Agronomy of ginger (*Zingiber officinale* Rosc.) - a review[1]

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ABSTRACT

Ginger (*Zingiber officinale*) is grown in tropical and sub-tropical regions of the world for it's spice and medicinal values. Successful production of ginger depends on efficient use of available resources by adopting suitable agronomic practices. Such practices like land preparation, seed selection, seed rate, seed treatment, planting season, depth of planting, mulching, nutrient management, use of growth regulators, weed control, irrigation, shade requirement and harvest management are reviewed in detail. The review also covers climatic requirement for cultivation, soil suitablity, establishment and growth, pests and diseases, cropping systems, ratooning and economics of cultivation.

Key words: agronomy, cultivation, ginger, *Zingiber officinale*.

Introduction

Ginger (*Zingiber officinale* Rosc.) (Zingiberaceae), a perennial herbaceous monocotyledon, usually grown as annual, is known to human generations as a medicinal and spice crop. It is a plant of very ancient cultivation and the spice has long been used in Asia. It is one of the earliest oriental spices known to Europe and is still in large demand today (Purseglove *et al.* 1981). The economic part is the underground rhizome, which is pungent and aromatic and used for culinary purposes in ginger bread, biscuits, cakes, puddings, soups and pickles. Ginger is traded in three basic forms - green (fresh), pickled or preserved and dry. Only dry ginger (whole, peeled or sliced) is regarded as a spice; green or fresh ginger is considered basically as vegetable, while pickled or preserved ginger is destined largely for the trade connected with Chinese and Japanese cuisine. In addition, ginger oil and oleoresins are also traded. Although a number of countries produce ginger, exports of dry ginger on a significant scale are limited to India and China, the two dominant suppliers, followed by Nigeria, Sierra Leone, Australia, Fiji, Bangaladesh, Jamaica, Nepal and Indonesia. The USA, UK,

[1]Contribution No. 198 of Indian Institute of Spices Research, Calicut - 673 012, Kerala, India.

Saudi Arabia, Morocco, Japan, Germany, Republic of Yemen and Canada are important importers of ginger. In India, ginger is cultivated in 21 states (Anonymous 1992) in an area of 53,000 ha with a production of 1,52,890 t. Ginger accounts for 8 per cent in quantity and 5 per cent in value and ranks fifth among various spices exported by India (Spices Board 1994). Various aspects of ginger production has been earlier documented in India (Aiyadurai 1966; Randhawa & Nandpuri 1970; Paulose 1973; CSIR 1976; Nair 1982; Korla & Dohroo 1991; Pruthi 1993) and elsewhere (Ridley 1912; Graham 1936; Hernandez 1944; Brown 1955; Bendall & Daly 1966; Whiley 1974; Purseglove *et al.* 1981; Lawrence 1984). Agronomical aspects of ginger production are reviewed here in detail.

Habitat and ecology

Ginger requires a tropical or subtropical climate. It thrives well up to an altitude of 1500 m above MSL in the Himalayas, the optimum being 300-900 m (CSIR 1976). The base temperature requirement is 13°C and upper limit 32°C/27°C (day/night) (Hackett & Carolane 1982), the favourable range being 19-28°C. The optimum soil temperature for germination is between 25-26°C and for growth 27.5°C (Evenson, Bryant & Asher 1978). The temperature range at which the crop is cultivated in Kerala, India is 28-35°C (Purseglove *et al.* 1981). A temperature in excess of 32°C can cause sunburn (Whiley 1974) and low temperatures induce dormancy. The crop requires short or long day length for its growth (Hackett & Carolane 1982). As day length was increased from 10 to 16 h, vegetative growth was enhanced, while it was inhibited and rhizome swelling promoted as the day length was decreased from 16 to 10 h. Further increase in day length from 16 to 19 h did not promote rhizome swelling and resulted in lowering of growth increment (Adaniya, Shoda & Fujiada 1989). Brilliant sunshine, heavy rainfall and high relative humidity are necessary for good yield (Ridley 1912). A rainfall of 1500-3000 mm, well distributed in 8-10 months is ideal. Dry spells during land preparation and before harvesting are required for large scale cultivation (CSIR 1976). Ginger is cultivated under rainfed and irrigated conditions. In areas receiving less rainfall, the crop needs regular irrigation. The crop is sensitive to water logging, frost and salinity and tolerant to wind and drought (Hackett & Carolane 1982). Deep slopes in hilly areas are not recommended for cultivation as it leads to soil erosion during heavy rainfall and rhizome yield has been negatively correlated with slope (Cho *et al.* 1987). Partial shade also increases rhizome yield (Jayachandran *et al.* 1991).

Soil

Ginger has wider adaptability for different soil types, and for higher yield the soil should be loose, friable and offer minimum resistance to rhizome development. Well drained soil with at least 30 cm depth is essential, but by adopting bedding and surface mulching, shallower soil can be utilized satisfactorily (Whiley 1974). As depth of soil increases, it's suitability for cultivation also increases (Cho *et al.* 1987). Compact clay soils which are subject to water logging or coarse sands without water holding capacity, gravelly soils or those with hard pan are not conducive for the production of high yielding healthy plants (Lawrence 1984). Soil hardiness should be less than 15.7 mm

(Cho *et al.* 1987). The most favourable soil pH is 6.0 - 6.5 (Whiley 1974; Cho *et al.* 1987). In India, ginger is grown on a wide variety of soils such as sandy loams, clay loams, black rich clay soils and lateritic soils. Virgin forest soils particularly after deforestation are ideal (Paulose 1973). Ridley (1912) quoted a farmer who grew ginger for 40 years in the same patch and it is therefore quite unnecessary to destroy forests of great value. It performs best on medium loams with a good supply of humus (John 1988). Organic matter has a positive effect on yield (Cho *et al.* 1987). Uniform loamy texture is more suitable than other types (Hackett & Carolane 1982). Sahu & Mitra (1992) reported that maximum yield was achieved in sandy loam soil having minimum bulk density (1.20 g/cc), moderate acidic reaction (pH 5.7) and high organic matter (organic carbon 1.1 per cent) and available potassium (351 kg/ha); the yield decreased with increase in soil clay content and decrease in pH.

