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Review on agronomic investigations on cardamom and cardamom-based cropping systems in Karnataka

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Abstract

Small cardamom (*Elettaria cardamomum* Maton), an eco-friendly high value spice and foreign exchange earner, is a native of Western Ghats of South India. India enjoyed near monopoly in its production till the seventies, but with the emergence of Guatemala as the main competitor, it has been relegated to second position both in production and export. The low production of cardamom up to eighties was due to lack of sound location specific agronomic package of recommendations. Hence, after a detailed survey of entire small cardamom growing areas in India and interaction with cardamom growers and other stake holders, a comprehensive location specific research programme was finalised and carried out for over 25 years. As a consequence of detailed agronomic investigations on cardamom and cardamom-based cropping systems, various agro techniques such as selection of elite lines of cardamom, rapid clonal multiplication technique, nursery techniques, systems and season of planting, irrigation, shade and weed management, apiculture, harvest and post harvest techniques, multistoried cropping system involving cardamom, coffee, arecanut, coconut etc. evolved. These high production technologies were effectively transferred to the cardamom growers based on local specificity which resulted in higher yields (average of 750 kg dry capsules ha^{-1} and a potential yield of 1945 kg dry capsules in demonstrations in farmers fields in Kodagu, Karnataka) from an initial benchmark average yield of 120-140 kg dry capsules ha^{-1}.

Keywords: small cardamom, agro techniques, cardamom cropping systems, high production technology

Introduction

Indian spices have carved out a niche of their own in the spice's world, over the years. There are 109 spices listed by International Standards Organisation (ISO) while the Spices Board, Government of India has listed 52 major spices of commercial importance. India produced 10.7 million tonnes of spices from an area of 45.28 lakh ha during 2020-21. About 80% of this

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production was for domestic consumption and only 15-20% was exported to over 150 countries (https://pib.gov.in>press release detail). The USA, Europe, Australia, Japan, the Middle East and Oceanic countries are the major importers of Indian spices. India is the largest producer, consumer and exporter of spices.

The small cardamom popularly known as the 'Queen of Spices' is native of Western Ghats of South India. It is an expensive spice in the world next only to vanilla. The low national average yield of cardamom especially during early 1970's prompted the cardamom research workers to look in to the reasons for low productivity and ways to ehance it. Till late 1970's, India had occupied an unique position both in production and supply of cardamom in international market, thus enjoying a near monopoly in the world trade. With the emergence of Guatemala as a main competitor in the international market from 80's onwards, India has been pushed to the second position both in production and export of this precious spice. As the international market becomes increasingly competitive, it is imperative to increase the productivity and bring down the cost of production to regain the premier position in global market. During 2015-16, India produced 23,890 tonnes of cardamom (from an area of 70,080 ha) with a productivity of 341 kg ha^{-1} but subsequently during the year 2019-20, the total production of cardamom was reduced to 11,230 metric tonnes with a productivity of 160 kg ha^{-1} from an area of 70,000 ha (Spices Board 2020-21).

Based on the initial survey and interaction with the cardamom growers and also research review during 1976-77, the research gaps were identified by the cardamom researchers and accordingly, various research programmes were conceptualized and were carried out at ICAR-Indian Institute of Spices Research, Cardamom Research Centre, Appangala, Madikeri, Kodagu, Karnataka on cardamom and cardamom-based cropping systems over a period of two and a half decades (1976 to 2002) to work out the location specific agro technologies for improving the overall productivity. Some of the field trials on cardamom-based cropping systems with arecanut and coconut were taken up in and around Sirsi, Uttar Kannada district, Karnataka. The coffee-based cardamom and pepper cropping systems research was conducted in Kodagu district of Karnataka.

Detailed investigations for evolving various agro-techniques *viz*., planting material production, soil fertility management, geometry of planting and plant population density, multi storied cropping of cardamom with high value perennial plantation crops like coffee (Robusta and Arabica), arecanut and coconut, citrus (Coorg mandarin) and other important spices like black pepper (Korikanthimath 2000a; Korikanthimath 2001a; Korikanthimath 2001b; Korikanthimath *et al*. 2005; Sudharshan & Korikanthimath 2005) and high production technology (HPT) package was under taken. These technologies helped the farmers in increasing production and productivity of cardamom to meet domestic demand and to produce surplus for the international market to earn precious foreign exchange for India.

Promising technologies

Though cardamom can be propagated both vegetatively (clonal and micro propagation) and through seeds, large scale propagation at the begining was carried out mainly through seeds. Since production of heterogeneous progeny is an inherent problem, an attempt was made on selection of elite clones and their evaluation both in clonal nursery and main field. A simple and reliable rapid clonal multiplication technique was developed. In order to select high yielding varieties of cardamom for clonal multiplication, systematic attempt was made at ICAR-Indian Institute of Spices Research, Cardamom Research Centre, Appangala, since 1974 (Korikanthimath *et al*. 2000i, Korikanthimath *et al*. 2000j, Prasath *et al*. 2001).

Identification of elite clones

During 1974, open pollinated (OP) seedlings of clone-37 (Cl. 37) were used for the trial on maximisation of cardamom production under rainfed condition at the Cardamom Research Centre, Appangala and 14 high yielding plants were selected and seedling raised in nursery from these plants. Nine hundred plants from this nursery were planted in a compact block which were also used for trial on maximisation of yield under irrigated condition in 1980. From these 900 progenies, 54 plants were selected based on yield attributes (3.743 kg plant^{-1} compared to 0.940 kg plant^{-1} of original OP population). Subsequently, based on capsule size, shape and yield, a total of 40 plants were shortlisted for clonal nursery. With the production of sufficient planting units, a comparative yield trial in a CRD was laid out using materials of above 40 selections during 1986, at a spacing of 2x1 m (5000 plants ha^{-1}) and provided with protective irrigation and recommended package of practices for cultural, nutritional, pest and disease management.

Among these 40 lines, the line Cl. 872 recorded the highest yield (409 kg dry ha^{-1} which was an increase of 63% over control (Malabar cultivar). It recorded the highest yield in multilocation trials and also in farmers' fields in four test locations across Madikeri district (71% increase over Malabar cultivar). The dry yield (mean of three crop seasons) in different locations varied from 372 to 1125 kg ha^{-1} (Korikanthimath *et al*. 1989b; Korikanthimath *et al*. 1989c). During the Group Meeting of the All India Coordinated Research Project on Spices (AICRPS) held at Trivandrum in July, 1991 this line was recommended for release as CCS-1 (Coorg Cardamom Selection 1). Later, this variety was released by the Central Variety Release Committee for cardamom growing areas in Karnataka and areas with similar agro ecological conditions like adjacent cardamom growing areas in Wayanad and Palakkad districts in Kerala (Korikanthimath 2002). CCS-1 is a Malabar type with prostrate panicles and oval bold capsules. It has 18 seeds per capsule, 8.7% essential oil and 37.1% α-terpinyl acetate & 42% 1,8 cineole in essential oil.

