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Review

Can the productivity of mango orchards be increased by using high-density plantings?

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ABSTRACT

Mango (*Mangifera indica*) trees are traditionally established at about 100–200 trees per ha and eventually grow into large specimens 10 m tall or more, making spraying and harvesting difficult. It also takes a long time to recover the initial costs of establishing and maintaining the orchard. There has been considerable interest in planting orchards up to 4000 trees per ha to take advantage of early production and to increase economic returns. However, trees planted at high density soon begin to crowd and shade each other and production falls. We reviewed the performance of high-density orchards in different growing areas, and the role of dwarfing cultivars and rootstocks, tree canopy management and the growth regulator, paclobutrazol to control tree growth. There has been no general agreement on the optimum planting density for commercial orchards which vary from 200–4000 trees per ha in different experiments. Some potential dwarfing material has been developed in India and elsewhere, but these cultivars and rootstocks have not been widely integrated into high-density orchards. Canopy management needs to take into account the effect of pruning on the regrowth of the shoots and branches, light distribution through the canopy and the loss of the leaves that support the developing crop. Pruning must also take into account the effect of vegetative growth on flower initiation. Annual light pruning usually provides better fruit production than more severe pruning conducted less regularly. There have only been a few cases where it has been demonstrated that paclobutrazol can counteract the negative effect of pruning on flowering and fruit production. There are also concerns with residues of this chemical in export markets and contamination of ground waters. The future development of high-density plantings in this crop is dependent on the use of dwarfing cultivars and/or rootstocks and better canopy management strategies. Dwarfing cultivars and rootstocks should provide small- to medium-sized trees with medium to large yields. This can readily be identified in experiments by examining the relationship between yield and tree growth. Research on canopy management should assess the impact of pruning on flowering, light distribution within the canopy and the leaf area supporting the developing crop. The productivity of mango is not likely to be increased by the use of high-density plantings without extensive efforts in plant breeding and canopy management.

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1. Introduction

Mango (*Mangifera indica*) is a member of the family Anacardiaceae from Asia and has been cultivated for at least 4000 years (Crane, 2008). It is one of the most important members of this family. It is ranked fifth in overall fruit production worldwide (Normand et al., 2015). Other popular large trees from the same family include cashew (*Anacardium occidentale*) from tropical America and pistachio (*Pistacia vera*) from Iran and Central Asia, both important nut crops. Related fruit trees include marula (*Sclerocarya birrea*) from Africa and Madagascar, and yellow mombin or tropical plum (*Spondias mombin*) from tropical and subtropical South America.

The main centre of origin for mango is within the region between north-east India and Myanmar (Crane, 2008; Bompard, 2009; Dinesh et al., 2015a; Sherman et al., 2015; Krishnapillai and Wijeratnam, 2016; Sahu et al., 2016). India is considered to be the centre of domestication of mono-embryonic cultivars, while South-east Asia including Indonesia, the Philippines, Thailand, Vietnam and Myanmar is the main centre for poly-embryonic cultivars. The poly-embryonic cultivars produce a seed with several genetically identical embryos. Cultivars from India tend to have highly coloured skin at maturity and are susceptible to anthracnose, *Colletotrichum gloeosporoides*. In contrast, cultivars from South-east Asia tend to have green to yellow skin and are less susceptible to anthracnose. Cultivars from the two main groups hybridize readily and this gives rise to a wide variation in the productivity and quality of commercial material.

Many of the cultivars grown in India are at least 400 years old (Mukherjee et al., 1968). There are more than 100 different cultivars in some parts of India, including West Bengal (Mitra et al., 2015). Productivity is strongly dependent on environmental conditions, with cultivars not always performing well when introduced to new growing areas (Costa, 2004; Le Lagadec and Köhne, 2004).