Cultivars

As ginger rarely sets seed, the general mode of propagation is asexual. Crop improvement is mainly through introduction and selection (Muralidharan & Sakunthala 1975). Micropropagation through tissue culture (Hosoki & Sagawa 1977; Ilahi & Jabeen 1987; Bhagyalakshmi & Singh 1988; Pruthi 1993; Bhagyalakshmi, Shanthi & Singh 1994), mutation (Mohanty & Panda 1991; Giridharan & Balakrishnan 1992) and polyploidy breeding (Sasikumar, George & Ravindran 1994) are also reported. Several commercial cultivars of ginger are cultivated throughout the world especially in India, and many land races and improved cultivars which excel in yield and one or more quality traits are available (Ravindran *et al.* 1994). Yield, percentage recovery of dry ginger from fresh ginger and fibre content are the criteria used to differentiate these types (Aiyadurai 1966). Nybe & Nair (1979 a) studied 25 cultivars for morphological characters and observed significant differences among them except for breadth of leaves, leaf area index and primary fingers. The performance of various varieties under different locations in India was evaluated by Thomas & Kannan (1969), Nair, Sasidhar & Sadanandan (1976), Nybe & Nair (1981), Thangaraj *et al.* (1983), Rattan, Korla & Dohroo (1988), Mohanty *et al.* (1990) and NRCS (1991; 1992). Potential yield and quality of genotypes may vary with agroclimatic conditions, soil fertility and agronomic practices. However, a thorough study on ginger genotypes, its interaction with environment and its effect on value added products has not been attempted. Ginger cultivars were also evaluated for fertilizer response (Muralidharan & Ramankutty 1975), shade requirement (KAU 1992; Beena, Sreedevi & Nair 1994), disease resistance (Balagopal *et al.* 1975; Dohroo *et al.* 1986), reaction to insect pests (Nybe & Nair 1979 b) and quality (Jogi *et al.* 1972; Govindarajan 1982; Ratnambal, Gopalan & Nair 1987; AICRPS 1992 a).

Planting

Season

Planting seasons are March-June in India (Thomas 1961; Randhawa, Nandpuri & Bajwa 1972 a; CSIR 1976; Kingra & Gupta 1977; GAU 1986; Jha, Maurya & Pandey 1986; Pawar & Patil 1987; Phogat & Pandey 1988; Mohanty, Naik & Panda 1990), September at Australia and Fiji (Whiley 1974; Sivan 1979), March-April at West Indies

(Ridley 1912), mid-April at South Eastern Nigeria (Okwuowulu *et al.* 1990), May-June at Jamaica (Graham 1936), February-April at Taiwan (Lawrence 1984), April-May at Sierra Leone and Hawaii (Lawrence 1984; Furutani, Villanueva & Tanable 1985) and June at Ghana (Lawrence 1984). However, ginger can be planted anytime during the year in areas where irrigation facilities exist (Paulose 1973). The main considerations while planting ginger are: time of year in relation to climate and depth of seed placement and spacing (Whiley 1974). The time of planting has considerable influence on yield of ginger (Kannan & Nair 1965) and it depends on the time of occurrence of wet season (Ridley 1912). In India, ginger is planted with commencement of South West monsoon. In areas where the monsoon is late, planting is done in June or later. A higher yield of 100-200 per cent was recorded by planting during the first week of April, with the receipt of summer showers, than the general practice of planting in May-June (Khan 1959; Aiyadurai 1966). Early planting is beneficial (Randhawa & Nandpuri 1970; Randhawa, Nandpuri & Bajwa 1972 a) and ensures that the crop grows sufficiently to withstand heavy rains and grows rapidly with the receipt of heavy rains (Nair & Varma 1970). Growth and yield characters and rhizome yield were the highest in mid-March planting than February and May planting at Nainital (Phogat & Pandey 1988).

Cultivation

To produce high yields of ginger the soil should be loose and friable. The mode of preparing soil depends to a considerable extent upon climate, and the planter must use his judgement as to the most suitable method. The soil should be thoroughly broken up and pulverised with a hoe or plough and if possible harrowed afterwards; without such improvement in tilth the crop fails to produce good shaped rhizomes. Good shaped rhizomes are desirable for marketing and post-harvest processing. Land preparation may vary with soil type, slope and irrigation. In Jamaica, clay lands are forked and left to dry 3 months before planting and again a month before planting, forked and drained by means of trenches (Graham 1936) and ridges and furrows method is used. In the furrow method, the seed rhizomes are sown in furrows 22.5 cm deep and 22.5 cm apart. When ridge method is used the rhizome pieces are planted 30 cm apart but only a few centimetres below the surface in prepared ridges about 30 inches high (Lawrence 1984). In Queensland, preparation of land for planting begins in November-December. After initial ploughing, a cover crop of maize is planted during summer or oats are sown during autumn to build up organic matter in the soil or the land is fallowed until July. Poultry manure or mill mud (resi-dual material from the processing of sugarcane) is incorporated before cover crops are sown to provide additional organic matter (Whiley 1974). Root knot nematode is controlled by soil fumigation, a month before planting. In Bengal, the field is ploughed during March-April after the first rain, and altogether the field receives 12 to 13 ploughings. It is then levelled, and water channels are made to irrigate the ground. The water channels are made 60 to 80 ft apart, and connected by smaller ones running at right angles to the main channels, about 8 ft apart (Ridley 1912).