Selection of elite lines and evaluation in clonal nursery

The clones which yielded more than 1.5 kg dry capsules per plant (1982-1987) at M/s Chettoli Estate, Chettali, Kodagu, Karnataka were initially identified from an area of 1.5 ha and 12 clones (Sel.1 to 12) and a local check were selected and used for further studies. During the third year after planting, Sel. 9 recorded maximum dry capsule yield (2,038 kg ha^{-1}) followed by Sel. 7 (1,818.3 kg ha^{-1}), Sel. 4 (1,730.0 kg ha^{-1}), Sel. 8 (1,668.0 kg ha^{-1}) and Sel. 2 (1626.5 kg ha^{-1}) and were significantly superior to local check (607.8 kg ha^{-1}) (Korikanthimath *et al*. 1997f). Age of the cardamom plant was critical in assessing the genotype for growth parameters (Korikanthimath *et al*. 1997e). Leaf area of index leaf, number of tillers 12 months after planting and number of panicles 13 and 14 months after planting were identified as efficient early selection technique in cardamom (Korikanthimath *et al*. 1997i).

Sel. 9 had maximum number of capsules (2244.80) per plant followed by Sel. 7 (2200.3) and Sel 5 (1983.8). The lowest was recorded in local check (847.8). Dry weight of capsules was maximum in Sel. 9 (234.3 g plant^{-1}) followed by Sel 7 (227.7 g plant^{-1}), Sel. 4 (217.8 g plant^{-1}) and the lowest in local check (33.0 g plant^{-1}). Essential oil yield was the highest in Sel. 7 (190 kg ha^{-1}), followed by Sel. 5 (189 kg ha^{-1}), Sel. 6 (174 kg ha^{-1}) and Sel.10 (160 kg ha^{-1}), and was the lowest in the local check (54 kg ha^{-1}) (Korikanthimath *et al*. 1997g). Sel.7 (7.3%), Sel. 1 (7.0%), Sel. 6 (6.8%) and Sel. 9 (7.7%) were significantly superior to local check (6.5%) for essential oil content of dry capsules. α - terpinyl acetate and 1,8-cineole significantly varied among the clones. High yielding clones generally had higher oil (>7%) (Korikanthimath *et al*. 1999g). Maximum harvest index was observed in Sel. 9 (0.091) followed by Sel. 4 (0.062), Sel.12 (0.059), Sel. 7 (0.050) and the lowest in local check (0.006). Partitioning efficiency and harvest index clearly indicated superior yielding ability of Sel. 9, Sel. 7, Sel. 4 and Sel. 12 (Korikanthimath & Ravindra Mulge 1998a).

Evaluation in plantations

Yield and yield parameters of these selections recorded in two successive seasons (1992-93 and 1993-94) in cardamom grower's plantation at M/s Chettoli Estate, Chettalli, Kodagu district, Karnataka indicated the superiority of these selections over local check. All the clones except Sel. 8 were significantly superior to local check for dry capsule yield. Sel. 9 had the maximum dry capsule yield (2564 kg ha^{-1}) followed by Sel. 7 (2528 kg ha^{-1}), Sel. 5 (2239 kg ha^{-1}), Sel. 2 (2100 kg ha^{-1}) and Sel.10 (2099 kg ha^{-1}). Local check recorded the lowest capsule yield (847 kg ha^{-1}). Sel. 7 was found to be early type giving 18.3% of its total yield in first three pickings while Sel. 9 was the highest total capsule yielder. For total dry capsule yield, Sel. 9, Sel. 7 and Sel. 5 were found superior (Korikanthimath *et al*. 2002c). All the 12 high yielding clones had shorter panicle length compared to local check. Total number of capsules per panicle was maximum in Sel. 9 (75) followed by Sel. 7 (70), Sel. 4 (64) and Sel. 3 (62) and was minimum (34) in local check. Fresh weight of capsules per panicle was maximum in Sel. 9 (110 g) followed by Sel. 7 (107 g). Dry capsule yield per plant was significantly correlated with total number of capsules per panicle and fresh weight of capsules per panicle (Korikanthimath & Ravindra Mulge 2005). Dry capsule yield ha^{-1} was positively correlated with number of capsules per plant in early harvest (r=0.690) and fresh weight of capsules per plant in early harvest (r=0.860) suggesting that high yielding clones can be identified at early stage of bearing by assessing them for number of capsules and fresh weight of capsules in the early harvests (Korikanthimath *et al*. 1999h).

Selection of elite Cl 37 seedling progenies in farmer's field

The investigation carried out to select the high yielding clones of cardamom from the seedling population (5000) of popular Cl 37 in a farmer's field in an area of 2 ha in a plantation at Chettalli, Madikeri resulted in selection of 275 plants where the fresh yield ranged from 325 to 7,555 g $clump^{-1}$ and the 'high' yielding group comprised of 49 plants with a mean fresh yield of 6,537 g $clump^{-1}$. Among the 275 entries, 81 were classified as early types with Bartlet Index ranging from 0.6000 to 0.6999. The study indicated that the farmers can select high yielding cardamom plants from their own plantations and use them for clonal propagation to generate superior planting material for further expansion of area (Korikanthimath *et al*. 1999d).

Selection of multiple branching panicle types in farmer's field

Considerable variation exists in cardamom with reference to morphological traits. Some of the pronounced variants have characteristics such as compound panicles of various types and terminal panicles. Forty nine multiple branching plants were identified in 10 ha at farmer's plantation near Madikeri and were classified as basal branching, terminal branching and uniform branching types. Among the 49 entries, 17 entries showed very less number of branches (22.64) per panicle. Twelve entries recorded 26.25 branches and three entries recorded more than 29 branches per panicle. The number of panicles per plant ranged from 12-148 and number of branches ranged from 17-31 per panicle. The study indicated large variation among the 49 multi branch types segregated from Cl-37 seedlings. The superior multi branch types were further multiplied for large scale evaluation (Korikanthimath *et al*. 1998s).

Rapid clonal multiplication technique for generating elite planting material

Rapid clonal multiplication technique of elite cardamom clones consisted of selection of elite clones, multiplication in trench system (60 cm width and 45 cm depth) of planting with high density (1.80 m x 0.6 m), monitoring of mother clumps in plantation, and adoption of precision farming practices. This technique resulted in the production of 1:20 planting units within a span of 10 months (as against 1:9 under conventional propagation) with a cost of just Rs. 1.11 per planting unit. This technique of clonal multiplication has worked out to be much cheaper compared to cost (price) of tissue cultured plantlets (Rs 12 plant^{-1}) and even the open pollinated seedlings (Rs 2.50 seedling^{-1}). This technique is simple, reliable and economically feasible for production of quality planting material and can be easily adopted by farmers in their own plantations (Korikanthimath 1997).

Within a short span of 20 months in the high-density planting (1.80 x 0.6 m) in clonal nursery in farmer's field, 183.14 g dry capsule per plant was obtained besides generating 32 planting units per mother rhizome. During the two-year period, the planting material and yield obtained were of the order of 14,816 and 90.29 kg at an average cost of cultivation of Rs. 7,527 (two years average). The gross and net returns realized from the rapid clonal multiplication both for yield and planting material generation were Rs. 57,807 and Rs. 42,752 from an area of 0.05 ha. (BCR of 3.50 and NPW of Rs. 29,644 also signified the economic sustainability of rapid clonal multiplication both for generating planting material and dry cardamom yield (Korikanthimath 1999).

Propagation of cardamom by seeds

Studies indicated that storage of seeds for a long time resulted in loss of viability and delay in germination. Germination was found to be the highest in case of fresh seeds (59 and 50.6 % in *Mysore* and *Malabar* types, respectively) (Korikanthimath, 1986). Cardamom seeds are covered with hard seed coat, which delays germination. Treating the seeds with nitric acid (20%) resulted in more than 50% germination (Korikanthimath & Ravindra Mulge 1998b).

