital agriculture, conservation agriculture, secondary agriculture, etc. He also organized many national and international conferences and symposiums as organizing secretary.

As, Horticulture Commissioner, Govt. of India he immensely promoted more innovative technology for sustainable development of horticulture and also promoting holistic development of bamboo sector as national mission director of National Bamboo Mission. He immensely contributed to give fillip to sweet revolution as mission director of National Honey and Bee keeping Mission. As CEO of Coconut development board, Kochi contributed a lot for development of sector particularly in value addition and climate resilient production system. He has been elected as Chairman, TWG (Technical Working Group) of coconut in ICC, Jakarta. Dr Kumar visited many countries like The Netherlands, Switzerland, Germany, Belgium, Spain, France, Indonesia, Japan, Singapore, Sri Lanka, Thailand and Maldives. He is a life member of many professional societies in the field of Horticulture and Agriculture. He has been honored with awards and fellow by many scientific societies. He is member of Board of Management.

Dr Gograj Singh Jat born on March 10, 1989 at Village Mukandpura First, Jaipur (Rajasthan). He obtained his B.Sc. degree in Horticulture (Hons.) from MPUA&T, Udaipur, Rajasthan, and M.Sc. and Ph.D. degree in Vegetable Science from ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi. Currently, Dr Jat is working as a Senior Scientist in frontier areas of pre-breeding, genetic improvement and breeding for protected environment in bitter gourd, muskmelon and tomato crop at Division of Vegetable Science, ICAR-IARI, New Delhi. During his career spanning over nearly 10 years, Dr Jat is having his association in release of 6 varieties/ hybrids and 4 genetic stocks of bitter gourd and tomato. He has published 40 research papers in journals of international and national repute, 5 edited books, 16 book chapters, 7 technical bulletins, 6 training manuals, 7 extension folders, and 32 popular and technical articles in his credit. Dr Jat is the recipient of awards like

ICAR-Jawaharlal Nehru Award-2018, IAHS-Dr B. R. Barwale Young Researcher Award-2017, SPH-Dr G. S. Randhawa Award-2019, IAHS- Associateship-2021, SHRD-Young Scientist Award-2019, 13 best poster/paper/oral presentation awards. Recently, Dr Jat had visited Texas A&M University, College Station, Texas, USA for 3 months under NAHEP-CAAST project funded by World Bank-ICAR.

Dr Prawal Pratap Singh Verma is currently serving as Senior Technical Officer (Agriculture) at the Council of Scientific and Industrial Research-Central Institute of Medicinal and Aromatic Plants (CIMAP), Regional Research Centre, Purara, Bageshwar, Uttarakhand. He is a recognized expert in the field of high-altitude herbs and medicinal & aromatic crops in the Himalayan region of Uttarakhand. Mr. Verma has submitted his Ph.D. in Vegetable Science at Integral University, Lucknow, focusing on the fenugreek crop. Prior to this, he completed his M.Sc. (Ag.) in Horticulture with 1stDivision from Babasaheb Bhimrao Ambedkar University (BBAU), Central University, Lucknow, and his B.Sc. (Ag.) with 1st Division from Dr. B.R. Ambedkar University, Agra (Uttar Pradesh). He has also qualified the ICAR-NET in Vegetable Science, conducted by ASRB, New Delhi.Since he joined CSIR-CIMAP in 2013, Mr. Verma has made remarkable contributions to R&D, significantly advancing the cultivation and management of high-altitude medicinal and aromatic crops. His work focuses on agro-technology development and post-harvest management of economically important herbs such as rosemary, geranium, oregano, marjoram, Himalayan thyme, and lemon balm.

He has successfully trained over 2,500 farmers across Uttarakhand in the cultivation of rosemary, damask rose, lemongrass, geranium, and lavender. As an active project member, he has contributed to more than five research and development projects. Mr. Verma has an extensive publication record, including 45 research papers in national and international peer-reviewed journals (NAAS-rated and impact factor journals), 10 review articles, 8 book chapters, 215 popular articles in Hindi and English magazines and newspapers, and 2 edited books. His academic engagement includes participation in 12 national and international conferences, delivering 8 seminar presentations, and giving 25 expert lectures at Kisan Melas and Gosthis. Through these platforms, he has directly addressed over 8,000 farmers, disseminating his expertise in medicinal and aromatic crop cultivation. Mr. Verma has been honored with several awards, including the Young Scientist Award and the Young Researcher Award from various professional societies. He also holds membership in 8 reputed agricultural and horticultural societies.

His key scientific contributions include the standardization of agro-technology and post-harvest management practices for high-altitude herbs, research on propagation methods and optimization of nutrient management of Rosemary, Oregeno, Thyme, Lemon Balm, Merjorum, stevia, pyrethrum, and geranium. His work has significantly advanced sustainable cultivation practices and promoted the economic viability of medicinal and aromatic herbs in the hilly regions of Uttarakhand.

Dr Som Dutt did his M.Sc. and Ph.D. in Botany from the CCSU, Meerut. He started his professional career as a Research Scholar at the IARI, New Delhi in 1982. Since Dr Som Dutt had keen interest in popular science writing, he joined Publications and Information Division (the then Directorate of Information and Publications of Agriculture (DIPA), and now Directorate of Knowledge Management in Agriculture (DKMA) at the ICAR Headquarters, New Delhi, in 1984. Dr Som Dutt edited the *Indian Journal of Agricultural Sciences* and *Indian Horticulture,* a national semi-technical magazine disseminating all research and developmental activities taking place in all horticultural crops across the country. Besides, he has edited the *Handbook of Horticulture* (the Encyclopaedia of Horticulture), the first ever published the bulkiest book of the ICAR and other important horticultural publications of the ICAR, New Delhi.

Dr Som Dutt has written about 500 articles on agricultural sciences, book chapters, and one book, '*Phoolon Ki Vyavsayik Kheti*', in Hindi. In the field of electronic media, he has made a tremendous impact on farmers by giving radio talks in different programmes of All India Radio on agriculture. He has given several lectures to farmers, extension specialists, young scientists and Horticulture Development Officers of various states, that has contributed in increasing the agricultural production of farmers significantly. Dr Som Dutt has been awarded with the *Chaudhary Charan Singh Award for Excellence in Journalism in Agricultural Research and Development* 2008 (ICAR National Award), *Raizada Memorial Award for Young Information Scientist* 1990, and the *Best Editor Award* 2008, for the popularization of agricultural sciences in different media. At Present, Dr Dutt is Managing Editor of *Current Horticulture*, a peer reviewed research Journal published by SHRD, Ghaziabad, Uttar Pradesh, and also organized the *Indian Horticulture Summit*-2020 and Webinar on *Boosting Immunity through Horticulture* during 2020 as Secretary SHRD, Ghaziabad, Uttar Pradesh.