In India, the land is dug or ploughed several times with the onset of summer showers in April, to make a fine tilth. With the onset of monsoons, the field is given a last ploughing and then laid into raised beds, separated by channels. Usually, the beds are of 1 m width, 15 cm height and of convenient length varying from 3 to 6 m, the width of the channels between the beds being about 30 cm. When planted on hill slopes, the beds are formed along the contours to reduce soil erosion. In level lands, deep drains are provided at sufficient spacings to drain out excess water during rainy season (Paulose 1973). In Kerala and Tamil Nadu, the land is given about six ploughings and the soil brought to a fine tilth. Aiyadurai (1966) stated that there was no added advantage in ploughing the land more than the minimum required (3 to 5 times). Two distinct methods of cultivation are adopted in India (CSIR 1976). In the Malabar system, 3 x 1 m beds are laid out at a distance of 30-45 cm from each other and small shallow pits for planting are then made on the beds at required spacing. Beds are smaller in slopy areas. A handful of cattle manure is applied to each of these pits. In the South Kanara system, no beds are laid out. A mixture of manure and burnt earth is applied in the form of a 5 cm thick ridge in between the rows 100-200 cm apart from each other. The seed rhizomes are placed at required distance in the rows and earthed up to make the ridges 15-20 cm high. The field is given a light irrigation soon after sowing. Aiyadurai (1966) suggested that flat bed system for sandy loam soil and raised beds for clay loam soil were the most suited for successful cultivation.

Seed material

Size

Ginger is propagated vegetatively from rhizome and the length and weight of pieces used varies from place to place and variety to variety. A direct relationship has been established between size of planting material and final yield Timo (1982). Rhizome pieces weighing 0.5-2.0 ounces with two to three sprouts are recommended for increased yield and better returns (Groszmann 1954; Meenakshi 1959; Randhawa & Nandpuri 1969). Different sizes of pieces, namely, 15 g (Kannan & Nair 1965), 28-56 g (BAE 1971), 50-80 g (Whiley 1974), 20-30 g (CSIR 1976), 40-45 g (Lee, Asher & Whiley 1981), 15-20 g (Panigrahi & Patro 1985), 15-19 g (Mohanty, Naik & Panda 1990), 20-25 g (AICRPS 1992 b) were adopted. Higher yield and profit were obtained from larger seed pieces (Khan & Natesan 1955; Kannan & Nair 1965; Aiyadurai 1966; Randhawa, Nandpuri & Bajwa 1972 b; MACD 1977; Whiley 1981; Sengupta *et al.* 1986; Okwuowulu 1988 b; Korla, Rattan & Dohroo 1989; Roy & Wamanan 1989). Seed pieces with two or three constrictions along their length produced better growth than with four constrictions (Lee 1974). Whiley (1974) observed that seed size influences rhizome size at harvest and increases with larger seed pieces.

Seed rate

In general, a seed rate of 1200-1400 kg/ha (Kannan & Nair 1965; Aiyadurai 1966; Nair & Varma 1970; GAU 1986) is being used and it varies with variety and soil fertility. A seed rate of 1250 kg/ha was optimum with each seed rhizome weighing 30 g (Randhawa & Nandpuri 1970). A seed rate of 800-1100 kg/ha is adopted in Kerala (Mirchandani 1971). For plains and lower altitudes, 1500-1800 kg and at higher altitudes (> 1000 m) 2000-2500 kg are recommended (Aiyadurai 1966; CPCRI 1985; NRCS 1989 a). Kingra & Gupta (1977) used 2.3-3.5 t/ha at Himachal Pradesh. In Australia, Bendall and Daly (1966) and BAE (1971) recommend a rate of 2.5-3.7 t/ha, whereas Whiley (1974) reported that 10 t/ha appeared to be economical but farmers plant 4-6t/ha. Lee, Asher & Whiley (1981) adopted approximately 6t/ha corresponding to 1,40,000 plant population. The yield increased with seed rate (Mohanty *et al.* 1988); Jayachandran, Vijayagopal & Sethumadhavan (1980) reported that high seed rate accounted for 40-46 per cent of the total cost of production. Seed rhizomes remain undecomposed at crop maturity and can be detached during crop growth without significantly affecting yield (Okwuowulu 1988 a). A mean of 58 per cent of seed ginger from smaller setts and 86 per cent from larger setts can be recovered in fully plantable condition. In some places farmers plant whole rhizomes and unearth them when the crop reaches 30-35 cm height (Singh 1982) and recovery was 94.6 per cent at 3 months after planting (Jayachandran, Sethumadhavan & Vijayagopal 1982). By this method farmers get back 60 to 70 per cent of the seed cost. Detaching and recycling the setts in the same season or later, provides a means of achieving rapid seed ginger multiplication and for obtaining a higher aggregate yield from a given quantity of setts.

Seed treatment

The aim of seed treatment is to induce early germination and to prevent seed-borne pathogens and pests. Rhizome rot is a serious disease which is seed-borne and the seed rhizomes should be treated before planting. The beneficial effect of seed treatment against *Sclerotium rolfsii* was reported by Park (1937). Farmers in Kerala dip seed rhizomes in cowdung emulsion (Mirchandani 1971). Smoking seed rhizomes once or twice before storage is also beneficial (Muralidharan, Nair & Balakrishnan 1973). Seed rhizomes are also treated in hot water at 48°C for 20 min before planting (Colbran & Davies 1969). The cut end of the seed may provide entry for fungal pathogens and to prevent this the cut seeds are dipped in benomyl 0.25% for 10 min (Whiley 1974). Formulations such as Agallol 0.5% for 3 min or wettable Ceresan 0.1% for 30 min or Coppersan 0.3 % for 60 min can also be employed (CSIR 1976). As a prophylactic measure against soft rot disease, wettable Ceresan 0.25% (Kannan & Nair 1965), Dithane M-45 (Mohanty, Naik & Panda 1990) can be used for seed treatment. Treating the rhizomes in ethrel increased growth and develpment of ginger (Islam *et al.* 1978). Furutani, Villanueva & Tanable (1985) observed that pre-plant soak application of ethephon at 750 ppm in combination with 51°C water soak for 10 min increased shoot number of ginger cultivars. Ra *et al.* (1989) observed that low temperature (5, 0 and -5°C) treatment of seed rhizomes decreased plant weight and rhizome yield.