When the cardamom seeds were sown at monthly intervals from September to January, maximum germination was obtained in September sown seeds (79.8%) and the least in January sown seeds (0.8%) (Pattanshetti and Prasad 1973). The beds covered with paddy straw recorded the highest germination (40 %) which was on par with dry leaves of rose wood mulch (37%), goose berry leaves (37%) and wild fern (38%). Optimum spacing in secondary nursery was found to be 22.5 cm x 22.5 cm (Korikanthimath *et al*. 2001a). Application of 45 g N, 30 g P and 60 g K per bed of 2.5 x 1 m size in three equal splits at an interval of 45 days resulted in better growth and higher number of tillers. First dose should be applied 60 days after transplanting in secondary nursery (Korikanthimath *et al*. 2001b). Polythene bags of 20 x 20 cm size and thickness of 200-300 gauges with six-eight holes filled with nursery mixture in the ratio of 3:1:1 of forest top soil, farm yard manure and sand can be used for raising cardamom seedlings.

Soil fertility evaluation

Adequate nutrition management is of utmost importance for realizing higher yields and returns (Korikanthimath 1994; Korikanthimath *et al*. 2001e). Analysis of 36 surface soil (0-15 cm depth) samples from plantation belt of cardamom in Kodagu district revealed that the soils were acidic in reaction with pH ranging from 4.2 to 6.9 with a mean of 6.11. Correction of soil acidity through liming enhanced the availability of essential nutrients such as P, K, Ca, Mg and S and improved the efficiency of the applied fertilizers leading to significant increase in yields (Murugan *et al.* 2022). Organic carbon status was high and ranged between 0.79 to 3.3 per cent. The organic carbon content of cardamom growing soils showed significant positive correlation with the available nitrogen (r = 0.382**) (Korikanthimath *et al*. 2000b). The available phosphorus ranged from undetectable level to 35.0 kg ha^{-1} and about 75 per cent of the total soil samples were observed to be deficient with respect to phosphorus. The available potassium in soils varied from 84 to 966 kg ha^{-1} with a mean value of 331.8 kg ha^{-1} and 83.7% of total samples were sufficient in available potassium status. The available micronutrients *viz.*, Fe, Zn, Cu and Mn were sufficient in all the soil samples studied. However, the available Zn was sufficient in 80.6 per cent and marginal in 19.4 per cent of the soils and it ranged from 0.68 to 2.35 ppm with a mean value of 1.59 ppm. Increased solubility in acidic environment led to adequate levels of micronutrients in soils (Korikanthimath *et al*. 2002a). Analysis of surface soil samples from ICAR-IISR, Appangala revealed that the available nitrogen and potassium were medium to high and phosphorus was deficient. The available nitrogen, phosphorus and potassium ranged from 317.7 to 933.1 kg ha^{-1}, 1.4 to 196.0 kg ha^{-1} and 100.0 to 523.9 kg ha^{-1}, respectively. The availability of iron (92.5%), copper (97.5%) and manganese (97.5%) was sufficient while that of Zn was low (37.5%) to medium (45.0%) (Shivprasad *et al*. 2001).

Selection of index leaf for nutrient diagnosis

Studies revealed that 5th and 6th or 2nd and 3rd leaves from the top could be used for nutrient diagnosis for nitrogen as the linearity was observed between 5th (5.40%) and 6th (5.34%) leaf positions and also between 2nd (6.07%) and 3rd (6.42%). The stable curve position was obtained between 2nd and 3rd leaf position for phosphorus. For potassium, the linearity was found between 2nd, 3rd and 4th leaf position. The results suggested that for analysis of N, P and K in cardamom plant, the 2nd and 3rd leaf position from the top can be used as an index leaf and also for calcium as it had a lowest CV of 5.66% for 2nd leaf position (Korikanthimath *et al*. 2003a).

Nutrient uptake pattern

The nitrogen concentration was more in young (2.45%) and green leaves (2.62%) when compared to other parts. The higher nitrogen uptake (0.76 g) was accounted by green leaves and constituted 44.69 per cent of total uptake. This was followed by grown up tillers (36.38%), rhizomes (9.37%), roots (7.03%), young (immature) tillers (1.99%) and dried leaves (0.53%). Tillers (29.6%) followed by green leaves (28.93%) and dried leaves (19.86%) together accounted about 80.0% of the total nitrogen uptake. The major part of phosphorus uptake was noticed in roots (0.17 g) and green leaves (0.76 g). However, higher concentration of P was found in rhizomes (0.35%) and seeds (0.26%) in one year old and pre potent seedlings respectively. In pre potent plants, tillers accounted 45.16% of total K uptake followed by green leaves (30.88%), rhizomes (10.24%), roots (8.17%), dried leaves (2.14%), panicles (1.48%), seeds (1.45%) and the lowest in husk (0.48%). The broad uptake ratio worked out for pre potent plants was 9:1:17 N:P:K, respectively suggesting that cardamom plant requires more of potassium and phosphorus requirement is very less (Korikanthimath 1993a, Sadanandan *et al.*1993, Korikanthimath *et al*. 2000c). Soils with high cardamom yields in Karnataka (Kulkarni *et al*. 1971) and Kerala (Vadiraj *et al*. 1998) have high fertility ratings for potassium.

Plant population density and fertilizer levels

Studies on seedling derived plants of PV variety (Malabar prostrate type) showed that for obtaining a satisfactory yield (540 kg average per ha), plants should be supplied with 150:75:300 kg N:P:K ha^{-1} $year^{-1}$ with a spacing of 2x1 m (5000 plants per hectare) (Korikanthimath *et al*. 1998k). Highest doses of nutrient combination with lowest planting density recorded the highest number of tillers. Number of tillers per clump at 22 months after planting (MAP) and 45 MAP and number of green leaves per clump at 45 MAP significantly improved with increased nutrient levels. Plant height increased, number of tillers and green leaves reduced with increased plant density. Thus, for obtaining optimum tillers and yield in cardamom, application of 150:75:300 kg N:P:K per ha with a planting at a density of 5000 plants (2 m x 1 m) seemed to be ideal (Korikanthimath *et al*. 1998o; Korikanthimath *et al*. 1998p). Increasing doses of fertilizer tended to decrease the intensity and incidence of vesicular arbuscular mycorrhiza (VAM) in cardamom rhizosphere (Rohini Iyer *et al*. 1986). Light transmission ratio improved significantly (44 to 54%) in taller canopies (Korikanthimath *et al*. 1999e).

Response to fertilizer doses under controlled shade

Cardamom clones (Clone P1, Mudigere) grown under controlled shade require 100:25:100 kg NPK ha^{-1} to realize optimum yield (Korikanthimath *et al*. 1998n). However, the increase beyond 50:25:100 kg NPK ha^{-1} had no significant effect on panicle emergence. The highest level of nutrient combination (100:50:200 kg NPK ha^{-1}) resulted in better growth performance of cardamom (Korikanthimath *et al*. 1998l). Except in panicles, in all other parts like roots, rhizome, pseudo stem, leaves, the dry matter accumulation increased with increased nutritional levels. Thus, there was congenial condition for efficient photosynthesis with the supply of adequate nutrients (Korikanthimath *et al*. 1998m). Seed percentage increased and husk percentage decreased with increased nutrients supply. None of the chemical quality parameters studied were influenced by varying levels of NPK. However, 1-8 cineole and α-terpinyle acetate contents showed decreasing trend with increased level of phosphorus and increasing trend with increased level of potassium suggesting that the chemical quality attributes are determined mainly by genetic factors (Korikanthimath *et al*. 1999f).