CHAPTER 1

HIGH-DENSITY PLANTING IN TEMPERATE FRUIT CROPS FOR ENHANCING PRODUCTIVITY

M.K. Verma, O.C. Sharma, J.I. Mir, W.H. Raja, S.U. Nabi and M.A. Shah

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Sustainable and maximum quality fruit production is the dream of every fruit grower. The yield and quality of the fruits are dependent factor of the number of trees /ha, ideal tree architecture (training system) and the annual required practices like pruning, fertilization and plant protection measures. Such results are expected from high density plantings (HDPs). High density planting is the accommodation of maximum number of plants per unit area for producing the maximum yield of quality fruits. This technique was first commercially exploited for apple in Europe during sixties and now majority of the apple orchards in Europe, America, Australia and New Zealand are grown under this system.

Increasing the number of trees/ha increases yields, up to a point, in young orchards. However, as trees matures, too many trees per hectare results in over crowding and shading with commensurate declines in yield and fruit quality and increases pest problems. Therefore, the ideal tree density varies greatly depending on soil type and topography, varieties, rootstocks, training systems, the presence of irrigation and the grower's management capabilities. Traditionally, it was common to set an orchard "on the square," in which the distance between trees in-a-row equalled the distance between-rows. Oftentimes, the orchard floor was kept free of grasses and weeds by cultivating down the rows and across rows. High fruit quality could be attained because mutual shading was not a problem. Yields were low to moderate because a relatively high percentage of the orchard space was devoted to drive areas and, hence, not covered with fruiting wood. Planting trees close enough in the row that they almost touch at maturity and leaving an extra eight feet between rows to accommodate equipment movement resulting in more trees per acre, which promises potentially higher early yields plus greater yield potential in the mature orchard.

Orchard establishment is a long term process. A good orchard gives profitable returns and unplanned orchards are unprofitable venture. Therefore, it is essential for orchardists to plan their new plantings according to the availability of resources judiciously. Among the resources, land is the most limiting factor and must be utilized to the fullest of its potential. This is only possible by adoption of the closer plantings. Accommodation of maximum plants per unit area to get the maximum possible profit per unit of the tree volume without impairing the soil fertility status is called the high density planting. It is defined as planting a density in excess of that which suffices to give the maximum crop yield at maturity if the individual trees grow to its full natural size. The underlying principle of high density planting is to make the best use of vertical and horizontal space and to harness the maximum possible return per unit of inputs and natural resources. In other words, it is nothing but accommodating more number of plants per unit area than optimum through manipulation of tree size. This gives better light distribution within tree canopy increases the number of well illuminated leaves and promotes the rate of photosynthesis that leads to high yield per unit area. This system of planting is going to revolutionize the fruit industry by enhancing the production of quality fruits with minimum damage coupled with reduction in production costs. Basically, the availability of a dwarf plant is the first and foremost prerequisite for establishing high density or meadow orchard. Fertilizer doses, 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 its successful adaptation.

Principles of HDP

In the process of evolution in planting density several important principles have been discovered which have guided the shifting from wider planting to high density plantings. These mainly include-

- To achieve higher yield, orchard canopies must intercept a high proportion of available light (70-75%). Pedestrian orchards do not intercept more than 55% of available light.
- Dense canopies have too much heavily shaded area with poor fruit quality. Narrow canopies or planar canopies with a depth of not more than 3 feet have better light distribution. This has led the effort to narrow the canopy of modern orchards to no more than 3 feet deep.
- High early yield to pay back the initial investment to plant the orchard through the use of feathered trees, planting higher tree densities, maximizing tree growth after planting with irrigation and fertigation, minimizing pruning at planting and in the first 3 years and branch bending to induce early cropping.

- Simple and sparse tree canopies are more adaptable to partial mechanization of some orchard management practices than thick and complex tree canopies.
- Orchard planting density is limited by the economic law of diminishing returns. As planting density is increased, the additional benefit in yield is smaller and smaller with each additional tree. At some point the cost of additional trees is greater than the gain in yield.

Impact of low planting density

When the planting density is too low, each individual plant may perform at its maximum capacity, but there are not enough plants as a whole to reach the optimum yield. Therefore, total yield of the crop becomes a limiting factor. Also, when there is too much space left between plants, causing more weed growth and increases the weeding cost.

Impact of high planting density

If the planting density is too high, plants may compete against each other, known as intra-specific competition. Under such circumstances, the performance of individual plants becomes a limiting factor to achieve maximum crop yield.

Using right density

As the planting density increases, the total crop yield increases and reaches to its maximum, at this point further increase in planting density results in reduced yield. It is, therefore, important to use appropriate planting density, keeping in mind the fact that the density that provides the highest yield and the density that provides the highest revenue may be different. Growers should consider both optimum yield and revenue when balancing their planting density.

What is optimum planting density?

In general, it is established that the greater the planting density, the greater the investment cost to establish the orchard. However, due to higher early yield and higher cumulative yield, profitability is generally increases with increase in tree density up to a point. Nevertheless, the law of diminishing returns which results in less gain in cumulative yield as more trees are planted per hactare, meants that very high tree densities are not more profitable than more moderate densities. In addition, economists suggest that risk increases with increasing level of investment, thus making the very high-density systems riskier. In a study conducted by Robinson (2013) on net present value (NPV) of the accumulated profit over 20 years showed that the per unit land area the greatest profitability was at a tree density of 1,050 trees/acre when feathered trees were used.

Tree density guide

- Semi-dwarf orchards have densities of 123-311 trees per acre at spacings of 16′ x 22′ to 10′ x 14′.
- Dwarf orchards are planted with spacing's as tight as 2′ x 10′, but more commonly 4′ x 14′ and up to 7′ x 16′ for densities of 388-777 trees per acre.
- Standard orchards are no longer planted because they take too long to produce.
- High density means more than 500 trees to the acre and will exceed 1000+ with multi row systems.

Categories of HDP

The establishment of an orchard is a long term investment, with orchards having a life expectancy of more than 20 years. It is important that the establishment of an orchard be well planned including the site planning, planting and tree care. The high density plantings can require a grower investment in excess of $20,000 per acre for the establishment. The extensive planning for high density plantings will pay off in maximizing yields and returns over the productive life of the orchard. Mistakes made in the planning and planting can be very costly and are difficult to correct in later years. It is paramount that careful attention be paid to the site selection, soil preparation, tree quality, cultivar selection and early tree care. Within this range, the decision of how close to plant a new orchard should be made with consideration of the Vigour of the variety, vigour of the rootstock, and soil strength. With vigorous scion cultivars, growers should use a more dwarfing clone of M.9 or B.9 rootstock and/or greater planting distances. With weak scion cultivars, a more vigorous clone of M.9 rootstock should be used and/or closer planting distances. For weak and moderate growing cultivars such as Honeycrisp, Delicious, Braeburn, Empire, Jonamac, Macoun, Idared, Gala, NY674, Golden Delicious, etc it is suggested an in-row spacing of 3′. For vigorous varieties such as McIntosh, Spartan, Fuji, Jonagold, Mutsu, etc. and tip bearing varieties such as Cortland, Rome, Granny Smith and Gingergold an in-row spacing of 4′ is suggested. Between-row spacing should be 12′-13′ on slopes and 10′-11′ on level ground.

