

Agronomy of black pepper (*Piper nigrum* L.) - a review

K SIVARAMAN¹, K KANDIANNAN, K V PETER & C K THANKAMANI

Indian Institute of Spices Research

Calicut - 673 012, Kerala, India.

Abstract

Black pepper (*Piper nigrum* L.), a highly valued spice crop, is a perennial vine which originated in the Western Ghats of India and subsequently spread to other countries. Various aspects of crop ecology and agronomical practices such as planting material production, spacing and supports, training and pruning, irrigation, mulching and weeding, nutrition, harvest and cropping systems are reviewed.

Key words : agronomy, black pepper, *Piper nigrum*.

Introduction

Black pepper (*Piper nigrum* L., Piperaceae) called the 'king of spices', is one of the oldest spices known to mankind. It originated in the tropical evergreen forests of the Western Ghats of India and is presently largely cultivated in India, Brazil, Indonesia, Malaysia, Sri Lanka, Vietnam and People's Republic of China. India has the largest area (1,77,340 ha) under the crop and is also the largest producer (55,000 t) in the world (IPC 1994). However, the productivity of the crop in India is low (310 kg/ha) due to (i) poor genetic potential of the vines, (ii) high population of senile and unproductive vines, (iii) losses caused by pests, diseases and drought, (iv) non availability of quality planting material of improved varieties, (v) non adoption of appropriate agro-

nomical practices, and (vi) extension and technology constraints. In India, Kerala alone accounts for 95% of area and production. Though different aspects of black pepper cultivation and production in various countries has been documented (Menon 1949; David 1951; Brown & Reader 1952; Sandford 1952; Blacklock 1954; Aiyadurai 1966; Kay 1970; Pospisil *et al.* 1972; Harper 1974; Schut 1974; Brando *et al.* 1978; Nambiar *et al.* 1978; Raj 1978; Philip 1980; De Waard 1986; Wahid & Sitepu 1987; Tsuda 1989; Pruthi 1993), a comprehensive review on agronomical aspects of the crop is lacking. The available information on various agronomical aspects of black pepper is comprehensively reviewed in this paper.

Crop ecology

Black pepper grows successfully be-

¹ Present address : Directorate of Arceanut and Spices Development, Calicut - 673 005, India.

tween 20° North to 20° South of equator and from sea level up to 1500 m above MSL. It is a plant of humid tropics, requiring 2000 - 3000 mm of rainfall, tropical temperature and high relative humidity with little variation in day length throughout the year. Black pepper does not tolerate excessive heat and dryness.

Rainfall and relative humidity

Total rainfall and its distribution play an important role in black pepper cultivation and productivity. An annual rainfall of 2000 mm with uniform distribution is ideal. Rainfall of 70 mm received in 20 days during May - June is sufficient for triggering off flushing and flowering processes in the plant, but once the process is set off there should be continuous shower until fruit ripening. Any dry spell even for a few days, within this critical period of 16 weeks (flowering to fruit ripening) will result in low yield (Pillay *et al.* 1988). In black pepper growing areas of Indonesia and Malaysia (Sarawak), the average annual rainfall is 2300 mm (Wahid & Sitepu 1987) and 3950 mm, respectively (De Waard 1969). In India, black pepper growing areas receive 1500 mm to more than 4000 mm rainfall. Rainfall after stress induces profuse flowering (Pillay *et al.* 1988). Growth of fruit bearing lateral shoots (plagiotrophs) and photosynthetic rate are maximum during peak monsoon in India (June - July) (Mathai 1983). A relative humidity of 60-95% is optimum at various stages of growth.

Temperature

The crop tolerates temperature between 10 - 40°C. The ideal temperature is 23 - 32°C with an average of 28°C. Optimum soil temperature for root growth is

26 - 28°C (De Waard 1969; Wahid & Sitepu 1987).