System of planting-cum-fertilizer levels in cardamom under rainfed condition

The field experiment comprising two systems of planting *viz*., pit and trench (60 cm width and 45 cm depth) and five levels of fertilizer (0:0:0, 40:40:80, 80:80:160, 120:120:240, 160:160:320 kg NPK ha^{-1}) using Cl.37 seedlings with the plant population of 5000 plants ha^{-1} revealed that application of 160:160:320 kg NPK ha^{-1} resulted in the production of the highest number of tillers per plant (24.4) which was recorded at the time of panicle initiation. The control (no fertilizer) had the lowest number of tillers per plant (10.2). A positive correlation between yield and number of bearing tillers per plant (0.97**), number of green leaves per plant (0.92**) and number of panicles (0.95**) was observed (Korikanthimath 1989 a). The trench system of planting recorded higher yield (294.4 kg ha^{-1}) when compared to the pit system (256.7 kg ha^{-1}). The control had the lowest yield (110.1 kg ha^{-1}). During summer (March) the trench system recorded the highest soil moisture percentage (18.5) followed by the pit system (14.0). The trench system was more effective in conserving soil moisture and supplementing it to the plants even during dry spell which is crucial for better crop stand and early initiation of panicles. Regarding fertilizer levels, application of 120:120:240 kg and 160:160:320 kg NPK ha^{-1} resulted in yields of 347.3 and 374.5 kg (dry) ha^{-1}, respectively, which were on par. Hence under rainfed condition, planting of cardamom (Cl.37) with 5000 plants ha^{-1} in trench system with a fertilizer dose of 120:120:240 kg NPK ha^{-1} is recommended (Korikanthimath, 1989 a).

Impact of rainfall

Frequency and probability of dry spell at Madikeri was analysed by Ratnam and Korikanthimath (1985) which greatly influences cardamom production under rainfed conditions. Studies on analysis of rainfall and its impact clearly indicated that pre – monsoon showers have great impact on physiological process of cardamom such as initiation of panicles, flowering and setting of capsules. As cardamom growing region suffers from acute soil moisture shortage during summer months, it is essential to conserve the available soil moisture by following appropriate strategies like shade management, trench system of planting, shelter belts, earthing up, mulching and soil conservation practices etc. (Korikanthimath, 1987). Yield is influenced more by the distribution of monthly rainfall and number of rainy days than total rainfall. Data collected from various cardamom estates have shown that in 10 out of 13 estates, the highest yield was recorded when the annual rainfall was around 2000 mm which was well distributed. Another survey data from 57 locations of the Coorg district in Karnataka has shown that in 42 locations more than 100 kg ha^{-1} dry capsule yield was obtained when the annual rainfall (evenly distributed) was less than 2000 mm indicating rather than total annual rainfall, an annual rainfall of 2000 mm evenly distributed may be optimum for cardamom cultivation (Korikanthimath 1989, Subbarao & Korikanthimath 1983).

Management of shade and weeds

Studies carried out to evaluate the performance of different shade trees for optimum growth and yield of cardamom showed that the crop growth under Karimaram (*Diospyros ebenum*) produced significantly higher number and longer panicles than Elengi (*Mimusops elengi*), Nandi (*Lagerstroemia lanceolata*) and Jack (*Artocarpus integrifolia*). Cardamom grown under *Diospyros ebenum* recorded 40-50% more yield (121g dry capsules plant^{-1}) than under other shade trees (George *et al*. 1984). Besides several species of indigenous fast growing shade trees, a few exotic /introduced shade tree species such as *Maesopsis eminii* were also evaluated for proper establishment, growth and yield of cardamom (Korikanthimath 1983). The study by Murugan *et al.* (2022) has revealed the possible link between the intensive growing practices that were positively reflected in its local climate and production system in cardamom and suggests that 75% shade level under the cardamom canopy influences the cardamom microclimatic conditions. A survey carried out during 1980-81 in the cardamom estates of Coorg, Karnataka with special reference to the dicotyledonous weeds to plan for efficient weed control measures revealed 23 dicotyledonous weed sp. Spraying paraquat (1 kg a.i. ha^{-1}) in the inter-spaces twice (pre and post monsoon) in a year was effective in controlling weeds (Korikanthimath & Venugopal 1986; 1987).

Irrigation

As cardamom is mainly cultivated on the undulating topography of hills and hill slopes, sprinkler irrigation is most suited. Wherever feasible fertigation is advised for effective utilization of water and nutrients. Rain water harvesting in suitable structures such as check dams, farm ponds etc. to recycle the stored water during critical stages of cardamom growth during summer months is very crucial (Korikanthimath, 1993b, Korikanthimath and Rajendra Hegde 1998). Studies indicated that planting of cardamom in June-July in well drained areas is most suitable for better establishment and growth than late planting (Korikanthimath & Venugopal 1989).

Apiculture

The Indian honey bee (*Apis cerana indica*) was identified as the principal pollinator of cardamom flowers. The behaviour of bees showed that the pollination mechanism in cardamom was essentially through cross pollination between flowers of the same clump or geitonogamy. An increase of 43% in fruit set could be obtained in bee pollinated flowers over flowers which were prevented from bee visits. A limited pollination occurs through ants and rain water. An increase of 13% fruit setting could be obtained in plots where bee hives were provided. It is advocated to maintain bee hives in cardamom estates to improve the pollination, fruit set and also to get additional income (Korikanthimath & Venugopal 1989).

Harvest and post harvest measures

Pre harvesting, post harvesting care and clean processing with appropriate grading etc. are essential in reliazing better returns (Korikanthimath 1993c; John Zachrariah & Korikanthimath 2000; Korikanthimath 2001a). Women labourers are very efficient in harvest and post harvest operations of cardamom (Korikanthimath *et al*. 2000e). Random market sample survey revealed the presence of immature capsule to the extent of 41.50% of dry cardamom. Recovery percentage of cardamom cured in a commercial drier varied from 11 to 30 with majority of the samples recording less than 18%. The mean percentage of recovery at ripened (fruit) stage was 29 and at physiologically matured stage was 24 as against 14 at immature stage in Malabar type indcating the need to resort to correct stage of picking the capsule at physiologically matured to ripened (fruit) stage for better recovery (Korikanthimath & Naidu 1986). Grading of the dried cardamom is advantageous as there is scope to get better returns. Grade I (7 mm and above sized cardamom) fetched higher price in the market and about 1.75 times more return inflow could be expected from the graded lot than from the un-graded lot of cardamom for the same level of average yield (Korikanthimath *et al*., 2001d).