Spacing

Spacing may vary with soil fertility, variety, climate and management practices. Closer spacings gave higher yield (Loknath & Das 1964; Aiyadurai 1966; Randhawa, Nandpuri & Bajwa 1972 b; Nair 1982). Whiley (1974) reported that spacing has no effect on final knob size. Different spacings (15-45 x 15-45 cm) have been recommended in India (Loknath & Das 1964; Kannan & Nair 1965; Aiyadurai 1966; Paulose 1973; Muralidharan 1973 a; Muralidharan & Sakunthala 1975; CSIR 1976; Kingra & Gupta 1977; Nair 1982; CPCRI 1985; Panigrahi & Patro 1985; GAU 1986; Jha, Maurya & Pande 1986; Korla Rattan & Dohroo 1989; Mohanty, Naik & Panda 1990; Jayachandran *et al.* 1991). Spacings of 40 x 15 cm (Lee, Asher & Whiley 1981) and 60 x 11.8 cm (Whiley 1981) at Australia, 38.1 x 38.1 cm at Mauritius (Owadally, Ramtohul & Heerasing 1981) and 45 x 40 cm at Trinidad, West Indies (Wilson & Ovid, 1993) have been recommended.

Depth of planting

Planting depth may vary depending upon seed size, soil type and soil moisture content. In general, bolder seeds are planted deeper and smaller seeds at a shallow depth. Seed rhizome pieces are generally planted at 4-10 cm depth (Kannan & Nair 1965; Aiyadurai 1966; Vevai 1971; Paulose 1973; Lee, Asher & Whiley 1981; Mohanty, Naik & Panda 1990; Wilson & Ovid 1993). As depth of planting influences the time of germination, it is necessary to plant at optimum depth.

Germination and growth

Under ideal conditions ginger appears above ground 10-15 days after planting, but may be prolonged up to 2 months. Anderson (1991) identified three distinctive growth phases. Dasaradhi, Sriramamurthy & Rao (1971) identified 120-135 days after planting (DAP) as the active growth stage. Progressive increase in dry matter production of whole plant and rhizome was observed up to 240 DAP, after which there was a decline (Ravisankar & Muthusamy 1986); accumulation of drymatter in the above ground portion was noticed up to 210 DAP while in the rhizome it continued upto 240 DAP and was maintained at more or less the same level even at harvesting. Whiley (1980) observed that crop growth rate and net assimilation rate declined with age up to flowering and then increased during the later period of rhizome bulking.

Mulching

The beneficial effect of mulching was reported by several workers. Mulching enhances germination, prevents washing of soil due to heavy rain and surface run-off, increases infiltration, conserves moisture, regulates temperature, decreases evaporation, suppresses weed growth, enhances microbial activity and improves soil fertility by adding organic matter. Mulching could change the physical and chemical environment of the soil resulting in increased availability of phosphorus and potassium (Muralidharan 1973 a). The quantity of mulch applied varies with availability of material. In general, 10 to 30 t/ha is applied twice or thrice, one at planting, second at 45th day and third at 90th day after planting. Commonly used mulch materials are green and dry forest leaves, residues like sugarcane trash, paddy, wheat, finger millet, little millet and barley straws and also weeds and vegetation of the locality. Farm yard manure (FYM) and compost are also used. Coconut leaves (Aclan & Quisumbing 1976), banana leaves (Mohanty 1977), dry *sal* leaves (AICSCIP 1985), *shisam* (Jha, Maurya & Pandey 1986) and green forest leaves (Roy & Wammanan 1988) were found best. If the quantity of above materials are in short supply, live mulches like sunhemp, greengram, horsegram, blackgram, niger, common sesbania, cluster bean, french bean, soybean, cowpea, daincha (*Sesbania acculeata*) and redgram can be grown as intercrop and used for *in situ* mulching between 45-60 days after planting. Straw mulching increased yield by 12.2 per cent over unmulched (Joachim & Pieris 1934). Application of forest leaves at 20 t/ha in two equal splits, one at planting and second at 45th day after planting increased yield by 200 per cent (Kannan & Nair 1965). Application of 14 t of FYM as mulch per acre enhanced yield by 65 per cent (Aiyadurai 1966) and 12.5, 5.0 and 5.0 t/ha of mulch for the first, second and third mulching, respectively, are considered optimum (Randhawa & Nandpuri 1970). Kingra & Gupta (1977) used dry grass and forest leaves as mulch at 15 t/ha, whereas Mohanty & Sarma (1978) used 15 t/ha green leaves at planting and 7.5 t/ha each at 45 and 90 DAP. Owadally, Ramtohul & Heerasing (1981) stated that mulching with sugarcane trash and rice straw was beneficial. Performances of different live mulches were similar but superior to unmulched plots (AICRPS 1990). Korla, Rattan & Dohroo (1990) found that FYM mixed with grass, pine needles and pea straw was effective as mulch and increased the yield. Daincha can be grown in inter-rows and applied as second mulch after cutting at 60 DAP (Valsala, Amma & Devi 1990). Mulching three times with leaves and growing intercrop of soybean as live mulch, was equally effective (AICRPS 1992a). Polythene as mulch material gave 19.9 t of fresh rhizome per ha compared to 12.0 t in unmulched plots (Mohanty, Naik & Panda 1990).

Crop nutrition

Adequate amounts of nitrogen, potassium, calcium, magnesium, phosphorus, sulphur, chlorine, iron, boron, manganese, zinc, copper and molybdenum are essential for healthy growth of the crop and higher yield. The first six are needed in relatively large amounts and are referred as major elements of macronutrients. The remaining elements are needed in much smaller amounts and are known as trace elements of micronutrients (Asher & Lee 1975). The macronutrients were accumulated in the following decreasing order: N, K, Ca, Mg, S and P and the order for micronutrients were: Fe, Mn, Zn, B and Cu (Haag *et al.* 1990). Ginger rhizomes were mainly K and N exhausting, while Mg and P removals were intermediary and Ca removal was the least (Nagarajan & Pillai 1979). Hackett & Carolane (1982) stated that nutrient need for ginger is in the following order: N, K, P, Ca and Mg. Asher & Lee (1975) identified deficiency and toxicity symptoms for various nutrient elements.