Light / Solar radiation

Black pepper is a day neutral plant. Vijayakumar *et al.* (1984) found that black pepper vines exposed to direct solar radiation developed physiological disorders even under favourable soil moisture conditions. Black pepper vines kept under shade (7% incident light) remained green and healthy whereas those exposed to sunlight turned yellow and developed necrotic patches during summer (Vijayakumar & Mammen 1990). Fifty per cent shade boosted the growth of black pepper cuttings in the nursery (Senanayake & Kirthisinghe 1983). Illumination above 50,000 lux ($900 \mu \text{ mol s}^{-1} \text{ m}^{-2}$) decreased carbon fixation in a few varieties of black pepper (Mathai 1983). The top portion of the black pepper vine receives more sunlight which declines gradually downwards and this is attributed to mutual shading of the vine (Ramadasan 1987; Mathai & Chandu 1988).

Shade regulation of live standards is an important cultural practice during rainy/cloudy weather to allow sufficient light for crop growth; if not, the yield will be reduced to 50% or more (Ramadasan 1987). Use of reflectants is common to reduce stress during summer. Spraying lime over the leaf surface enhanced the chlorophyll content (Vijayakumar *et al.* 1984); however, it reduced the yield compared to china clay (Vijayakumar & Mammen 1990).

Soil

Soils suitable for black pepper at different production centers have been reviewed earlier (De Waard 1969; Purseglove *et al.* 1981; Wahid & Sitepu 1987; Sadanandan 1994). Black pepper

grows well on soils ranging from heavy clay to light sandy clays rich in humus with friable nature, well drained, but still with ample water holding capacity. Soils with near neutral pH, high organic matter and high base saturation with Ca and Mg enhanced the productivity (Mathew *et al.* 1995). Soil for black pepper cultivation requires a composition of 0.26% N, 0.25% P₂O₅, 0.41 % K₂O, 0.18% MgO and 0.5% CaO (Wahid & Sitepu 1987). Wardani & Zaubin (1984) reported that black pepper varieties differ in their growth with respect to soil pH and soils with pH above 7.5 inhibit growth. However, Sangakkara (1989) reported that growth of the variety Panniyur 1 was the highest at pH 7.8 and 8.1. Water logged soils and diseased soils are not suitable for black pepper cultivation (Nambiar *et al.* 1965; De Waard 1979). Well drained loamy soils rich in humus nourish the crop well and the best crop could be obtained in virgin forest soil.

Cultivation

In most of the producing countries black pepper is a small holder's crop and more than 1 million farmers depend on it for their livelihood (UN 1995). Cultivation varies from very intensive monoculture to extensive homestead gradens. In India, 95% of it's production is from homesteads (Nair & Sreedharan 1986) with promiscuous planting of black pepper along with perennials. Black pepper is also trailed on arecanut and coconut, shade trees in coffee and tea plantations and on avenue trees.

Planting material production

Black pepper is propagated vegetatively as well as through seed. As the crop is heterozygous in nature, seedlings raised from seeds will not breed true to type.

Hence, vegetative propagation is preferred for commercial cultivation. Though black pepper can be propagated through cuttings, grafting, layering and budding, rooted cuttings are preferred for commercial cultivation. Runner shoots (orthotrophs) are used for producing cuttings. The length of the cuttings vary from 30 cm (Pospisil *et al.* 1972) to 60 cm (Creech 1955) and consist of a single node to seven nodes. For direct field planting, lengthier cuttings are preferred. The availability of sufficient runner shoots to produce enough cuttings to establish large plantations is limited. Direct field planting of cuttings results in poor establishment (<5%) (Creech 1955); hence, cuttings with 2 or 3 nodes have to be raised in the nursery initially and transplanted to the main field after attaining sufficient growth. A rapid multiplication technique through bamboo method (Bavappa & Gurusinghe 1978; Sivaraman 1987) for meeting the large scale demand of quality planting material has also been developed.

Standards and spacing

Black pepper vines require support for their establishment. Both living and non - living standards are used to trail black pepper. An ideal living standard should be (i) straight growing, (ii) have a tap root system and should not compete with black pepper for water, nutrients and solar radiation, (iii) be slender but with a strong trunk with a rough surface, (iv) withstand regular pruning and pollarding, and (v) have economic value after life span of black pepper. A variety of trees are used as living standards (Wardell 1991; Salam *et al.* 1991). Some of the common living standards are *Erythrina indica* Lamk., *E. lithosperma* Blume ex. Miq., *Garuga*