High density plantings were initially categorized in to four planting densities for apple viz., low HDP (< 250 trees/ha), moderate HDP (250-500 tree/ha), high HDP (500 to 1250 trees/ha) and ultra-high HDP (>1250 trees/ha). Recently, super high density planting system has been also established in apple orchards with a plant population of 20,000 trees per ha. In some orchards, still closer, planting of apple trees are followed (70,000 trees/ha) which is often referred as 'meadow orchards'. Corelli and Sansavini (1989) proposed 9 categories of planting densities in apple is given in Table 1.

Table 1. Classification of high density orchard in apple

Density category	Standard variety	Spur variety
Very low	226/seedling	-
Low	270/M26	-
Medium low	670/M26	1000/M26
Medium	670/MM106	1000/MM106
Medium high	1000/M9	2000/M26
High	1000/M26	3000/M9
Very high	2000/M26	5000/M9
Bed system	-	10000/M9
Meadow orchard	-	40000/MM106

Six type of planting systems *viz.*, low density, moderate density, high density, ultra-high density and super high-density plantings or meadow orcharding were categorised. The exact limits of plant density in high density planting are based on several factors and for many crops it is not yet well defined. It varies with the region, land fertility, species, variety, rootstock, economic feasibility of the farmer to adopt the system, farmer's knowledge about HDP and crop, labour and the likely return from the orchard and natural resource to support HDP. The brief about different HDPs are as under-

Low Density Planting (LDP)

It is the traditional method of planting in which trees are planted at wider spacing and accommodates the minimum number of plants (100 plants/ha). There is no use of dwarfing rootstocks, minimum training and pruning, favours maximum development of canopy availing the scarce water and nutrients. The trees come in to commercial production potential after 10 to 15 years of planting and the output of orchard during early years found to be very low.

Medium Density Planting (MDP)

The medium density planting accommodates 250 to 500 plants /ha. Proper pruning is undertaken to restrict the tree for desired shape. It requires intensive care and labour since the return found to be sustainable. It gives more yield and quality fruit in crops and better water and nutrient managements are also required for maintaining the orchards for a long productive life.

High Density Planting (HDP)

In HDP, the tree density is more than 1000 plants/ha depending on fruit crops. It requires heavy or rigorous training and pruning to restrict the growth. Dwarfing rootstock and chemicals are normally required to maintain the optimum growth. Both yield and expenses are high under this planting density. Establishment and maintenance of such a high density orchard could be demanding and require technical backup.

Ultra-High Density Planting (UHDP)

Ultra-High-Density Planting can accommodate more than 2000-5000 trees per hectare and requires severe pruning and training after planting. Ultra-high density in apple accommodated 1111 plants /ha at a spacing of 3 × 3 m (444 plants /acre). For sustainable yield and quality under ultra-high density, proper canopy management, chemical assistance and nutrient management are required.

Meadow orcharding

"Meadow - grassland system" is also known as "Super High Density Planting", widely popular in temperate crops. It can accommodate more than 10,000-40000 or more plants per hectare in which severe top pruning is practiced similar to mowing of grass land. The tree yields after one or two years of planting. Heavy uses of growth regulators as well as judicial canopy managements are required for fruiting. In apple, 10000 plants /ha can be accommodated at a spacing of 1 × 1m (4000 plants /acre). For high density planting, compact varieties are used whereas in ultra-high density and super high-density planting, dwarfing rootstocks are used to limit the natural growth of the plant besides the constant use of growth retardants every now and then to have a control over the growth.

Factors affecting HDP

Tree quality

Tree quality is an essential components that must be considered on priority. Several studies have shown that greater the number of lateral branches or feathers the greater the yield in the second and third year. Modern high-density orchards can have significant 2nd and 3rd year yield if highly-feathered trees are planted and if trees grow well the first year. If growers use whips or small calliper trees these do not produce significant quantities of fruit until year 4 or 5. We recommend that nursery trees must have 10-15 well positioned feathers with a maximum length of 1 ft (30cm) and starting at a minimum height to 30" (80cm) on the tree.

Scion varieties

Table 2. Compact growth habit type temperate fruit varieties

Crop	Genetically dwarf cultivars	Desirable features
Apple	Spur bearing varieties Wijik Mc Intosh and Nugget Golden Delicious	Bear on short stems, spurs; grow to 60-70% the standard cultivar in vigour and bear more spurs and yield more
Peach	Redheaven	Dwarfing and high yielding
Cherry	Sweetheart, Hedelfinger, Compact Lambert, Meteor and North star	High yielding, self-fruitful, dwarf

Dwarfing rootstocks/interstocks

Table 3. Dwarfing rootstocks and interstocks recommended for temperate fruits

Crop	Dwarfing rootstocks
Apple	M-9, M-26, M27, MM-111, MM-106, Bud.9, Bud.146, P-22 and Ottawa 3
Pear	EM Quince A & C
Peach	Siberian C, St. Julien x *P. besseyi* and Rubira
Plum	Pixy
Cherry	Growth is 35 to 50% of standard (Gisela 5, Edabriz, Weiroot 72) to semi-dwarfing (Gisela 12, Ma x Ma 14, Weiroot 158) to 90 to 110% of standard (Gisela 6, M x M 60, Colt); Gisella-5, Edabriz, Ma x Ma 14, Weiroot 158, Colt, Charger and Rubira

Rootstocks, dwarfed than M.9, like P.16 and P.22 are able to increase yield efficiency by 5 to 8 % but loose total production by up to 30% on a hectare basis.

Tree establishment

In high density planting, the allotted space should be filled rapidly to ensure that the ceiling production level is quickly reached. Fill planting holes with fresh, organic soil mixtures and providing the trees with adequate water by localised irrigation. Enriching the irrigation water with nutrients adds improved flower-bud formation, indispensable for a crop in the second leaf. As fertigation may have more consistent effects on growth than soil sterilisation, it might become an environment-friendly alternative to overcome replant problems in apple. The quantity of water required for a good start depend on tree size, soil and climatic conditions. More insight in the water requirement of a newly planted trees are needed to get a good balance between growth and early cropping on the one hand and to avoid waste of costly water on the other. Obviously, more water is needed for heavily feathered trees to maintain a certain water status in and around the planting hole. Although it is clear that shoot growth, fruit set, yield, and fruit weight are reduce by low quantities of water, but it is not known what quantities are optimal.

Growth retardants

Various growth retardant have been used to restrict the vegetative growth of the plant. Among them the commercially adopted are AMO 1618, CCC, Ancymidal, Paclobutrazol, B-9 (Phosphon D) and chloramquat.

Induction of viral infection

Though still not popular and emerged as commercially but tree size can be reduced by inducing viral infection e.g. in apple, virus free rootstocks series East Malling Long Ashton (EMLA) are vigorous than their infected counterparts.

Use of incompatible rootstock

The use of graft incompatible scion and rootstocks also induces dwarfness in the composite plant e.g. in pear Bartlett and Quince.