Organic manures

The need for organic nutrition has been emphasised by many workers; soil organic matter has positive correlation with yield (Cho *et al.* 1987). Staple manure, bat guano, marl, sheep manure (Ridley 1912), FYM (Meenakshi 1959; Loknath & Das 1964; Kannan & Nair 1965; Muralidharan & Ramankutty 1975; Lawrence 1984; Panigraghi & Patro 1985; Pawar & Patil 1987), green leaf (Nair 1969), poultry manure (Tewson 1966; Whiley 1974; Haag *et al.* 1990), press mud (Tewson 1966; Whiley 1974), compost (Vevai 1971), oil cake (Ridley 1912; Aiyadurai 1966; Rajan & Singh 1974; Sadanandan & Iyer 1986; NRCS 1993), biofertilizer (Konde, Patil & Ruikar 1988), night soil and urine (Brown 1955) were used as sources of organics. The quantity of organics applied may vary with availability of material and generally it varies between 5-30 t/ha. Organics are mostly applied as basal doses and in certain places it is also applied after the emergence of crop as a mulch. The magnitude of response to FYM was significantly less in the presence of nitrogenous and phosphatic fertilizers, which indicates that the heavy requirement of the crop for FYM can be minimised by application of fertilizers along with leaf mulch (Thomas 1965; Aiyadurai 1966). Muralidharan, Varma & Nair (1974) observed a lack of response for fertilizer application and attributed it to the heavy basal organic dressing coupled with high initial fertility status of the soil.

Fertilizers

Fertilizer recommendation varies with variety, soil type and climate. A fertilizer dose of 36-225 : 20-115 : 48-200 N, P_2O_5, K_2O kg/ha has been adopted in different states in India (Lokanath & Das 1964; Kannan & Nair 1965; Nair & Varma 1970; Paulose 1970; Randhawa, Nandpuri & Bajwa 1972b; Muralidharan 1973a; Muralidharan & Sakunthala 1975; Kumar 1982; Nair 1982; GAU 1986; Pawar & Patil 1987; Rattan, Korla & Dohroo 1988; Singh 1988; Saha 1989; NRCS 1989a; Mohanty *et al.* 1990; Sahu & Mitra 1992; Panda, Edison & Mohanty 1993); in Australia 200 : 229 : 199 (Whiley 1981), 66:82:66 in West Indies (Wilson & Ovid 1993) and 105:241:126 in Nigeria (Okwuowulu *et al.* 1990) have been identified. For nitrogen, urea (Whiley 1974; Lee, Asher & Whiley 1981; Saha 1989), calcium ammonium nitrate (Nair& Varma 1970; Muralidharan, Varma & Nair 1974), ammonium sulphate (Nair 1969, Paulose [illegible] Lee & Asher 1981) and ammonium nitrate (Lee & Asher 1981) were used as sources. Superphosphate (Whiley 1974; Muralidharan, Varma & Nair 1974), diammonium phosphate (Saha 1989) were the sources for phosphorus and potassium sulphate (Whiley 1974) and potassium chloride (Muralidharan, Varma & Nair 1974) were the sources for potassium. Apart from these straight fertilizers, fertilizer mixtures containing NPK 8:8:16 were also used for ginger production (Kannan & Nair 1965). Pawar & Patil (1988) obtained a beneficial effect by using organic and inorganic nutrition together.

Nitrogen

Nitrogen is an extremely important element in commercial ginger production (Asher & Lee 1975). The recommendation varies from 36 kg/ha in India (Kannan & Nair 1965) to 125-830 kg/ha in Australia (Asher & Lee 1975). Whiley (1974) reported that when organic manure was used, more than 230 kg N/ha was not economical in Queensland and in the absence of organics, 275 kg N/ha should be used. Nitrogen significantly increased the number of third order shoots and fourth order rhizome branches and total yield of shoots (Lee, Asher & Whiley 1981) and tiller number (Muralidharan 1973 b). Application of 56-112 kg N/ha decreased dry matter content (Aiyadurai 1966). Increases in yield of ginger by N application were reported by Aiyadurai (1966), Muralidharan (1973b), Muralidharan, Varma & Nair (1974), Aclan & Quisumbing (1976), Sadanandan & Sasidharan (1979), Lee, Asher & Whiley (1981) and Gavande (1986). Patil (1987) observed that N application along with biofertilizers also enhanced the yield. The yield was doubled when the N level was increased from 30 to 90 kg/ha

(Aclan & Quisumbing 1976). However, application of N was also reported to be ineffective (Saraswat 1972; KAU 1994) and higher doses decreased the yield (Muralidharan 1973b). The fibre and starch contents of ginger were not affected by N (Aclan & Quisumbing 1976) but Saraswat (1972) found an adverse effect on oil content. Critical nitrogen concentration in all parts of the plant decreased linearly with time (Lee, Edwards & Asher 1981). Nitrogen requirement was higher during active growth (120-135 DAP) (Dasaradhi, Sriramamurthy & Rao 1971). Nitrogen is generally applied through the irrigation system in approximately 10 applications at Queensland. Rates and times of each dressing are related to growth rate of the crop and rainfall. However, approximately 30 per cent of the total N are applied during first 3 months, and the remaining 70 per cent are applied at 5-8 months after planting (Whiley 1974). As the number of splits increased, N recovery also increased and higher N recovery was obtained with eight splits (Lee, Edwards & Asher 1981). Koen, Plessis & Hobbs (1990) stated that N deficiency could be rectified even at 225 days after planting. Xu, Zhao & Jiang (1993) found that greatest (45.24 per cent) N utilisation was duri-ng the middle of vigorous plant growth. Nitrogen use efficiency decreased with increasing rate of N application (Lee, Asher & Whiley 1981). Lee & Asher (1981) observed that ammonium nitrate, ammonium sulphate and urea were equally effective; however, in terms of cost effectiveness, they rated in the order: urea > ammonium nitrate > ammonium sulphate.