Mixed (multistoried) cropping systems

Cardamom, being an ecofriendly spice crop, can be conveniently cultivated along with other high value plantation crops *viz*., coffee, arecanut and coconut in the higher elevations wherein all these crops require more or less the same agro-ecological conditions. Hence, by resorting to multistoried cropping system, it is possible to effectively utilize both horizontal and vertical space and the solar energy to get maximum returns per unit time. Multistoried cropping refers to a combination of crops having varying morphological frame and rooting habits; grown together in such a manner that their canopies intercept solar energy at varying vertical heights and roots forage soil mass at different depths and lateral distance. Studies on multistoried cropping systems involving cardamom (Malabar prostrate variety) in combination with robusta coffee, arabica coffee, arecanut and coconut were conducted to assess compatibility and economic returns in different agro-ecological conditions suited for main (floor) crops of coffee, arecanut and coconut with cardamom as a component crop (Korikanthimath, 2003).

Mixed cropping of robusta coffee with cardamom (double hedge)

The compatibility and yield pattern studies of robusta coffee both as mono (2.7 x 2.7 m) and mixed crop (5.4 x 2.7) with cardamom (1985 to 1994) revealed that robusta coffee mix cropped with cardamom recorded 1,988 kg ha^{-1} as against 2,626 kg ha^{-1} as a mono crop. Cardamom as a mixed crop with robusta coffee in double hedge (paired rows of cardamom with a spacing of 1.8 m x 1.2 m between two rows of coffee recorded the highest yield of 1400.5 kg dry capsule ha^{-1}

during the fourth year of its planting and the average of seven crop seasons was 672.30 kg ha^{-1}. Studies indicated that cardamom can be grown successfully in double hedge as a mixed crop with robusta coffee to increase the production and productivity per unit area and time by sharing of irrigation and other common cultural operations like weeding, mulching, shade regulation etc (Korikanthimath *et al.*, 1998r).

Monocrop of coffee received higher amount of PAR (1188.8 µmol $m^{-2} s^{-1}$, 86.8%) compared to that in mixed cropping system (787.5 µmol $m^{-2} s^{-1}$, 57.5%). In mixed cropping, cardamom intercepted 57.8% (792.5 µmol $m^{-2} s^{-1}$). Monocrop of coffee showed 45% increase in photosynthetic rate due to higher light availability. Cardamom recorded a photosynthetic rate of 3.2 µmol CO_2 $m^{-2} s^{-1}$ which was lower than coffee (monocrop) and higher than coffee in mixed crop. The transpiration rate (5.9 µmol H_2O $m^{-2} s^{-1}$) was higher in monocrop of coffee compared to mixed crop (4.4 µmol H_2O $m^{-2} s^{-1}$). Coffee as a monocrop showed higher water use efficiency (A/E) and also carboxylation efficiency (A/C_i) than as mixed crop. The study indicates that coffee-cardamom mixed cropping system is compatible (Korikanthimath *et al*. 1998b).

There was build up of mycorrhizae fungal spores and phosphate solubilizing fungi in the mixed cropping system of robusta coffee and cardamom as compared to their respective monocropping system. In addition, mixed cropping resulted in significant increase in the population of phosphate solubilizing bacteria in the rhizosphere of coffee (Korikanthimath *et al*. 2000d).

Chemical analysis of dry fruit skin or pulp indicated that among the macronutrients K content was the highest (3.43%) followed by N (1.84%), Ca (1.00%), Mg (0.49%), P (0.48%) and S (0.1%). In case of micronutrients, the Fe content was 350 ppm, Cu 96 ppm, Mn 57 ppm and Zn 54 ppm. The coffee pulp compost is far more superior to farm yard manure wherein the cattle fresh dung contains 0.3 - 0.4% N, 0.1-0.2 %, P_2O_5 and 0.1 - 0.3% K_2O. Coffee pulp compost will help to replace/substitute a sizable portion of chemical fertilizers in the coffee-based cropping systems (Korikanthimath, 2000c). The coffee washed water along with mucilage collected after 45 days of storage in the effluent pit contained the highest K (7.62%) followed by N (3.1%), Ca (1.81%) and P (0.25%). This can be effectively used in the adjacent paddy fields to enrich soil fertility and to raise a successful crop of paddy by restricting the vegetative growth before panicle initiation (Korikanthimath & Anke Gowda 2000).

During the study period of nine years, on an average the monocrop of robusta coffee required 180 men and 407 women labour days per ha. On the contrary, the mixed cropping system, required 237 men and 710 women labourers per ha. (1.67 times higher than the monocropping system) highlighting that the mixed cropping of cardamom with robusta coffee generated gainful employment to on farm and hired agricultural labourers in the region (Korikanthimath *et al*. 1999c).

The total cost of cultivation of mixed and monocropping was worked out to be Rs. 40,235 and Rs. 26,727 per ha respectively. The net returns of Rs. 1,4,2689 ha^{-1} realised in mixed cropping was 4.06 times more than monocropping. In both the systems, the cost of labour accounted for bulk share *i.e.* 71.91 per cent in mixed cropping and 68.98 per cent in monocropping. In the mixed cropping a common expenditure of Rs. 6,831 (16.95% of cost of cultivation) was incurred on various combined cultural operations and other items (Korikanthimath *et al*. 1997c). The resepective NPW and BCR in mixed cropping were 2.57 and 1.74 times higher (Korikanthimath *et al*. 2000h). Thus, mixed cropping of robusta coffee helped to build up farmer's economy by generating additional income and employment.

Mixed cropping of robusta coffee with Coorg mandarin, black pepper and cardamom (single hedge)

Cardamom was introduced as a complementary crop to the black pepper and Coorg mandarin cropping system in the Robusta coffee plantations to enhance the economic returns from the cropping system. Overhead shade trees (15-18 m) formed the top most storey (first tier), followed by Coorg mandarin (8.0-8.5 m) which constituted the second tier, black pepper trained on *Erythrina lithosperma* (6 m) constituted the third tier, cardamom (2.0-2.5 m) the fourth tier and coffee (1.6-1.8 m) the fifth and lower most (ground) tier. Dry yield of coffee was significantly high when it was grown as mono crop (2,163 kg ha^{-1}) compared to mixed crop (1,568 kg ha^{-1}). Cardamom introduced as a single hedge (6 m x 1.2 m spacing) with coffee by trimming the side branches of alternate rows of coffee, recorded 204.83 kg ha^{-1} capsule yield. Black pepper vines trained on live standards of shade trees yielded 1,222.15 kg ha^{-1}. Mandarin was severely infested with greening disease and there was no appreciable yield. The study indicated the feasibility of introduction of high value crops like cardamom and black pepper as mixed crops in increasing the production and productivity of robusta coffee plantations (Korikanthimath *et al*. 1997h).

Robusta coffee when grown as sole crop received the higher amount of light (295.5 µmol m^{-2} s^{1}, 46.17%) whereas in mixed crop situation it received comparatively less light (32.08%) and other crops intercepted more or less equal amount of light (16%). In the mixed cropping system also, coffee recorded the highest PAR (205.3 µmol $m^{-2} s^{-1}$) and other crops received 100-110 µmol $m^{-2} s^{-1}$). Cardamom had cooler leaf temperature (20.4°C) compared to other crops. Photosynthetic rate was higher in robusta coffee as a monocrop (2.3 µmol CO_2 m^{-2} s^{-1}) than as mixed crop (1.89 µmol CO_2 $m^{-2} s^{-1}$). This study clearly indicated the bright scope for multistoried mixed cropping in robusta coffee plantations (Korikanthimath *et al*.1999a).