Branch angle manipulation

An important method of shifting the balance between vegetative growth and cropping in young trees is tying down of the scaffold branches below horizontal to induce cropping. In the vertical position, a shoot grows more vigorously than in a horizontal or pendant position and tends to remain non-fruitful. A horizontal or pendant limb grows less vigorously and then crop heavily the next year and bend under the weight of the fruit. The fruits are also strong competitors for resources and moreover it limit the growth of the branches. If a vertical limb is manually bent horizontal, lateral buds are released from dormancy. If the vigour of the branch is excessive, these buds may grow into vigorous upright shoots by themselves and remain unfruitful. However if the branch has more moderate vigour, the lateral buds grow into short shoots which become fruitful.

After the initial tying or weighting down of feathers at planting, new lateral branches that arise along the leader do not need to be tied down. In most climates, if moderate vigour shoots are not pruned, often crop load in the third year will bend branches down below horizontal and a natural balance between vigour and cropping will be established without additional limb positioning. Thus with the tall spindle, no additional limb tying is needed after the initial tying or weighting down of the feathers at planting. However, in vigorous and/or warmer climates where winter chilling is insufficient, often limbs become too large before they set sufficient crop loads to bend the branches down. In these climates, tying down of all vigorous limbs must be done annually for the first 3-5 years until the tree settles down and begins to crop heavily. However, in most traditional apple growing areas, growers often invest too much money in limb tying which should be limited to only the feathers at planting. Thereafter, the precocity of the rootstock induces heavy cropping and a natural balance is established.

Irrigation and fertigation

Irrigation is crucial for viability of the production system. Large, highly-feathered trees often undergo water stress shortly after planting despite adequate soil moisture levels. This is due to the damaged root system of a transplanted tree which cannot adequately support the large top without frequent irrigation. Large, highly feathered trees produce much more leaf area shortly after planting than unfeathered trees which creates a high water demand before the root system can re-grow sufficiently to support the trees. In-addition during many years, dry weather following planting results in water stress of newly planted trees which can limit tree growth. Frequent and early trickle irrigation can help these trees to produce good growth in the first year. In humid areas growers are unaccustomed to installing irrigation immediately after planting and delay its installation until mid-summer. It is recommend to the growers to install trickle irrigation soon after planting with high density orchards that use feathered trees to prevent water stress and maximize first year tree growth. Frequent low doses of nitrogen fertilizer delivered at least twice in a week through the trickle system (fertigation) for the first 12 weeks of the season will greatly improve tree growth during the first 2 years to speed up the development of the canopy. Ground fertilization with dry fertilizers is often ineffective since too much time elapses between applying the fertilizer and uptake by the tree. With high tree densities as with the Tall Spindle system and highly-feathered trees, almost no lateral tree growth is required and only vertical extension growth is needed. In this case fertigation for the first 2 years is essential both for the water to avoid water stress and for the nitrogen which is rapidly moved to the root zone and is readily available to the tree as soon as it starts growing. Adoption of fertigation considerably improves tree growth and yield potential in the 2nd and 3rd year. 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. However, excessive fertilization, especially nitrogen, can cause too much growth which results in delayed flowering, reduced yields, poor fruit quality and greater pruning.

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. Soil or fertility must be considered when calculating the amount of nitrogen to apply to mature high-density orchards especially with vigorous and poor colouring varieties. Soils having excess fertility often results in excessive vegetative growth, delayed cropping and soft and poorly coloured, unmarketable fruit.

Weed control

Weed competition can drastically reduce tree growth during the first few years and can cause failure of the orchard to fill its allotted space which always results in diminished yield and profitability. Good weed control during the first 3-4 months of a growing season is the most critical time period. In later summer months if weed control is poorer it is not detrimental to the trees. Thus, It has been recommended that growers provide excellent weed control for the first 4 months of the season for the development years of the orchard. In India, weed control in often carried out manually which involves maximum production cost. Therefore, chemical weed control offers fruitful results to increase the net returns per unit area.

Crop load management

Management of cropping with high-density orchards during the first 4 years to avoid biennial bearing is critical in maintaining a proper balance between vegetative growths and cropping as the trees begin to bear. With precocious dwarfing rootstocks, young apple trees can often overset in the 2nd or 3rd year resulting in biennial bearing as early as the 4th year. These then results in increased vigour in the 4th year just when the trees have filled their allotted space and when reduced vigour is needed. Varieties differ in their biennial bearing tendency and this must be incorporated into the crop load allowed on young trees. For annual cropping varieties like Gala, a crop load of 6 fruits/cm2 TCA (25-40 apples/tree in the second year, 40-60 apples/tree in the third year, and 100-120 apples/tree in the fourth year) is recommended. For slow growing and biennial bearing varieties like Honeycrisp we recommend crop load of 4 fruits/cm2 TCA (15-20 apples/tree in the second year, 25-40 apples/tree in the third year, and 50-70 apples per tree in the fourth year). Within each year, the low end of the range should be used for low vigour trees and the high end of the range for high vigour trees.

Pruning

During the developmental years of an orchards life the trees have a juvenile character and the balance between vegetative growth and cropping is shifted toward vegetative growth. With high density systems such as the tall spindle the goal is to get the trees into cropping as soon as possible. This is best accomplished by minimizing pruning during the first 4 years. No heading cuts should be done to the leader or lateral branches at planting or for the next 4 years since the maximum growth and earliest cropping is achieved with no pruning. For the first 4 years pruning should be limited to the complete removal of unsuitable branches such as those lateral branches that are larger than 2/3 the diameter of the leader. Of much greater importance during the first 4 years is limb angle manipulation to change a young and vigorous tree from a vegetative state into a reproductive state. With the Tall Spindle and Vertical Axis systems the artificial limb bending is limited to the 1st tier of branches while with the Solaxe even upper branches tied down. With the Tall Spindle and the Vertical Axis systems the bending of upper branches is achieved naturally by crop load.

As the orchard reaches maturity, containment pruning of the canopy is essential in maintaining trees within the allotted space and to improve the light distribution to the lower portion of the tree. Good light distribution and good fruit quality can be maintained as trees age if the top of the tree is kept narrower than the bottom of the tree and if there is a good balance between vegetative growth and cropping. Pruning strategies based on shortening or stubbing back permanent branches that outgrow their allotted space generally are not as successful as limb renewal pruning strategies. This is partially because the most productive fruiting wood is cut off when a branch is shortened. In addition, stubbing cuts stimulate localized vigour on the affected branches which results in shading of the lower canopy. In our studies on how to manage the canopies of high-density systems, treatments where branches were shortened to maintain the conic shape to the tree, resulted in unacceptable yield reductions, a dense canopy resulting in interior canopy shading, excessive vigour compared to an unpruned control and poor fruit quality.

Use columnar apple

Columnar habit apple trees have short internodes and axillary buds grow into spurs rather than lateral branches, so the tree naturally grows like a sturdy cordon.

Optimum use of light resource

High density plantings achieve earlier cropping than wider plantings, but they show a decline in fruit quality, fruit bud formation and yield. These are mainly attributed owing to its influence on light interception and distribution. Therefore, high light interception is a prerequisite for higher yield, better fruit quality, especially colour. Light interception increases as the height increases for trees of triangular in shape.