Potassium

As with other 'root' crops, ginger is expected to remove a large amount of potassium from the soil (up to 500 kg/ha) (Asher & Lee 1975). The crop when grown on any soil type with a replaceable potassium level greater than 0.5 m e % is unlikely to respond to additional potassium (Whiley 1974). Below 0.5 m e % two levels are recognised: less than 0.3 m e % of replaceable potassium and 0.3 to 0.5 m e % of replaceable potassium. In the lower range, a positive field response was recorded with application upto 325 kg K_2O/ha, while above 0.3 m e % no responses were recorded with rates above 60 kg K_2O/ha. Aclan & Quisumbing (1976) observed slight increase in yield with application of K. However, a higher dose of K_2O reduced height of plants and yield (Muralidharan, Varma & Nair 1974); JDA (1953) and Saraswat (1972) also reported that there was no response for potassium. Split application of potassium (20 per cent given as basal dose followed by 40 per cent at 2 months after planting and remaining 40 per cent at 4 months after planting) gave greater response than a single basal dressing (Whiley 1974).

Phosphorus

The amounts of phosphatic fertilizer needed varies greatly from soil to soil. A heavy crop removes only 35 to 50 kg/ha. In soils of high phosphorus fixing capacity, high rates of P application may be necessary, particularly if the soils have not previously received large amounts of P fertilizer (Asher & Lee 1975). Phosphatic fertilization with 56-112 kg of P_2O_5/ha not only registered 14-20 per cent higher yield but also improved the dry matter content of rhizomes (Aiyadurai 1966). Phosphorus at 20 and 40 kg/ha increased the yield by 21.5 and 11.5 per cent, respectively (Saraswat 1972). However, the response for P was not clear in some cases (JDA 1953; Muralidharan 1973 b; Muralidharan, Varma & Nair 1974; Aclan & Quisumbing 1976). Phophorus is mostly applied as a basal dose at the time of planting.

Calcium

Ginger requires only a very low external calcium (Islam, Edwards & Asher 1982) for healthy growth. The upper leaves of calcium deficient plants contained 0.05 to 0.07 % calcium while corresponding leaves of healthy plants contained 1.1 to 1.3% (Asher & Lee 1975). A solution of calcium concentration as low as 2 ppm appears sufficient to achieve 90 per cent of maximum yield (Islam, Edwards & Asher 1982). Sahu & Mitra (1992) recorded encouraging response of ginger to liming and obtained 23 per cent higher yield but Joachim & Pieris (1934) observed no response for liming in slightly acidic soil. Calcium deficiency of ginger is uncommon because relatively large amounts of calcium are added to the soil through superphosphate and organic manures.

Micronutrients

Roy *et al.* (1992) reported that combined spraying of Zn (0.3%) + Fe (0.2%) + B (0.2%), twice at 45 and 75 days after planting resulted in maximum yield.

Irrigation

Water requirement of ginger has been estimated by the Queensland Irrigation and Water Supply Commission to be between 1320–1520 mm during complete crop cycle. In areas receiving less rainfall, the crop needs regular irrigation. Irrigation is given at fortnightly intervals, usually during the middle of September to middle of November in India which increased the yield by 56 per cent and also improved the quality (Aiyadurai 1966; Paulose 1973). Increased water supply increased the yield of rhizomes and essential oil content also (Lawrence 1984). Irrigation is given to ensure that the crop receives approximately 10 mm of water every second day from mid-January until early March when the most rapid growth occurs at Queensland (Whiley 1974). Further, overhead sprinkling for protection against sunburn is extremely important in late October, November and December. When sunburning weather occurs, irrigation is usually done from 10 am to 3 pm daily. This establishes a microclimate over the crop, by cooling both air and soil (Whiley 1974). When the temperature reached 26°C during October-November and 30°C during December-March at South Africa, impulse sprinkle irrigation created a favourable microclimate (Anderson *et al.* 1990) which improved plant growth and increased the yield by more than 25 per cent. Ginger crop raised in the first week of May in Orissa (India) needs two or four initial pot waterings at an interval of 7 days depending on soil type. After this the crop receives monsoon rainfall, and comes up well till end of September. Subsequently, the crop has to be given pot watering commencing from mid-October to end of December at 15 day intervals. (Panigrahi & Patro 1985). They also identified that germination stage, rhizome initiation stage (90 DAP) and rhizome development stage (135 DAP) were the critical stages. Vaidya, Sahasrabudhhe & Khuspe (1972) recomended that the first irrigation is given to ginger immediately after planting and subsequent irrigations are given at intervals of 10 days with a total water of 90-100 cm in 16-18 irrigations. A fortnightly irrigation during the drier part of monsoon months contributed significantly to increased yield and improved the quality of the produce (Gupta 1974). Scheduling of irrigation at 60 mm cumulative pan evaporation (CPE) (Gavande 1986) and IW/CPE ratio of 1.0 (KAU 1994) produced maximum rhizome yield.