During the study period of four years, the mono crop of robusta coffee on an average required 245 men and 289 women labour days per ha and the mixed cropping system required 331 men and 472 women labour days (1.50 times more than the monocropping system). The spread over of harvesting period of cardamom, robusta coffee and pepper for 10 months, besides the other cultural operations provides employment opportunities round the year (Korikanthimath *et al*. 1998f).

Out of the total cost of cultivation of Rs. 46,322 ha^{-1}, the cost of labour accounted 71.72% (Rs. 33,222 ha^{-1}) and the rest (28.28%) for other inputs like fertilizers, pesticides and irrigation charges (Korikanthimath *et al*. 1997b). The net returns of Rs. 1,05,191 ha^{-1} realised in mixed cropping was 3.69 times more than monocropping. The financial feasibility indicators (NPW and BCR) were also found to be higher by 3.55 and 1.56 times, respectively in mixed cropping. Thus, the mixed cropping of cardamom with robusta coffee generated income to the farmers over a period of ten months and gainful employment both for on farm labourers and agricultural workers round the year (Korikanthimath *et al*. 1998j).

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Mixed cropping of arabica coffee with cardamom (single hedge)

Experiment to study the compatibility and economic returns of arabica coffee with cardamom (where alternate rows of 10 years old arabica coffee were removed to introduce cardamom as a mixed crop with 4.2 m x 1.5 m spacing) revealed that the dry yield of arabica coffee as a sole crop was significantly higher (1790.3 kg ha^{-1}) with full plant population (2,268 plant ha^{-1}) compared to mixed cropping with cardamom (574.7 kg ha^{-1}) with half the population (1,134 plants ha^{-1}). Dry cardamom capsule yield was the highest (626 kg ha^{-1}) during the third year of its mixed cropping with arabica coffee (Korikanthimath, 2001c).

Light intercepted by cardamom (58.5%, 801.2 µmol m^{-2} s^{-1}) and arabica coffee (57.2%, 783.9 µmol m^{-2} s^{-1}) were on par in mixed cropping system. The study indicated that crop combinations create congenial climate for the growth and development of component crops. The photosynthetic rate was higher in monocrop of arabica coffee (4.8 µmol CO_2 m^{-2} s^{-1}) compared to the mixed crop of arabica coffee (3.6 µmol CO_2 m^{-2} s^{-1}). Mixed crop of arabica coffee recorded higher water use efficiency and lower carboxylation efficiency at gas exchange level, which indicates the survival strategy of arabica coffee under competition by cardamom as mixed crop (Korikanthimath *et al*. 1998c).

Substantial nutrients present in dry arabica coffee pulp (4.21% K, 2.38% N, 1.07% Ca, 0.55% P and 0.42% Mg) can be recycled in the cropping system to enrich the soil fertility and to substitute part of chemical fertilizer requirement (Korikanthimath & Hosmani 1998).

The mixed cropping of arabica coffee with cardamom was able to generate employment 1.90 times higher (824 man days per ha) than the mono crop of arabica coffee. Among cash inputs, maximum expenditure was incurred towards labour (Rs. 39,144 ha^{-1} which was 69% of total cost of cultivation). Common expenditure (Rs. 13,692 ha^{-1}) accounted for 24% of the total cost of cultivation which helped in sharing the common expenditure compared to the monocrop (Korikanthimath *et al*. 1998g). In both the crops, the utilisation of women labourers was maximum. In cardamom, the variation in labour requirement in tune with the yield levels was observed as indicated by their coefficient of variation. Thus, mixed cropping of arabica coffee with cardamom was found superior both with respect to generation of gainful employment and income in the high ranges of Western Ghats (Korikanthimath *et al*. 1998e).

The cost of cultivation was the highest (Rs. 55,001 ha^{-1}) in mixed cropping as against Rs. 27,781 ha^{-1} under mono cropping of arabica coffee and maximum expenditure was incurred towards labour (about 70% of the cost of cultivation). Net returns of mixed cropping (3 years average) was 4.04 times that of monocropping with an incremental net gain of Rs. 47,346. NPW and BCR were also found to be higher by 3.41 and 1.26 times, respectively in mixed cropping. The mixed cropping of cardamom with arabica coffee generated income to the farmer over a period of 8 months (July-February) and provided gainful employment both for on farm labourers and agricultural workers round the year (Korikanthimath *et al*. 1996).

Mixed cropping of arecanut with cardamom

Field investigation conducted on the mix cropping of arecanut with cardamom at Sirsi, Karnataka, during 1986-87 to 1993-94 revealed that arecanut yield was significantly higher when it was grown as a mono crop (3,450 kg ha^{-1}) compared to that as mixed crop (3,221 kg ha^{-1}). The average yield of cardamom for six crop seasons was 324 kg dry ha^{-1} (Korikanthimath *et al*. 1998q).

Arecanut received higher amount of light (59.06%) compared to cardamom (40.25%) Air and leaf temperature were higher in arecanut than cardamom due to high light interception. The photosynthetic rate and its related parameters in arecanut and cardamom mixed cropping system showed significant variation. Photosynthetic rate of arecanut (4.2 µmol CO_2 m^{-2} s^{-1}) and cardamom (4.115 µmol CO_2 m^{-2} s^{-1}) were comparable. Transpiration rate was higher in arecanut (4.8 µmol H_2O m^{-2} s^{-1}) compared to cardamom (4.0 µmol H_2O m^{-2} s^{-1}) (Korikanthimath *et al*. 2000a).

Monocrop of arecanut required 704 labour days whereas, mixed cropping of arecanut required 1,175 labour days annually per ha (Korikanthimath *et al*. 2003c). The cost of cultivation of mixed and monocropping were Rs. 40,683 and Rs. 27,571 ha^{-1}, respectively. Common expenditure incurred in mixed cropping of arecanut with cardamom brought down the total cost of cultivation (Korikanthimath *et al*. 1997a). The net returns (Rs. 1,61,837 ha^{-1}) realised in mixed cropping was 1.56 times higher than that in monocropping (Rs. 1,03,626 ha^{-1}) and NPW was higher by 1.48 times. Mixed cropping of cardamom with arecanut generated income to the farmer over nine months (July to March) and gainful employment throughout the year (Korikanthimath *et al*. 1997d).

Mixed cropping of coconut with cardamom

Experiment conducted at Sirsi, Karnataka during 1992-93 to 1994-95 cropping seasons to explore the possibility of cultivating cardamom as a mixed crop with coconut, their compatibility and yield pattern revealed that the yield of coconut was higher (15.7 thousand nuts ha^{-1}) as a monocrop compared to coconut mixed crop with cardamom (14.7 thousand nuts ha^{-1}). Dry yield of cardamom mix cropped with coconut varied with years with the highest yield (554.2 kg ha^{-1}) in the third year of its planting (Korikanthimath *et al*. 2000k). Coconut canopy intercepted more light (75.43%, 1207 μmol m^{-2} s^{-1}) compared to cardamom (32% and 388 μmol $m^{-2} s^{-1}$) and also had higher photosynthetic rate, transpiration rate and carboxylation efficiency (Korikanthimath *et al*. 1998a).