pinnata Roxb., *Gliricidia sepium* (Jacq.) Steud. and *G. maculata* (H B & K) Steud. Rajagopalan & Mammooty (1996) and Mathew *et al.* (1996) reported that *Ailanthus malabarica* DC and *G. pinnata* are the best living standards. Raising black pepper on live standards reduced the capital cost apart from increasing productivity on long term basis (Azmi & Yau 1993; Varughese & Ghawas 1993; Wong & Paulus 1993). Under organised monocrop cultivation, black pepper is planted normally at a spacing of 2.5 m x 2.5 m. Kurien *et al.* (1994) recorded the highest competition between living standards and black pepper at closer spacings of 2 m x 2 m. India, Madagascar and Lampung in Indonesia use live trees at wider spacings which decrease plant population and yield (George 1981).

The non-living standards used include, reinforced concrete posts, granite pillars and teak poles which require high initial investment compared to living standards. Dead wood standards are used in Malaysia, Brazil and Banka in Indonesia facilitating closer spacing resulting in higher yields (George 1981). Growing black pepper on non-living standards at closer spacings is known to enhance the yield (Belger 1977; Brando *et al.* 1978; Chong & Shahamin 1981; Kumar & Cheeran 1981; Menon *et al.* 1982; Kurien *et al.* 1985; Ramos *et al.* 1986; Reddy *et al.* 1991 & 1992). However, poor growth and productivity were observed on concrete poles (Wahid & Sitepu 1987). During summer, concrete poles and stone pillars absorb heat and become hot resulting in drying of clinging roots and poor growth of black pepper vines under exposed situations.

For raising living standards, seedlings are preferred over rooted cuttings since

seedlings have a tap root system and do not compete with black pepper for resources. Living standards should be planted 3-4 years in advance so as to attain sufficient height at the time of planting black pepper. During establishment of living standards, the side branches are pruned to enable the standard to grow erect. After establishment, periodical pruning is important to allow sufficient light penetration into the black pepper canopy (shade regulation). Pruning is dependent on the growth of foliage and normally one or two prunings in a year are sufficient. Pruning of living standards before flowering enhances the yield of black pepper (Mathai & Sastry 1988). Green matter of 15 t ha⁻¹ per year was obtained by pruning black pepper standards (Anon 1938).

Normally the height of the living standard is not restricted; however, for easy harvesting the height may be restricted. Kato & Albuquerque (1980) found that 2.5 m height was more beneficial than 1.5 m, but 3.6 m to 4.2 m tall wood with 18-20 cm diameter are also used. However, it is common to raise black pepper on coconut and arecanut plants which are more than 5 m height. One or two cuttings of black pepper are planted per standard during the rainy season or with irrigation. If the circumference of the stem of the standard is more, more cuttings may be planted. Young seedlings in the field should be given adequate care by providing shade and irrigation until their establishment.

Other methods of growing black pepper are raising on trellis (Groome & Salleh 1977; Gillot & Van Dingene 1960) and hedge system (Raj 1978) which are less successful.

Training and pruning

Training is an essential step for establishment of black pepper vines. The vines have to be tied to the standards at the nodes by suitable materials for anchorage. The leaves are removed from vines after attaining a height of 1 m and 10 days later they are brought down and 3/4th of the basal portion is buried around the standard or wound round the base of the standard and covered with good top soil to induce a good root system and for production of more leader shoots from the nodes. Three to five leader shoots (main stems) are enough to produce sufficient laterals or to form a full canopy around the trunk of the standard.

Pruning is practiced to ensure leader shoot production within 4-6 months of planting and to induce the development of lateral shoots. In Malaysia, three types of pruning (Kuching, Sarileri and Semongok methods) are adopted and no difference was observed among them (MACD 1981). Azmil & Yau (1993) stated that pruning is essential for increasing the yield. Three rounds of pruning are enough to obtain necessary number of climbing shoots as well as appropriate bushiness. In India, no marked influence on yield due to pruning was recorded (Pillai 1977); however, pruning of unwanted terminal growth encouraged the development of lateral shoots and production of spikes (Kurien & Nair 1988).