Total world mango production is more than 40 million tonnes, with only 3% of the crop traded around the globe (Evans and Mendoza, 2009; Gallo, 2015; Galán Saúco, 2015; Balyan et al., 2015; Mitra, 2016). India is the most important producing country, and accounts for nearly 40% of total world production. Other important mango growing countries include China (11%), Kenya (7%), Thailand (6%), Indonesia (6%), Pakistan (6%), Mexico (5%), Brazil (3%), and Bangladesh (2%). Although India is the main producer, it accounts for only about 16% of world mango trade. Exports are more important for Mexico, with 20% of total world trade. Other important exporting countries include Thailand (11%), Brazil (9%), Peru (9%), and Pakistan (7%). The United States and Europe are the main markets for imported mangoes. Mexico is by far the main supplier to North America, while Brazil and Peru are the main suppliers to Europe (Galán Saúco, 2000; Gallo, 2015). India exports mainly to the United Arab Emirates and other countries in the Middle East (Balyan et al., 2015).

Mango orchards are normally planted at fairly wide spacings because the trees can grow into large specimens. Non-domesticated wild seedling trees often grow up to 10 m in suitable environments (Khan et al., 2015). Traditional orchards are commonly planted out at 100–200 trees per ha. Yields per unit area are low for the first few years after planting and keep increasing until the trees start to shade each other. This period can last from ten to twenty years. There is usually a long period to recover the costs of planting and establishment under this scenario. Trees are planted on a range of different rootstocks and pruned in various ways, which affects the performance of the trees and the commercial life of the orchard. There is strong interest in the use of plantings up to 4000 trees per ha to increase the long-term productivity and economics of growing mango, with several studies in India, South Africa and elsewhere (Fivaz, 2009; Gunjate et al., 2004; Gunjate, 2009; Oosthuyse, 2009; Bally and Ibell, 2015; Kumar, 2015).

Early experiments conducted in India showed that an orchard of 'Amrapali' planted at 1600 trees per ha yielded 12, 13, 17 and 22 t per ha in the four to seven years after planting (Majumder et al., 1982; Majumder and Sharma, 1989). These yields were well above the average national yield of 9 t per ha. Yields usually start to decline after ten or twelve years in these orchards as they do in traditional plantings due to overcrowding and shading (Singh et al., 2010). The lower shoots start to die, productivity falls, and the trees become susceptible to pests and diseases. In the experiments of Majumder et al. (1982) and of Majumder and Sharma (1989), the trees were grown on unnamed seedling rootstocks. There was no indication if the trees were pruned or not. Majumder et al. (1982) noted that the trees were relatively slow growing and were about 2 m high after seven years.

Rajbhar et al. (2016) investigated the productivity of mango trees planted at high density in Uttar Pradesh. After 11 years, the yields of the plots planted at 1111 trees per ha were more than ten times the yields of plots planted at 100 trees per ha (59 t per ha versus 5.9 t per ha). The trees growing in the close plantings were beginning to grow into each other (canopy diameter of about 3 m) and needed to be pruned after harvest. Many of the orchards in India are grown on relatively poor soils and are dependent on rainfall, and pest control is highly variable. These factors contribute to low productivity in many growing areas.

Intensive orchard management systems based on high-density plantings have been implemented to various degrees in apple, pear, cherry and stonefruit for more than 50 years (Tustin, 2014). In these crops, the success of the new orchards has been based on the availability of suitable dwarfing rootstocks and productive scions. The architecture of the trees is carefully manipulated to improve the capture and distribution of sunlight throughout the canopy. Research conducted in apples where the technology is well developed has demonstrated that there is a strong relationship between productivity and light interception across different cultivars and growing environments (Wünsche and Lakso, 2000; Palmer et al., 2002). In some areas with low radiation levels, yields often increase with increasing light interception, although in areas with high radiation levels, the leaves and the fruit can be damaged by excessive light and high temperatures in summer (Corelli-Grappadelli and Lakso, 2007). In a study in pear in the United States, a high-density planting came into production sooner, showing a profit after six years compared with nine years for the traditional planting (Elkins et al., 2008). The costs of establishing the orchards were recov-