Commercial use of HDP

High density production technology in various fruit and nut crops has already made a dent in the several countries which showed significant results in terms of productivity and net returns. The salient details of the high density production technologies are given in the tables includes the high yielding varieties, compatible rootstock combination, tree training system, appropriate spacing, tree density per hectare and yield per hectare.

Apple

In modern high-density orchards in-row spacing range from 3-5 ft. and between row spacing from 10-14 ft. (780-1450 trees/acre). Within this range, the decision of how close to plant a new orchard should be made with consideration of the vigour of the variety, vigour of the rootstock, and soil strength. With vigorous scion cultivars, growers should use a more dwarfing clone of M.9 or B.9 rootstock and/or greater planting distances. With weak scion cultivars, a more vigorous clone of M.9 rootstock should be used and/or closer planting distances. Despite some latitude in planting distances, growers should remember that to obtain high early yields high tree densities are essential. In New Zealand in the 1970s semi-intensive system of apple growing was found most profitable. The results from Lincoln University in apple grown on 'Malling 9' rootstock with tree density of 1905 trees/ha gave higher yields as compared to those grown on 'Malling-Merton-106' rootstock at 635 trees/ha.

In apple, most productive system recorded in 'Empire' grafted on dwarfing rootstock M-26 and trees trained on Y-trellis system at a closer spacing (2.1 x 3.7 m) accommodated 1283 trees per hectare gave maximum yield (275 t/ha). High density in apple around the world entirely depends upon few varieties (Red Delicious, Empire, Granny Smith, Fuji, Gala, McIntosh, Golden Delicious, Oregon Spur and Red Chief) and rootstocks (M-9, M-26, MM-106 and MM-111). Open canopy and vertical type training systems like Y-trellis, slender spindle, central leader as well as modified leader systems are highly efficient for photosynthesis results in to greater yields. Closer tree spacing along with open canopy were found more productive. However, higher densities gave significantly more yield during initial years (Table 4).

Table 4. Assessment of high densing Planting in India and abroad on apple

Variety	Root-stock	Training system	Spacing (m)	Density (trees/ha)	Yield (t/ha)	Reference (Country)
Empire	M-26	Y-trellis	2.1 x 3.7	1283	275.0	Robinson *et al*. 1991
Granny Smith	EM-9	V- shape	0.4 x 3.5	7140	210.0	-
COE Red Fuji	M.26	Vertical axis	0.75x1.5	8889	135.30	CITH, 2013-14
Red Delicious	M-26	Y-trellis	-	960	130.0	-
Mollies Delicious	M-9	Head and spread	0.75 x 1.5	8889	126.33 (5^{th} Yr)	CITH, 2012-13
Red Delicious	M-26	Y-trellis	2.4 x 4.3	961	122.0	Robinson *et al*. 1991
Mollies Delicious	M-9	Modified leader	0.75 x 1.5	8889	108.33 (5^{th} Yr)	CITH, 2012-13 (India)
COE Red Fuji	M-9	Espalier	1.5 x 3.0	2222	95.36 (5^{th} Yr)	CITH, 2012-13 (India)
Red Delicious	M-9	Slender spindle	-	1495	95.0	-
COE Red Fuji	M-9	Vertical Axis	0.75 x 1.5	8889	93.82 (5^{th} Yr)	CITH, 2012-13 (India)
Fuji	M-26	Spindle bush	2.0 x 4.0	1250	88.00	
Royal Delicious	MM 106	Modified leader	2.5 x 3.5	1143	67.73 (10^{th} Yr)	CITH, 2012-13 (India)
Marshal McIntosh	M-9	Slender spindle	1.7 x 4.0	1429	60.0	Wunsche and Lasko 2000 (USA)
Golden Delicious	M-9	Central leader	1.5 x 3.0	2222	47.4 (8^{th} year)	CITH, 2010 (India)
Red Spur	Standard	Modified Leader	4.0 x 4.0		52.5	CITH, 2012-13 (India)
Vista Bella	M-9	Central leader	1.5 x 3.0	2222	42.5 (8^{th} year)	CITH Annual Report, 2010 (India)
Golden Delicious	MM-106	Central leader	2.5 x 3.5	1143	39.5 (8^{th} year)	CITH, 2010 (India)
Mollies Delicious	M-9	Central leader	1.5 x 3.0	2222	35.5 (8^{th} year)	CITH, 2010 (India)
Gala Redlum	M-9	Tall Spindle	3.0 x 1.5	2222	86.5 (7^{th} year)	CITH Annual Rep. 2023
Super Chief	M-9	Tall Spindle	3.0 x 1.5	2222	53.0 (7^{th} year)	CITH Annual Rep. 2023
Red Jona Prince	M-9	Tall Spindle	3.0 x 1.5	2222	60.0 (7^{th} year)	CITH Annual Rep. 2023

Variety	Root-stock	Training system	Spacing (m)	Density (trees/ ha)	Yield (t/ ha)	Reference (Country)
Golden Delicious Reindeers	M-9	Tall Spindle	3.0 x 1.5	2222	48.5 (7th year)	CITH Annual Rep. 2023
Red Velox	M-9	Tall Spindle	3.0 x 1.5	2222	46.0 (7th year)	CITH Annual Rep. 2023
Pinnova	M-9	Tall Spindle	3.0 x 1.5	2222	52.0 (7th year)	CITH Annual Rep. 2023
Elstar	M-9	Tall Spindle	3.0 x 1.5	2222	46.0 (7th year)	CITH Annual Rep. 2023

Figure 1. High density orchard of apple at CITH, Srinagar

Table 5. Spacing and planting density for different scion-stock combinations

Scion/ cultivar	Rootstock	Tree size (Vigour)	Spacing (mxm)	Density (tree/ ha)
Standard	MM 109	Semi-vigorous	6.0 x 6.0	278
	MM 111	Semi-vigorous	6.0 x 6.0	278
	M 7	Semi-dwarf	4.5 x 4.5	494
	MM 106	Semi-dwarf	4.5 x 4.5	494
	M 9	Dwarf	1.5 x 1.5	4444
Spur type	Seedling	Semi-vigorous	5.0 x 5.0	400
	MM 109	Semi-dwarf	3.5 x 3.5	816
	MM 111	Semi-dwarf	3.5 x 3.5	816
	M 7	Dwarf	3.0 x 3.0	1111
	MM 106	Dwarf	3.0 x 3.0	1111

In the management of an ultra-high density (20000 trees/ha) apple orchard, control of tree size is an important objective to obtain optimal yield of quality fruit. If horticultural practices are applied to supplement the effect of rootstock in vigour management then these practices should be economical, effective, and environmentally sound. Root pruning was effective in reducing vegetative growth in the 2nd year after treatment.

In India, Red Spur varieties found productive on PSM-1, an indigenous rootstock (*Malus baccata* bio-type Shillong) and maximum yield (62.79 t/ha) was recorded at 4444 density with lowest leaf nutrient content. However, tree density 1111 (3 x 3m) was found ideal with moderate yield (25.13 t/ha) for sustainable orchards life under Himachal Pradesh conditions (Pramanick *et al*. 2012).