Irrigation

Black pepper is very sensitive to moisture stress. The high evapo-transpiration coefficient of the crop demands a continual supply of moisture. During the dry period when there is no rain for 2 to 3 weeks, the soil moisture in the top

30 cm of soil is reduced to 50% or less. The feeder roots of black pepper are distributed in the top 50 - 60 cm depth of soil and therefore sensitive to moisture stress (Raj 1978). Unshaded vines show wilting during this dry period. Seibert (1988) stated that irrigation is required for black pepper in dry seasons. Basin irrigation of vines with 100% once in 10 days per vine at IW/CPE ratio of 0.25 from December to March increased the yield of the crop (AICRPS 1991) but resulted in more insect and fungal pollu attack (Satheeshan *et al.* 1998) at Panniyur, Kerala; however, at Calicut 7 l vine⁻¹ day⁻¹ through drip from October to March recorded maximum yield (IISR 1996). Satheesan *et al.* 1998) reported that evapotranspiration (ET_c) values of black pepper and *E. indica* (standard) obtained by Bowen ratio-energy balance (BREB) method and vapour diffusion model (VDM) ranged from 2.45 to 3.15 mm day⁻¹ and 2.86 to 3.40 mm day⁻¹, respectively, during the period of moisture stress from January to March of 1994-96 and the crop coefficient values for crop stand ranged from 0.53 to 0.78. Similarly, in the multi-storeyed cropping system of black pepper trained on coconut and arecanut, the ET_c values of black pepper ranged from 0.31 to 0.42 mm day⁻¹ and the crop coefficient of black pepper ranged from 0.07 to 0.10. These values will help in the estimation of water requirement of black pepper in different cropping systems.

Mulching and weeding

The roots of black pepper are concentrated in the top 50-60 cm soil layer, and to protect them from heat during summer and to avoid soil loss due to run off during rainy season mulching is essential. Mulching depends on the moisture

content of the soil (Wahid & Sitepu 1987). Various organic materials and green leaves are used as mulch. Mulching withalang (*Imperata cylindrica* (L.) Beauv.) prevented soil erosion in black pepper gardens of hilly land at Sarawak, Malaysia (Sandford 1952). Application of *Chromolaena* (*Eupatorium*) *odoratum* L. as mulch controlled yellow disease and improved the stand of black pepper at Cambodia (Litzenberger & Lip 1961). Kato *et al.* (1980) compared rice husk, hay and saw dust as mulch and found that saw dust gave the highest black pepper yield followed by rice husk at Brazil. Terada & Chiba (1971) suggested mulching the entire area with straw, haulm or other grasses to conserve moisture and protect the soil in black pepper gardens. Mounding is also practiced to protect black pepper roots at Ghana (Pospisil *et al.* 1972).

Providing soil mulch by digging twice a year is optimum to maintain the health and yield of black pepper vines (Nambiar *et al.* 1978). Cover crops such as *Calapagonium mucunoides* Desv. and *Desmodium trifolium* (L.) DC have also been suggested (Nair 1982; Ahmad 1993).

Weeds are a major problem in black pepper plantations that are not maintained properly. Weed flora change with location, soil type and season. Abraham & Abraham (1998) recorded 55 weeds (41 dicots, 9 grasses, 3 ferns and 2 sedges) in black pepper gardens of Kerala. Ipor (1993) stated that weeds are one of the major constraints in black pepper cultivation at Sarawak. Use of glufosinate (Bast 15) or organic cover with coconut fibre or paraquat or glyphosate (Round Up) resulted in significantly higher yield when compared with natural cover (Kueh *et al.* 1993).

Harper (1974) stated that 5-6 manual weedings are done at Indonesia. Clean weeding and use of herbicide led to occasional soil erosion. As an alternative, Ipor (1993) reported that cover crops like *D. trifolium* and *Centrosema pubescens* Benth. can be raised to smother the weeds. Maintenance of cover crop also reduced *Phytophthora* infections (Ramachandran *et al.* 1991).