Mixed cropping system of coconut and cardamom generated four times more employment (487 labour days) than the mono cropping of coconut (122 labour days). Significant positive correlation between labour utilization and yield signifies the importance of labour force in cardamom based cropping system (Korikanthimath *et al*. 2000g). The cost of cultivation of mixed cropping of coconut with cardamom was Rs. 35,000 ha^{-1} and that of monocropping of coconut was Rs. 18,272 ha^{-1}. Sharing of common expenditure (Rs. 6,045 ha^{-1}) for operations such as weeding, mulching, irrigation etc. brought down the cost of cultivation in mixed cropping compared to monocropping (Korikanthimath *et al*. 1998h).

Net returns (Rs. 1,01,017 ha^{-1}) from mixed cropping was 2.50 times more than that of monocropping (Korikanthimath *et al*. 1998h). NPW and BCR were found to be higher by 2.24 and 1.11 times, respectively in mixed cropping compared to mono cropping (Korikanthimath *et al* 1998i). Further, the spread of harvesting period of cardamom and coconut helped the farmers to get continuous income and employment round the year.

Large scale demonstration of High Production Technology (HPT) in farmers' fields

The various agronomic techniques incorporated in the HPT package include - planting material production (clonal selection and multiplication and propagation by seeds), systems of planting, spacing (geometry of planting), method of planting, season of planting, after care and upkeep- mulching, weed control, trashing, soil and moisture conservation measures, shade regulation, nutrient management, irrigation, harvesting and processing and adoption of ecologically feasible and economically viable cropping systems (Korikanthimath *et al.,* 1991).

HPT programme launched in 1986 in 42 farmers plantations covering an area of 94.1 ha by using 1,70,500 Cl.37 seedlings in five distinct zones *viz.,* Virajpet (13 nos.), Bhagamandala (7 nos.), Madikeri (12 nos.), Somwarpet (2 nos.) and Yeslur (8 nos) in collaboration with Spices Board (technical guidance from IISR, Cardamom Research Centre, Appangala and monetary assistance from Spices Board to the beneficiaries) resulted in an average yield of 495 kg ha^{-1} dry cardamom capsules. The pre-planting bench mark survey had revealed that the average size of the plantation was 6.54 ha and average age was 17 years. The mean rainfall was 3150.5 mm per annum and average yield was 63.21 kg ha^{-1}. The increase in yield from 63 kg to 495 kg per ha clearly illustrated the tremendous potentiality to boost cardamom production through adoption of HPT (Korikanthimath, 1992).

As cardamom is highly location specific, HPT was implemented in twelve research-cum-demonstration plots in farmer's plantations. The 10 ha cardamom plantation at M/s Lakshmi Estate, North Kodagu was selected to demonstrate high production potentiality. The rainfall ranged from 800-2000 mm per annum. The soil was acidic with high available nitrogen, low phosphorus and medium potash contents. Prior to adoption of HPT, nine years' average yield of dry cardamom was 116.55 kg ha^{-1} which declined to 75 kg ha^{-1} during the tenth year and to 47 kg ha^{-1} during eleventh year (1982) (Korikanthimath *et al*. 1989c; Korikanthimath 1996). After adopting HPT, the highest maiden yield was 850 kg and the average yield of seven crop seasons (1985-86 to 1991-92) was 460 kg dry capsules ha^{-1}. The labour requirement was 299 and 306 man days during pre-bearing and bearing periods as against 504 and 787 man days by adopting HPT. During bearing, requirement of women labourers was the highest (85%, 672 nos.), followed by men (15%, 114 nos.), which indicates the generation of additional employment mainly for women (Korikanthimath *et al*. 1989d). Implementation of HPT resulted in 6.7 times more yield than the national average (60 kg ha^{-1}). The cost of production was Rs. 88.18 kg^{-1} with an overall average benefit cost ratio (BCR) of 4.02.

Intensive cultivation of cardamom by adopting HPT at Chettalli, Kodagu recorded the highest maiden yield of 1,625 kg ha^{-1} with an average yield of 662.72 kg ha^{-1} capsules for ten crop seasons. Out of 729.59 labour days required per ha per year during bearing period, the women labourers constituted a major chunk (64.08 per cent). About 55.56 % and 11.01 % of labour requirement was for harvesting and trashing operations respectively. A net income of Rs. 1,09,147.53 ha^{-1} (average of 10 years crop seasons) was obtained with a production cost of Rs. 60.92 per kg (dry) (Korikanthimath *et al.* 1989b; Korikanthimath 1995; Korikanthimath *et al.* 2001c). Promising varieties/improved selections coupled with optimum inputs and adoption of technologies can increase cardamom yield up to 2,000 kg ha^{-1} (Vijayan *et al.* 2018).

Performance and economics of cardamom under replanting

The performance and economics of replanting of cardamom was studied at Chettalli, Kodagu. An average yield of 749 kg ha^{-1} of cardamom was obtained for 5 crop seasons which was more than 5.35 times the national average yield of 140 kg ha^{-1}. The highest yield of 1,775 kg ha^{-1} was recorded during second year after replanting. Out of 869.8 labour days required/ha per year during the bearing period, the requirement of women labourers was higher (87.4%); 57.8% labour requirement was for picking cardamom capsules only. Maximum expenses (69.45%; Rs. 57,230 ha^{-1}) was incurred on labour charges. A net income of Rs. 1,96,986.20 ha^{-1} (average of 5 crop seasons) was obtained with a production cost of Rs. 130.97 kg^{-1} (dry). The discounting cash flow measures namely, Net Present Value (NPV) of Rs. 5,09,296, Benefit Cost Ratio (BCR) of 2.78 and Pay Back Period (PBP) of 2.15 years indicated that replanting of cardamom by following HPT is economically viable and financially feasible (Korikanthimath, 2000b).

Intensive cultivation of cardamom in high elevation and high rainfall areas

The study carried out at Panya, Heravanad, North Coorg for six years (1993-94 to 1998-99) on cultivation of cardamom in high elevation (1050 m above MSL) and high rainfall (3,000 mm) areas recorded an average yield of 309 kg ha-1 for the four crop seasons. The labour cost accounted for major share of 34.23% during establishment period (1993-94 to 1994-95) and 59.68% during bearing period (1995-96 to 1998-99) out of a total cost of Rs. 68,429 ha^{-1} and Rs. 37,614 ha^{-1} in the respective periods. The average gross return was Rs. 96,960 ha^{-1} with a net return of Rs. 44,852 ha^{-1}. Average cost of production of dry cardamom was Rs. 168.63 per kg. NPW of Rs. 69,297.9, BCR of 1.48, PBP of 3.12 years and IRR of 48% indicated that the cultivation of cardamom even in high elevations and high rainfall areas with appropriate timely and intensive care is economically viable and ecologically feasible (Korikanthimath & Govardhan Rao 2000b).

Performance of cardamom under low elevation and low rainfall situations

Cardamom cultivated in a non-traditional area situated comparatively at a lower elevation (825 m above MSL) and low rainfall (1,450 mm) at Polibetta, South Kodagu recorded a peak yield of 1,680 kg ha^{-1} in third year (1995-96) and an average yield of 829.30 kg ha^{-1} for four cropping seasons (1994-95 to 1997-98) with an average net return of Rs. 1,12,532 ha^{-1}. The economic and financial feasibility indicators *viz.*, NPV (Rs. 3,14,162 ha^{-1}), BCR (2.46) and IRR (128%) showed that investment on introducing cardamom in comparatively low elevation and low rainfall area with assured irrigation facilities is economically viable (Korikanthimath *et al.* 2000f).