Potential HDP systems in apple

The seven leading systems in the world are: *Tall Spindle, Super Spindle, Vertical or V-trellis, Solaxe, Bi-Axis and Fruiting Wall*. All seven systems use high tree densities (900-2,200 trees/acre) and depend on early production to repay the initial investment.

- The Tall Spindle is the most preferred system with most growers using 1,000-1,300 trees/ha. It is simple to learn and requires moderate initial investments, has high early yield and is estimated to provide the highest profitability over 20 years.
- The Super Spindle orchards are planted at 2,200 trees/acre but these are limited to growers who produce their own trees. The super spindle has a simplified pruning recipe and high fruit quality.
- The Organized trellis systems (V-trellis and Vertical trellis) are the two systems which are designed for precision pruning where bud numbers are reduced through pruning to a pre-calculated number. These systems also have less sunburn to fruits.
- The Solaxe system uses extensive limb bending and manual bud extinction to achieve a balance of vegetative growth and cropping even when vigour is excessive. The bud extinction also helps to control biennial bearing.
- The bi-axis system uses a two-stem tree to achieve a very high number of leaders per acre (1,800) with only a moderate number of trees per acre (900). It also distributes tree vigour to two leaders giving more moderate growth in each leader. The system has its greatest potential when tree vigour is difficult to manage with traditional Tall Spindle training. This system is well adapted to mechanical pruning.
- The "Mur Frutiere" or Fruiting Wall system uses mechanized sidewall shearing during the early summer to reduce pruning costs and achieve high yields and good fruit quality. It is interesting that some successful apple growers manage apple trees with complete precision of bud load as with the organized trellis systems while other successful apple growers use a completely mechanized system with no precision of bud management.

Pear

In pear, high density planting systems gave very high yields in varieties like Abbe Fetel, Conference and Doyenne du Comice. These all varieties found productive on dwarfing rootstock Quince and its various clones. Higher yields were mostly recorded at very high densities (5555 to 7936 trees/ha) which indicates that the planting in hedge-row pattern and trained with open centre systems like V-shape and Y-trellis facilitates maximum sunlight interception and results into maximum yields (Table 6).

Table 6. High density orcharding systems in pear

Variety	Rootstock	Training system	Spacing (m)	Density (Trees/ ha)	Yield (t/ha)	Reference
Abbe Fetel	Quince clone (MC)	V-shape	3.6 x 0.50	5555	262.0 After 7th year cumm.	Musacchi *et al*. 2005
Abbe Fetel	Quince clone (MC)	Vertical axis	3.6 x 0.50	5555	257.0 After 7th year cumm.	Musacchi *et al*. 2005
Conference	Quince clone (MC)	V-shape	3.6 x 0.50	5555	181.0 After 7th year cumm.	Musacchi *et al*. 2005
Doyenné du Comice	Quince clone (MC)	Vertical axis	3.6 x 0.35	7936	132.0 After 7th year cumm.	Musacchi *et al*. 2005
Conference	Quince-A	Y-trellis	4.0 x 1.50	1666	47.5	-

Peach

Peaches are the very important fruit crops adapted from temperate to subtropical climate. In this group, both peaches and nectarines are very productive. Genetically, dwarf rootstocks are not common in stone fruits. Therefore, these fruit crops could not be planted as closer as pome fruits. Results indicated that few varieties like Royal Giant, Flavour Crest, Baby Gold-5, Stark Red Gold, Early Grande, Red Globe, Cresthaven, Glohaven and Fantasia are found highly productive under high density (900 to 1600 trees/ha). Open canopy type training system always favours the higher productivity in peaches and nectarines as in case of pome fruits (Table 7).

In peach, the main tools for tree size control are rootstocks, summer pruning, deficit irrigation, genetic modification of tree growth habit, root restriction, growth regulators. Around the world, the most important training systems for HDP are free and sprint palmette, fusetto, delayed vasette, Tatura trellis and related training systems. In medium or low fertile soil the fusetto facilitates uniform distribution of leaf area, early entry into production, good light penetration and good fruit quality; fusetto allows maximum planting density of 1200-1500 trees ha. In contrast, on extremely fertile soil it is necessary to adopt training systems that allow the canopy to develop as a single or double wall of limited thickness. The palmette allows maximum planting densities of 700-900 trees/ha. For orchards with planting densities greater than 1000-1500 trees/ha, the Tatura trellis and its variants (KAC V, perpendicular V) appear the most appropriate. Overall, the right choice of training system and orchard density will have to be made on the basis of careful economic analysis, taking into account the greater costs involved for the establishment and often also for the management of HDP.

Table 7. High density orcharding systems assessed at various places in India and abroad in peach

Variety	Root stock	Training system	Spacing (m)	Density (Trees/ha)	Yield (t/ha)	Reference (Country)
Royal Giant	Nema guard	V-shape	2.0 x 5.5	909	353.0	-
Flavour Crest	Nema guard	V-shape	2.0 x 5.5	909	206.0	-
Baby Gold-5	Nema guard	V-shape	2.0 x 5.5	909	169.0	-
Cresthaven	Nema guard	Tatura trellis	2.5 x 2.5	1600	47.26 (6th Yr)	CITH, 2013-14
Glohaven	Nem guard	Tatura trellis	2.5 x 2.5	1600	42.99 (6th Yr)	CITH, 2013-14
Red Globe	Nema guard	Tatura trellis	2.5 x 2.5	1600	41.12	CITH, 2013-14
Glowhaven	Standard	V-Shape	3.0 x 3.0	1111	40.08 (5th Yr)	CITH, 2012-13
Fantasia	Balle	Central leader	2.4 x 4.5	900	38.0	-
Stark Red Gold	GF-655-2	Free Spindle	2.0 x 4.0	1250	34.3	-
Early Grande	-	Meadow system	-	-	29.6	-
Fantasia	Standard	Modified leader	2.5 x 2.5	1600	20.6 (3rd Year)	CITH, Annual Report, 2010 (India)
Red Globe	Standard	Modified leader	3.0 x 3.0	1111	16.86 (3rd Year)	CITH, Annual Report, 2010 (India)
Red Globe	Standard	Modified leader	2.5 x 2.5	1600	15.77 (3rd Year)	CITH, Annual Report, 2010 (India)
Cresthaven	Standard	Modified leader	2.5 x 2.5	1600	13.8 (3rd Year)	CITH, Annual Report, 2010 (India)

Variety	Root stock	Training system	Spacing (m)	Density (Trees/ha)	Yield (t/ha)	Reference (Country)
Glohaven	Standard	Modified leader	3.0 x 3.0	1111	13.22 (3rd Year)	CITH, Annual Report, 2010 (India)
Fantasia	Standard	Modified leader	3.0 x 3.0	1111	….. (3rd Year)	CITH, Annual Report, 2010 (India)
Cresthaven	Standard	Modified leader	3.0 x 3.0	1111	10.89 (3rd Year)	CITH, Annual Report, 2010 (India)

Plum

Growing of plum trees under high density is also a successful venture around the world. But a very few varieties were reported to grow under high densities. Simca, Mallard, Opal and Elda grafted on Nemaguard and St. Julian rootstock were found compatible as well as productive combinations (Table 8).