Crop nutrition

Black pepper is a surface feeder and feeding roots are concentrated on the top 50-60 cm layer of the soil. Many workers observed that the performance of the crop was the best in humus rich soils. During early days, black pepper plantations were established on virgin forests after clearing the vegetation. Owing to heavy rains and unsustainable soil management practices, the soil became poor in fertility and balanced manuring of crops became essential. Manuring practices at different centres have been documented (De Waard 1969; Raj 1973; Purseglove *et al.* 1981; Wahid & Sitepu 1987; Sadanandan 1994). Initially burnt earth, guano, prawn-dust, fish and bone meal, farm yard manure, liquid cattle manure, compost and castor, soybean, cotton seed, coconut and groundnut cakes are used apart from green leaves to replenish the soil nutrient status. Liberal manuring with a mixture of cowdung, compost and oil cakes resulted in high yield at Assam (Choudhury 1947). Adiyoga (1987) stated that cattle manure @ 15 t ha⁻¹ was more economical than goat and chicken manure at Brazil. In the course of time, transition took place from bulky organics to limited manufactured fertilizers, and as a consequence, die-back of branches, foliar disorders, low yields and considerable reduction in life span

of vines were observed (De Waard 1969). Raj (1978) stated that judicious use of organic manures and inorganic fertilizers is the most efficient and economical method for black pepper production.

Nutrient composition and removal

In the process of evolving nutrient needs and fertilizer recommendations, uptake and nutrient content of aerial parts of black pepper vines were studied. Nutrient removal and composition of black pepper vines varied with variety, age, season, soil type and management. Nutrient levels of leaves have been analyzed (De Waard 1969; Sim 1972 & 1973; Bataglia *et al.* 1976; Sushama 1982; Nybe *et al.* 1989; Sadanandan 1994). Ideal time of leaf sampling for foliar diagnosis is just before flushing and the youngest fully matured leaf is the ideal leaf to analyze. De Waard (1969) reported that the healthy vine contained 3.10%N, 0.16%P, 3.40%K, 1.66% Ca and 0.44% Mg. Sim (1971 & 1973) studied the N, P, K, Ca, Mg, Fe, Mn, Zn, Cu and B contents of both reproductive tissues in mature vines and vegetative tissues in vines varying in age from less than 1 year to about 17 years and found that the total dry matter production was about 11,426 kg ha⁻¹ in mature vines (1680 vines ha⁻¹) and nutrient removal was 233 kg N, 39 kg P₂O₅, 207 kg K₂O, 30 kg MgO, 105 kg CaO, 0.16 kg Fe, 0.47 kg Mn, 0.17 kg Zn, 0.15 kg Cu and 0.1 kg B. The range of nutrients in leaves of 12 cultivars studied were 1.75 - 3.12 % N, 0.12 - 0.16% P, 2.61 - 3.55% K, 1.40 - 2.37% Ca, 0.15 - 0.27% Mg, 78 - 139 ppm Fe, 161 - 542 ppm Mn, 19 - 30 ppm Zn, 248 - 800 ppm Cu, 53 - 92 ppm Al and 1.24 - 4.73 ppm Mo (Sadanandan 1994). Wahid *et al.* (1982) found that N and K

were higher in the leaves of healthy vines compared to diseased (slow decline) vines. Nybe *et al.* (1989) reported that phosphorus and potash had greater importance in enhancing yield. The order of nutrient concentration in leaves, branches, stems and fruits/spikes were N>K>Ca>Mg>P (Nagarajan & Pillai 1975) whereas in white pepper it was K>N>Mg>Ca>P and in flowers N>K>Ca>P>Mg (Adzemi *et al.* 1993). Mathew *et al.* (1995) found that nutrient removal by way of harvested produce followed the order of N>K>Ca>Mg>P>S>Fe>Mn>Zn. The range of nutrient withdrawal was 143 - 243 kg N, 10.3 - 27.0 kg P, 127 - 202 kg K, 68 - 86 kg Ca and 12 - 29 kg Mg ha⁻¹ year⁻¹ (De Waard 1979). Sankar (1985) recorded that 1 kg of dry black pepper removed about 26.6 g N, 1.5 g P, 21 g K, 8.8 g Ca, 5.2 g Mg, 0.9 g S, 0.1 g Fe, 0.017 g Zn, 0.11 g Mn and 0.028 g Cu. Geetha *et al.* (1996) reported that black pepper (bush type) raised from plagiotrophs (fruit bearing lateral branches) can be used as a material for studying the fertility status and nutrient supplying power of the soils in relation to black pepper nutrition but it is not a good substitute for black pepper vine as an experimental material for investigations on nutrient requirement and fertilizer response.