Feasibility of cardamom cultivation on the steep slopes of Western Ghats

Field trial conducted by adopting HPT at Karnangeri, Kodagu district, to study the input requirement and economic feasibility of cultivation of cardamom on moderate steep slopes (9-16%) of western Ghats resulted in the highest maiden yield of 1,173 kg ha^{-1} during third year after planting with an average yield of 609 kg ha^{-1} of four crop seasons (1994-95 to 1997-98). The annual average maintenance cost was Rs. 53,6646 ha^{-1}. Out of various inputs, maximum expenditure (69%) was incurred towards labour. A net income of Rs. 74488 ha^{-1} (average of 4 crop seasons) was obtained with a production cost of Rs. 88 kg^{-1} (dry). NPV (Rs. 1,55,476 ha^{-1}) and BCR (2.01) indicated the viability of investment on cardamom even on steep slopes (Korikanthimath & Hiremath 2000).

Cultivation of cardamom in valley bottoms under ever green forest shade

Studies on prospects of cardamom cultivation in valley bottoms in Coorg, Karnataka under ever green forest shade situations recorded highest maiden yield of 1,473 kg ha^{-1} during third year after planting with seven years average dry cardamom yield of 735 kg ha^{-1} (1988-89 to 1994-95). Labour charges accounted for 61.6% of the total expenditure. A net income of Rs. 1,45,065 ha^{-1} was obtained with an average production cost of Rs. 87 kg^{-1}. NPW of Rs. 5,23,455 ha^{-1}, BCR of 3.53, PBP of 2.14 years and IRR of 59.08% showed that cardamom is an economically viable and ecologically feasible crop for cultivation in valley bottoms which retain soil moisture round the year. However, it is very important to provide adequate drainage (Korikanthimath *et al*., 2002b).

Cultivation of cardamom in marshy areas

A research-cum-demonstration trial was carried out in Kodagu, Karnataka to study the feasibility of cultivation of cardamom under the shade of Neerangi (*Salix tetrasperma*, Willow) which comes up well even in water logged marshy areas (valley bottoms). A maiden crop yield of 1,463 kg ha^{-1} dry capsules was recorded during the third year of planting. Among the work force, women labour dominated the total labour force to an extent of 91.3%. Expenditure towards labour cost accounted for 47.50% (Rs. 27,959 ha^{-1}) of the total cost (Rs. 76,365 ha-

^{1}). Net return of Rs. 1,08,995 ha^{-1} was obtained with the cost of production of Rs. 108.63 kg^{-1} for an average production level of 703 kg dry capsules ha^{-1}. NPW (Rs. 2,72,100 ha^{-1}), BCR (2.46) and PBP (2.10 years) showed the prospects of successful cultivation of cardamom beneath shade of Neerangi (*Salix tetrasperma*, Willow) with proper drainage (Korikanthimath *et al.*, 1999b).

High density trench system of cardamom cultivation

Optimum utilization of natural resources and management of cash inputs is very crucial for sustainable cardamom production. High density trench system of intensive cultivation of cardamom in Chettalli, Kodagu district recorded a dry cardamom yield of 1,945 kg capsules ha^{-1} within 30 months after planting. An average dry caplsule yield of 886.25 kg ha^{-1} (1995-96 to 1998-99), which was 6.3 times the national average yield of 140 kg ha^{-1} indicated high income and employment generation potential of this system (Korikanthimath & Govardhan Rao 2000a).

Homestead cultivation of cardamom

The trial laid out in an area of 0.05 ha at Chettalli, Kodagu district during August 1991 to December 1993 crop seasons by adopting high density (1.8 m x 0.6 m) trench system of planting under controlled condition (by erecting an overhead pandal and covering with shade tree twigs which helps to retain leaves during summer) with HPT resulted in 103 kg of dry cardamom yield within 30 months. Total cost of cultivation was Rs. 21,213 for three years. The actual gross and net returns realised from the homestead cultivation were Rs. 47,388 and Rs. 26,175 respectively. The return per rupee invested on labour was 3.70 and the per day return was Rs. 23.90. The BCR (2.00) and NPW (Rs. 15,227) also indicated the profitability of the enterprise. It also generated a gainful employment of 380 labour days for effective utilization of spare time besides productive utilisation of backyards for profitable cultivation of cardamom. Thus, the study clearly indicated that homestead cultivation of cardamom is a profitable proposition (Korikanthimath *et al.* 1998d).

Conversion of upland open vacant areas for profitable cultivation of cardamom

Research-cum-demonstration trial carried out at Kadagadal, Madikeri, Coorg to study an agro forestry approach in conversion of upland, open vacant marginal area by resorting to afforestation with silver oak (*Grevillea robusta*) for profitable cultivation of cardamom recorded an average yield of 681.75 kg ha^{-1} for four crop seasons which is 4.5 times more than the national average yield of 140 kg ha^{-1}. It was observed that a total cost of Rs. 3546.60 ha^{-1} was incurred on establishing silver oak for shade. About 55.9 per cent of men and remaining 44.1% of women labourers were involved in pre bearing period amounting for total establishment cost of Rs. 11,685 ha^{-1} (material costs + labour + depreciation) for cardamom. The labour costs was the highest (66.87%, Rs. 29,294 ha^{-1}) during the bearing period. Total investment was Rs. 64,807 ha^{-1} and average net returns was Rs. 1,25,466 ha^{-1}. The discounting cash flow measures *viz.*, NPW (Rs. 2,72,029 ha^{-1}); BCR (2.93); PBP (2.3 years) and IRR (80.73) suggested the success of cultivation of cardamom in upland, open, vacant areas with agri-silviculture-agro-forestry approach (Korikanthimath *et al.* 2003b).

Farm forestry-based pepper and cardamom cropping systems in degraded marginal area

The open vacant areas in the high ranges of Western Ghats are prone for soil erosion due to heavy rains. Agro forestry approaches with high value spices like, black pepper and cardamom can bring profitability in such areas.

Agro forestry approach at Boikeri, Suntikoppa, Coorg showed an average yield of 1,531 kg (dry) ha^{-1} black pepper trained on silver oak. The average yield of dry cardamom was 1,034 kg ha^{-1} which was 8.62 times more than the national average yield of 140 kg ha^{-1}. The NPW was Rs. 3,83,743 ha^{-1} with a BCR of 4.21 and IRR of 80.56. The results of this study have direct bearing on the afforestation of degraded marginal lands in high ranges of Western Ghats for sustained production of ecologically feasible and economically viable spices like black pepper and cardamom (Korikanthimath *et al*. 2000).

Conclusion

Comprehensive agronomic investigations carried out during 1980-2000 in cardamom lead to the development of HPT which significantly boosted the cardamom production. Detailed field investigations on mixed (multi storied) cropping systems of cardamom with coffee (robusta and arabica), arecanut and coconut proved that the crop combinations can effectively utilise both horizontal and vertical space and the solar energy to get the higher returns per unit area and time. A close rapport developed with large number of cardamom growers, developmental organisations and stake holders has made a profound impact on the enhancement of cardamom production and productivity through effective transfer of technologies and earning the precious foreign exchange for India, besides meeting the domestic demand. Multipronged and multidisciplinary approaches are essential for evolving economically feasible and environmentally sustainable production technologies. These approaches in combination with effective implementation of location specific high production technologies through farmer participatory mode can harness the production and productivity of small cardamom to a great extent and enhance its share in the global trade.

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