Table 8. High density orcharding systems assessed at various places in India and abroad in plum

Variety	Rootstock	Training system	Spacing (m)	Density (Trees/ha)	Yield (t/ha)	Reference (Country)
Simca	Nemaguard	Central Leader	2.0 x 5.5	909	169.8	-
Mallard	St. Julian A	Y-trellis	0.5 x 4.0	5000	95.1	Meland, 2005 (Norway)
Opal	St. Julian A	Y-trellis	0.5 x 4.0	5000	77.6	Meland, 2005 (Norway)
Elda	St. Julian A	Y-trellis	0.5 x 4.0	5000	53.0	Meland, 2005 (Norway)
Mariposa	Standard	Modified leader	5. 0 x 5.0	625	27.26 (9th leaf)	CITH, 2014-15
AU-Cherry	Standard	Modified leader	5. 0 x 5.0	625	23.99 (9th leaf)	CITH, 2014-15
Tarrol	Standard	Modified leader	5. 0 x 5.0	625	23.40 (9th leaf)	CITH, 2014-15

Apricot

High density apricot cultivation is not common due to non-availability of the dwarfing rootstocks. Therefore, plantations were made in medium density. In 10th leaf stage, the maximum productivity was recorded in cultivar 'CITH-Apricot-3' as compared to exotic cultivar viz. Harcot and Rival (Table 9)

Table 9. High density orcharding systems assessed at various places in India and abroad in plum

Variety	Rootstock	Training system	Spacing (m)	Density (Trees/ha)	Yield (t/ha)	Reference (Country)
CITH-AP-3	Standard	Modified leader	5 x 5	625	23.64 (10th Yr)	CITH, 2014-15
CITH-AP-2	Standard	Modified leader	5 x 5	625	23.02 (10th Yr)	CITH, 2014-15
CITH-AP-1	Standard	Modified leader	5 x 5	625	19.06 (10th Yr)	CITH, 2014-15
Harcot	Standard	Modified leader	5 x 5	625	18.20 (10th Yr)	CITH, 2014-15
Rival	Standard	Modified leader	5 x 5	625	17.51 (7th Yr)	CITH, 2014-15

Sweet cherries

Production of sweet cherries (*Prunus avium* L.) in high density systems can be accomplished in a number of ways, but underlying principles exist across all systems that are critical to their success. Inherent vigour and productivity factors - scion, soil type, climate, and rootstock - must be taken into account before deciding upon a particular training strategy to impose. To develop high density sweet cherry orchards, for which growers have the choice of traditional rootstocks (Mazzard and mahaleb seedlings) that tend to promote excessively vigorous growth or relatively new dwarfing rootstocks (Gisela, Edabriz) that, thus far, tend to promote excessive cropping. Poor management of a high density orchard system that is prone to either excessive vigour or excessive cropping can provide disastrous results for yields, fruit quality, and even tree longevity.

For sweet cherry, increased tree density translates into more manageable cropping targets (yield and fruit quality) than traditional systems. Calculation of the number of fruit/tree/ton of yield of desired fruit size readily creates manageable production goals on a tree-by-tree basis. For example, at the relatively low density of 300 trees/ha and a target fruit size of 10 g, for each metric ton (per ha) of marketable yield, a tree must bear ~366 fruit (333 marketable fruit plus 33 additional fruit to account for a 10% factor representing cullage or fruit missed at harvest). In an orchard target of 15 MT/ha, each tree must produce 5,490 fruit. At a higher density of 900 trees/ha, each tree must only produce 1,830 fruit. In view of the production and management potential of various training systems such as central leader, slender spindle, Vogel spindle, Zahn spindle, HYTEC, Solaxe, Tatura trellis, Open vase, Spanish Bush, Steep Leader, Brunner, Palmette, etc.

Sweet cherries are the choicest fruit among stone fruits. It has been successfully growing in selected pockets of Kashmir valley. Bing and Summit grafted on Gisela-6 rootstock planted at closer spacing found very productive. New Cherry clones selected by CITH, Srinagar also showed promising results under high density. Trees trained with vertical as well as open centre canopies have positive effect on yield and fruit quality (Table 10).

Table 10. High density orcharding systems assessed at various places in India and abroad in sweet cherry

Variety	Rootstock	Training system	Spacing (m)	Density (Trees/ha)	Yield (t/ha)	Reference (Country)
Bing	Gisela-6	Palmette	2.6 x 4.9	864	27.1 (9 yr old)	Whiting *et al*. 2005 (USA)
Bing	Gisela-6	Central leader	2.6 x 4.9	864	25.8 (9 yr old)	Whiting *et al*. 2005 (USA)
Bing	Gisela-6	Y-trellis	2.6 x 4.9	864	23.9 (9 yr old)	Whiting *et al*. 2005 (USA)
Van	Damil	Y-trellis	0.5 x 4.0	5000	14.5	Meland, 1998 (Norway)
Summit	Tabel Edabriz	V-shape	0.7 x 3.8	3759	19.3 (6th year)	Radunic *et al*. 2011 (Croatia)
CITH Cherry-1	Colt	Modified centre	2.5 x 2.5	1600	7.93 (8th year)	CITH Annual Report 2010 (India)
Bigarreau Noir Grossa	Colt	Modified centre	2.5 x 2.5	1600	5.2 (8th year)	CITH Annual Report 2010 (India)
CITH -05	Colt	Modified centre	2.5 x 2.5	1600	8.3 (8th year)	CITH Annual Report 2010 (India)
CITH-05	Colt	Modified centre	3.0 x 3.0	1111	8.3 (8th year)	CITH Annual Report 2010 (India)
CITH-01	Colt	Modified centre	3.0 x 3.0	1111	8.3 (8th year)	CITH Annual Report 2010 (India)
CITH-02	Colt	Modified centre	3.0 x 3.0	1111	8.3 (8th year)	CITH Annual Report 2010 (India)

Almond

Almond is one of the most important nut crop grown only in the monsoon free areas of Kashmir valley. Domestic demand of almond is very high in India. But the productivity is very low. So, India is annually importing about more than 60% of the world almond imports. This demand could be compensated by resorting to high density orcharding in almonds using Non Pariel, Waris, Waris, Pranyaj and Shalimar (Table 11). Lack of dwarfing rootstocks for almond is a primary hurdle in high density orcharding. Therefore, high density orchards are more productive during early 5 years of tree bearing, but later they are at par with medium density orchards for nut yield.

In India, there is a lack of data from commercial temperate fruit plantings in relation to high density plantings. In apple, few experimental orchards have been established in apple growing areas of India including Jammu & Kashmir, Himachal Pradesh and Uttarakhand. The trials carried out in India have compared different rootstocks, densities and cultivars.