Weed control

As the crop receives a high amount of external nutrition coupled with initial slow growth, conditions favour weed emergence which later compete with the crop for moisture, nutrition, space and sunlight. When mulching is practiced, weed growth is suppressed to some extent (Mishra & Mishra 1982) which increases crop emergence, growth and yield. Generally, two to three weedings are done depending upon weed growth (Mohanty, Naik & Panda 1990). The first weeding is done just before second mulching (45th day) and the second weeding during 120-135 th day (Kannan & Nair 1965; Vevai 1971). Weed flora varies from place to place; Melifonwu & Orkwor (1990) recorded some of the commonly occuring weeds in ginger fields at Nigeria. Manual weeding consists of either pulling the weeds, chipping with a hoe or cutting the roots with a knife (Purseglove *et al.* 1981). The herbicide Diuron 4.5 kg ai/ha has been used for controlling weeds in Queensland but its action may be varied depending on soil type (Whiley 1974). Diuron has a broad spectrum control and is applied as pre-emergence herbicide before the shoots emerge. Paraquat is used as a post-emergence, in the early stages of plant growth applied between rows and in later stages limited to spot spraying between beds. Pre-emergence application of 2, 4-D at 1 kg ai/ha (Mishra & Mishra 1982) or atrazine at 1.5 kg/ha (Rethinam *et al.* 1994) was also effective. Pre-emergence applications of mixtures of alachhor + Chloramben or fluometuron at 0.75 + 0.75 kg ai/ha provided effective control of some weed species and resulted in higher yields (Melifonwu & Orkwor 1990).

Earthing up

The surface soil may harden after rain or irrigation. Soil stirring and earthing up are essential as it helps in enlargement of daughter rhizomes (Vevai 1971) and provides adequate aeration for roots and protects the rhizome from scale insects apart from controlling weeds (Panigrahi & Patro 1985). The first earthing up is done at 45th day and second at 120-135th day (Kannan & Nair 1965; Vevai 1971). Earthing up may be combined with handhoeing (weeding) and mulching.

Growth regulators

An assay of endogenous hormonal levels in ginger treated with 2-chloroethyl trimethyl ammonium chloride (CCC) showed that the ginger plant has only negligible endogenous gibberellins (Ravisankar & Muthuswamy 1984). The endogenous cytokinins and auxins in rhizomes exhibit a greater influence on initiation and development of ginger rhizomes. CCC spray at 180 and 200 ppm improved levels of auxins and cytokinins in the rhizome (Ravisankar & Muthuswamy 1984). Foliar application of CCC, ethrel and kinetin during active growth had no effect on plant height, but ethrel and CCC affected tiller production (Jayachandran & Sethumadhavan 1979). Application of ethrel (ethephon) at 50-400 ppm 2 months after planting and twice at 20 days intervals recorded the highest rhizome yield (25 t/ha) over untreated control (17 t/ha) (Phogat & Singh 1987). Das & Nair (1976) recorded the highest ginger yield when the crop was sprayed with 2% urea along with 200 ppm planofix. Furutani, Villanueva & Tanable (1985) observed that pre-plant soak application of ethephon at 750 ppm in combination with a 51°C water soak for 10 min to ginger rhizomes increased shoot number by 122 per cent after 16 weeks and rhizome weight by 38 per cent at harvest. Nair & Das (1982) reported that oleoresin content was increased with urea (2%) + planofix (400) ppm spray.

Shade requirement

Ginger crop prefers light shade for good growth, but shade is not absolutely necessary (CSIR 1976). Shading is helpful in reducing water loss and general cooling of the plant (Lawrence 1984). In Queensland, overhead sprinkler irrigation protects the crop from sunburn (Whiley 1974) and evaporative cooling with sprinkler during summer increases yield in South Africa (Anderson *et al.* 1990). Ginger grown under full sunlight was shorter with fewer leaves per tiller (Aclan & Quisumbing 1976). Shade increased height and tiller number (Wilson & Ovid 1992), net assimilation rate and chlorophyll content (KAU 1992). Under low to medium shade, dry matter production, nutrient uptake (KAU 1992), yield (Aclan & Quisumbing 1976; Beena, Sridevi & Nair 1994) and quality (Ancy & Jayachandran 1993) were the highest. Heavier shade (beyong 5[illegible] per cent) decreased number of tillers, number of leaves (KAU 1992) and yield (Aclan & Quisumbing 1976). Shade-grown ginger shrinks and hence, Graham ([illegible]6) recommeded to grow ginger under full sun (open). Growing ginger completely exposed to sun resulted in higher yield (Aiyadurai 1966) and oleoresin (KAU 1992) than in shade. But Ravisankar & Muthuswamy (1987) observed that shade had no adverse effect on quality of rhizomes.

Pests and diseases

The occurence of pests and diseases in ginger and their control measures at different production centres were periodically documented by Kannan & Nair (1965), Vevai (1971), Paulose (1973), CSIR (1976), Purseglove *et al.* (1981), Lawrence (1984) and Pruthi (1993). Insect pests were documented by Nair (1982), Jacob (1986), Mathew (1988), Koya, Devasahayam & Premkumar (1991) and Devasahayam & Koya (1993). Diseases were documented by Pegg, Moffett & Colbran (1969), Sarma & Nambiar (1974), Sarma, Indrasenan & Iyer (1978), Joshi & Sharma (1982), Dohroo & Edison (1989), Korla & Dohroo (1991) and Rao (1993) and nematodes by Koshy & Bridge (1990) and Ramana & Eapen (1995).

Harvesting and quality

Fibre and volatile oil contents and pungency levels are the most important criteria in assessing the suitability of ginger rhizomes for processing (Purseglove *et al.* 1981). The relative abundance of these three components are governed by stage of maturity at harvest (Natarajan *et. al.* 1972). Oleoresin and oil contents rose sharply up to $5^1/_2$ to 6 months beyond which there was a decline and fibre development was extemely rapid between 6 and 7 months of growth (Winterton & Richardson 1965). Crude fibre content increased beyond 260 DAP (Aiyadurai 1966). Although there is fibre in the rhizome from the time it begins to develop, the amount is nonsignificant in the initial stages. As the physiological age of rhizome increases, so does the diameter and strength of fibre. Fibrous ginger is unacceptable for processed confectionary because of its reduced palatability. Harvesting of confectionary grade ginger begins when 40 to 50 per cent by weight of the rhizome is free of commercial fibre, and continues down to 35 per cent level (Whiley 1980). Increase in crude fibre and decrease in fat and protein content of rhizome were noticed after $6\frac{1}{2}$ months (Jogi *et al.* 1972). Oleoresin and oil content for different cultivars reached its maximum 265 days after planting (Nybe, Nair & Mohanakumaran 1982). Ratnambal, Gopalan & Nair (1987) observed that dry recovery, starch and crude fibre were positively correlated with maturity whereas essential oil, oleoresin and protein were negatively correlated with maturity.