Nutrient management

Farmers adopt application of inorganic fertilizers @ 362 - 549 kg N, 206 - 549 kg P₂O₅, 228 - 777 kg K₂O and 92 - 137 kg MgO ha⁻¹ year⁻¹ (Sim 1972) at Sarawak. Yellowing of black pepper vines reduced and the crop improved considerably by the integrated application of organic manure and inorganic fertilizers @ 400 kg N, 180 kg P, 480 kg K, 425 kg Ca and 110 kg Mg ha⁻¹

year⁻¹ (De Waard 1979). Raj (1978) stated that fertilizer application advocated should contain 11-13%N, 5-7% P₂O₅, 6-18% K₂O, 4-5% MgO and trace elements. Organic farming can improve black pepper productivity (Zulkifly 1996) and addition of organic matter enhanced the growth and biomass of the vines (Mustika *et al.* 1994; Sivakumar & Wahid 1994). Biofertilizers and vermicompost application also enhanced the growth, biomass and nutrient uptake of black pepper (Bopaiah & Khader 1989; Kandianan *et al.* 1998). In India, the amount of fertilizer used is very low and only 4-10% of the farmers use fertilizers for black pepper (Anandaraj *et al.* 1989), as more than 95% are cultivated in homesteads (Nair & Sreedharan 1986) where multi species cropping systems is prevalent which helps in improvement of soil fertility (Bavappa *et al.* 1986). Sadanandan *et al.* (1994 & 1998) developed diagnosis and recommendation integrated system (DRIS) norms for black pepper leaf and black pepper growing soils to obtain optimum yield.

The critical stages of nutrient requirement are during initiation of flower primordia and flower emergence, berry formation and development (Raj 1978). However, fertilizer application depends on soil moisture availability. Fertilizers are applied in two splits in India (NRCS 1989), 3 - 4 splits in Indonesia (Wahid & Sitepu 1987) and 4 splits in Malaysia (Raj 1978). NRCS (1989) recommended one third at first year, two third at second year and full dose from third year onwards. Fertilizer application is restricted to a lateral distance of 30 cm in full circle area around the vine (Geetha *et al.* 1993). Fertilizer efficiency enhanced with slow release 'nimin'

(nitrification inhibitor) coated urea (Sadanandan & Hamza 1993) and mussoorie rock phosphate (Sadanandan 1986) to supply N and P, respectively to black pepper.

Harvest

Generally, the first harvest of black pepper is done during the third year after planting. Black pepper starts flowering even 1 year after planting but they are removed for getting good yield during subsequent years. Sandford (1952) stated that maximum yield was recorded during 5-7 years after planting and then it gradually declines; however, if the crop is maintained well, harvest extends up to 15 years. Govindarajan (1977) mentioned that vines bear well even at the age of 30 to 50 years or more. After flowering, it takes about 8-9 months for maturity. The symptom of maturity/harvest is when berries easily separate from the spikes upon rubbing between the hands (Govindarajan 1977) or when one or more berries turn red on a spike. Spike length and number of berries per spike vary with variety and there is considerable variation in the fullness of the spikes. In an ideal bunch, the berries are closely pressed together, with no empty space between and all the berries are full-sized or nearly so, and all approximately of the same developmental stage. Improper filling is due to presence of unfertilized flowers, imperfect fertilization and pest attack.

Single bamboo pole which has notches for steps (India), bamboo ladder (Indonesia), tripod ladders (Malaysia) and a sort of platform ladder (Ghana) are used for harvesting black pepper. Normally a single harvest is done in India. However, multiple harvests have been reported in Malaysia (Sandford 1952).

The number and frequency of harvests depend on crop vigour, season, quantum and distribution of rainfall and solar radiation. Harvesting is done once a week during harvesting period in Sarawak (Sandford 1952), whereas it is twice in a week in Ghana (Pospisil *et al.* 1972) and in Indonesia it is 4-5 times every 1-2 weeks (Wahid & Sitepu 1987). The stage of harvest depends on usage of the crop (white, black, oleoresin, oil, etc.). During the last harvest, the spikes, whether they are ripe or not, should be collected to ensure even and uniform bearing during next season. Sandford (1952) stated that in Sarawak, after final harvest has been completed, the leaves should be plucked and the vine heavily manured. However, leaf plucking is not required in India where the harvest ends at the commencement of summer and the leaves will shed automatically. For preparation of black pepper, the berries are harvested when they are just mature but before fully ripening. After harvest, the spikes are kept as such for a day or so, thereafter the berries are directly dried in sun for a few days on mats or on clean concrete floors, they are then turned over and later the berries are removed. When completely dried, the outer skin of berries become dark brown to black and shrink. For white pepper, the berries are harvested when ripe and prepared by retting or steaming/boiling and rolling or running water treatment (Gopalam *et al.* 1990). The yield of black pepper is generally about 33% and white pepper is 25-28% of the weight of green berries.