The effect of higher early yield and increased yield at full production with increased tree is density evident in several high density experiments around the world. However, it is the labour intensive system that involves higher expenses. A study conducted at Lincoln University showed that the more labour is required per hectare basis in semi-intensive orchards than the high density orchards during first 6 years for training and pruning. Because dwarf trees (0.6-2.4 m height) require half cost than the semi-intensive vigorous trees (3.0-3.7 m height). Although establishment costs for high density plantings are higher than any other semi-intensive systems and total establishment costs are not proportional to tree numbers.

Table 11. High density orcharding systems assessed at various places in India and abroad in almond

Variety	Rootstock	Training system	Spacing (m)	Density (trees/ha)	Yield (t/ha)	Reference (Country)
Supernova	Seedling	V-shape	2.5 x 5.0	800	24.5 (cummu. Yield 10 yrs)	Monastra *et al*. 1998
Ferragnus	Seedling	V-shape	2.5 x 5.0	800	23.5(cummu. Yield 10 yrs)	Monastra *et al*. 1998
Waris	Seedling	Modified leader	3.5 x 3.5		3.24 (12^{th} Yr)	CITH, 2012-13
Non Pariel	Nemaguard	Standard	3.0 x 6.6	500	3.28	Duncan R., Univ. California (USA)
Non Pariel	Hensin	Standard	3.0 x 6.0	500	3.63	Duncan R., Univ. California (USA)
Pranyaj	Seedling	Modified leader	4.0 x 4.0		3.07 (12^{th} Yr)	CITH, 2012-13
Non Pariel	Price	Hedge row	2.2 x 6.7	667	2.45	Duncan R., Univ. California (USA)
Pranyaj	Seedling	Modified Leader	4.0 x 4.0	625	2.94 (10^{th} yr)	CITH Annual Report 2010 (India)
Waris	Seedling	Modified Leader	4.0 x 4.0	625	2.78 (10^{th} yr)	CITH Annual Report 2010 (India)

Variety	Rootstock	Training system	Spacing (m)	Density (trees/ha)	Yield (t/ha)	Reference (Country)
IXL	Seedling	Modified Leader	4.0 x 4.0	625	2.58 (10^{th} yr)	CITH Annual Report 2010 (India)
Shalimar	Seedling	Modified Leader	4.0 x 4.0	625	2.37 (10^{th} yr)	CITH Annual Report 2010 (India)

Advantages of HDP

- Early production and higher returns i.e. many higher density orchards are breaking even in 6-7 years compared to 10-12 years for traditional systems.
- Efficient use of labour to harvest and prune from the ground or from a short stool.
- It has potential to produce high quality fruit for a longer period of time by maintaining light interception in the smaller trees of higher density orchards.
- Higher pesticide application efficiency.

Disadvantages of HDP

- It cannot be adopted in very steep, unfertile, shallow and drought-prone areas.
- The high cost of orchard establishment.
- Require highly skilled manpower.
- Require more training and minimal pruning during the first 6 years than traditional systems, especially during the summer. A lack of attention in the early life of this type of orchard creates a very high probability that the orchard will never be profitable given the high costs of establishment.

Orchards of future

Tall spindle: This system was developed to revive the New York apple industry economically. In 1993, Robinson and his cohorts at Cornell gave the birth of the high-density tall spindle system. "It contained concepts from slender spindle, vertical axe, Solaxe and super spindle. Adoption of the tall spindle system is yielding more and showing its economic superiority. The basic elements of tall spindle are:

- *High density*- The optimum tall spindle spacing for an average vigour variety and soil is 3 feet by 11 feet, or 1,289 trees per acre.
- *Full dwarfing rootstocks*- The most successful tall spindle orchards established to date have been on M.9 and B.9. Precocious dwarfing stocks are important since early cropping is essential.
- *Highly feathered nursery trees*- Nursery stock ideally have from 10 to 15 feathers per tree.

- *Minimal pruning at planting*- No heading.
- *Support system*- To carry the crop and support potentially brittle rootstocks.
- *Branch devigoration*- Upright scaffold branches are devigorated by bending them below the horizontal. This early investment of labour pays off in early cropping and less pruning later.
- *Limb renewal*- All scaffolds are removed as they become too large for the available space and become out of balance within the tree.
- *Early fruiting*- Fruiting in the second and third leaf is essential to keep a low tree vigour level and provide income from early fruit sales.
- This system gave cumulative production of more than 81.65 t/acre in the first five years, resulting in a 40 percent higher crop value than the slender vertical axis and Sol Axis planting systems.

Futuristic needs for HDP

The planting of a new high density orchard is a long time (more than 20 year) commitment. Therefore, before planting a grower should consider the possible changes in orchard management that will occur in the next 20 years and try to plant the new orchard so he can benefit from advances in orchard management that are likely to occur. The 5 basic principles or orchard design outlined above (1. high light interception, 2. good light distribution throughout the canopy, 3. high early yields, 4. simple canopies are more adaptable to partial mechanization, and 5. planting density is governed by the law of diminishing returns) will be a part of any future orchard system. Based on these five principal the design of a HDP should be

- Tall (10-11 feet) enough due to the need of intercepting 70-75% of available light.
- It will have narrow simple canopies no wider than 4-6 feet due to the need to have good light distribution in all regions of the canopy.
- Use of highly branched trees for high early yields. The only exception to this rule will be those growers who choose to plant very high tree densities (>1,500 trees/acre) where the cost of feathered trees is too high and the value of feathers is less due to very small space between trees.
- Simple canopies will offer significant benefits in mechanization with simple platforms for pruning, thinning and harvesting.
- The optimum planting density will remain close to 1,000 trees/acre.

In addition to high, early yields, a key goal is to increase the percentage of high quality fruit. That means having narrow canopies that allow good exposure to light from bottom to top. This can be achieved by narrowing canopies with mechanical hedging to form tree walls at suitable time. The next economic challenge is labour reduction. We need to grow temperate fruits with half the labour (180 hours/acre) we now (360 hours/acre) use. Key ingredients are machines platforms to thin, prune, and serve as carriers for harvest crews, but also hedgers to do much of the pruning now done by hand. Use of chemicals can reduce the thinning labour by half of the physical lines.

Conclusion

The change in planting systems over the last 50 years has been dramatic. High yield and high fruit quality can be achieved with a high-density orchard when the orchard has good light distribution throughout the tree canopy and there is a balance between vegetative growth and cropping ("calm trees"). This can best be accomplished by maintaining a narrow canopy shape and through regular limb renewal pruning and the development of pendant fruiting branches. Successful growers will maintain a balance between vegetative growth and cropping by regularly renewing the fruiting wood on the tree, moderate levels of nitrogen and proper cropload management. Growers should try to obtain 50cm of leader shoot growth in the first year, 75-100cm of leader shoot growth in the second and third years and 50cm of leader shoot growth in the fourth year. If this is combined with minimal pruning and a precocious rootstock, significant production should be obtained in the second-fourth years which will limit vegetative growth in future years resulting in a "calm" tree.

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