The time of harvest depends on the product for which the rhizomes are to be used, price trend in the market and climatic conditions. If the rhizomes are used for vegetable purposes or for preparation of ginger preserve, candy, soft drinks, pickles and alcoholic beverages, harvesting should be done 4-5 months after planting. If it is used for dried ginger and preparation of value added products like ginger oil, oleoresin, dehydrated and bleached ginger, harvesting is to be done between 8-10 months. Early harvest (200-215 days after planting) gave higher yield than late harvest (230-245 days after planting) in India (Aiyadurai 1966). In Australia, early harvest yielded 50 t/ha and late harvest 90-100 t/ha (Lee, Asher & Whiley 1981). But, Nair & Varma (1970) and Pawar & Patil (1987) observed no significant differences in yield when ginger was harvested 215 to 275 days after planting. Harvesting of ginger is done by using a spade, hoe or digging fork and also by mechanical diggers at Queensland. Care is required during harvesting to minimise damage to rhizomes. The soil, roots and tops are then removed and the rhizomes are washed. Export of ginger from India is mainly in the form of dry ginger. Chemical composition of dry ginger may vary due to varietal, soil and climatic differences. Dry ginger consist of volatile oil (1.25-2.80%), crude fibre (14-80%), cold alcohol extract (1.12 - 4.00%), total ash (6-9%), acid insoluble ash (0.30-1.23%), crude protein (8-11 %), starch (40-50 %), water extracts (10-20%), acetone extract (3-8%) and moisture (10-12%) (Natarajan & Lewis 1982). Dry ginger is used for manufacture of value - added products such as ginger oil, oleoresin, ginger essence, ginger powder, crystallised ginger and candied ginger. Irrigation (Lawrence 1984) and shade (KAU 1992) improved the quality of ginger. However, not much work has been done on the effect of agronomic practices on value - added ginger products.

Storage of seed rhizomes

The duration between first harvest and next planting is 120-150 days at Kerala, India. As ginger is vegetatively propagated, the rhizomes should be stored safely during the off-season; but it is a highly perishable commodity and is susceptible to soil-borne fungi and insects. The seed rhizomes should be stored appropriately so that rotting, shrivelling, dehydration and sprouting can be avoided until the next season. Different methods are being adopted by farmers for storage of seed ginger

(Kannan & Nair 1965; Paulose 1973; Muralidharan, Varma & Nair 1973; Lawrence 1984; Pruthi 1993). Storage losses can often be as high as 10-15 per cent. Recovery of seed rhizomes at planting was as high as 96 per cent by selecting fully matured rhizomes for storage, dipping in a solution of quinalphos 0.05% and Dithane M-45 0.3% for 30 min and drying under shade and storing in pits (wherever bacterial wilt is a problem, the seeds should be treated with streptocycline 200 ppm) (NRCS 1989 b). Timo & Oduro (1977) reported that the time taken for germination decreased with length of storage while percentage germination and yield of fresh rhizomes increased. Germination and yield were consistently lower after 35 days than after 21 days of storage. This anomalous behaviour was due to secondary dormancy during which seed pieces lost their dormancy up to 21 days of storage but regained or entered into secondary dormancy at 35 days and again lost dormancy at 42 days.

Cropping system

Ginger can be grown as a sole crop under open or shade apart from as a component in inter, mixed and undercropping systems. Ginger is intercropped with vegetables (cabbage, tomato, chillies, french bean and lady's finger), pulses (pigeon pea, black gram and horse gram), cereals (maize, finger millet), oilseeds (castor, soybean, sunflower and niger) and other crops (sesbania, tobacco and pineapple). Intercropping with soybean (Quimbo, Cadiz & Aycardo 1977; AICRPS 1992 a), lady's finger (Chowdhury 1988) and pineapple (Lee 1972) was advantageous. Ginger can also be grown as mixed crop with castor, redgram, fingermillet and maize. As ginger requires partial shade it can be grown as an undercrop in coconut, arecanut, rubber, orange, stone fruit, *litchi*, guava, mango, papaya, loquat, peach, coffee and poplar plantations. Singh, Rai & Pradham (1991) stated that ginger was the most favoured crop component under agroforestry. However, crop rotation is essential, as ginger depletes more nutrients in the soil coupled with rhizome rot problem under monoculture contuniously. The crop is rotated with tapioca, chillies, seasame, little millet and dry paddy in rainfed conditions, and with finger millet, groundnut, maize and vegetables under irrigated conditions. Crop rotation using tomato, potato, chillies, egg plant and peanut should be avoided as these plants are hosts of the wilt causing organism (*Pseudomonas solanacearum*). Pegg, Moffett & Colbran (1969) recommended beans, cucurbits and strawberries as suitable crops for rotation and as cover crop which would reduce the carry over of inoculum. Ridley (1912) stated that a farmer at Jamaica grew ginger repeatedly on the same land without yield reduction. However, Korla & Dohroo (1991) observed that no systematic studies have been made in developing efficient cropping systems involving ginger.

Ratooning

Ratooning is not common in ginger and is not preferred for marketing as it contains more fibre. Extracts from ratoon ginger had a more fiery taste and less flavour than those from planted ginger (Purseglove *et al.* 1981). However, Ridley (1912) mentioned that a few farmers at Jamaica practiced ratooning.

Economics of ginger production

Economics of ginger production varies

from place to place and depends on cost of inputs, price trend in the market etc. Data pertaining to ginger cultivation as an intercrop in coconut based homestead farms of Kerala in 1989-90 showed that it gave a net return of Rs. 7500/ha (Regeena & Kandaswamy 1992) whereas, in Orissa as per 1991-92 data the net profit was Rs. 90,000/ha (Mohanty, Panda & Edison 1994).

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