The yield of black pepper varies greatly in different production centres : Thailand (2918 kg/ha), Malaysia (1853 kg/ha), Brazil (833 kg/ha), Indonesia (239 kg/ha) and India (310 kg/ha) (IPC 1994).

Productivity depends on elevation, temperature, rainfall, soil fertility, cultural practices, age of the crop, and climatic conditions during flowering, fruit set and development. Plant characters like green berry yield, spike number, spike length and the angle of insertion of plagiotrophs has direct positive influence on yield (Sujatha & Namboothiri 1995). Visual scoring for yield was found to be an easy method to estimate black pepper yield (Balakrishnan & Abraham 1986).

Cropping systems with black pepper

Black pepper as a climbing vine is well adapted to grow as an under crop/mixed crop/intercrop with plantation crops. The humid rain forest ecosystem with tropical and sub-tropical climate provides appropriate environment for raising annual, biennial and perennial crops as inter and mixed crops in high density multi species cropping systems (Bavappa *et al.* 1986; Rethinam & Venugopal 1994). Ginger, turmeric, coffee, banana, cocoyam, cereals like upland paddy, pulses like redgram, vegetables, flowers, fodders and other annuals are intercropped with black pepper. Black pepper is also intercropped with coffee, arecanut and coconut (Nelliat *et al.* 1974; Nair 1979; Chandra & Etherington 1982; Liyange *et al.* 1985; Bheemiah & Shariff 1989; Wardell 1991; Korikanthimath & Peter 1992; George & John 1992; Yufdy 1993). Among different cultivars, Karimuda and Panniyur 1 were found to be ideal in coconut and arecanut plantations (Koyamu & Albuquerque 1956; Potty *et al.* 1979; Khader *et al.* 1990). Maximum return was achieved with the combination of coconut + black pepper + pineapple + cocoa (Ditabalan & Astete

1986) and coconut + cocoa + cinnamon + black pepper + pineapple (Yufdy 1993).

Mixed cropping is known to influence the occurrence of various diseases on the crop. Mixed cropping of black pepper + rubber + pineapple + clove; black pepper + cocoa + Hawaiian papaya + orange + Tahitian lemon + guava reduced the incidence of *Fusarium* disease in Brazil (Duarte & Albuquerque 1988). However, black pepper is not recommended as a mixed crop with cocoa, pawpaw, and cardamom in Sri Lanka as these crops are attacked by foot rot caused by the same pathogen (Bandara *et al.* 1985). Sitepu & Kasim (1991) suggested avoiding intercropping black pepper with cocoa and capsicum in Indonesia.

Conclusion

Black pepper is cultivated in different agroecological situations. Production technologies adopted at a particular location may not be suitable for others; hence, location specific production packages for black pepper is to be standardised for precision farming. Although more than 100 popular cultivars are being cultivated only few are high and stable yielding. Information on cultivars suitable for different regions is lacking. Popularisation of rapid multiplication of black pepper is essential to meet the high quality planting material requirement and research effort is needed to simplify the technique at the farm level. Limited information is available on whether black pepper needs irrigation or not in different locations and information on drought management aspects are also meagre. The general observation is that dry moisture stress induces profuse flowering and yield. The quantum of moisture stress

required for optimum spiking and yield are yet to be quantified. Organically grown black pepper fetches premium prices at international market. The technologies to produce organic and value-added products need to be evolved. Literature on the use of different organics on black pepper yield and quality are limited. Profitable and sustainable cropping systems with black pepper as a component for different locations are yet to be evolved. Not much work has also been done on mechanized harvest which may increase the efficiency of harvesting.

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