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Original Article

Chasing Productivity in Cardamom (*Elettaria cardamomum Maton)*

V. Ranganathan

Author's Affiliation: Retired Scientist, Block-12, Flat H-1, Jains green acres, 91 Darga Road Pallavaram Chennai 600043 Tamil Nadu, India.

Abstract

Cardamom, the Queen of Spices and the native of evergreen forests of Western Ghats, of South India, is a high value crop grown for its dried seeds which contains the aromatic oil (***mainly 1,8 cineole, terpinyl acetate, linalyl acetate and linalool***)used to flavor foods. Important soil and climatic conditions and eco-systems which are necessary for economically sustainable productivity are reread to align the cultivation practices to realize the purposes for which it is grown. Some focal features about Cardamom and for its productivity are précised below.

Keywords

Theoretical Maximum; Threshold; Limits of Productivity.

Introduction

Cardamom is a perennial underground rhizome with leaf sheaths forming aerial pseudo stems above the soil, growing to 2 to 4 m height. The inflorescence or the panicle arises from pseudo stem below the soil and come out above the soil as racemic clusters carrying bisexual flowers and fertilized by entomophily cross pollination. Flower initiation starts in March /April after the drought is broken, expending 30 days to full bloom and 5to 6 months to reach harvestable stage. Harvesting or picking of capsules starts around end August and extends up to Dec/January in 6 to 8 pickings. The fruits are about 2 to 3 cm long ovoid and triangular turning brown to pinkish on ripening and carry 40 to 50 seeds. New tillers are also initiated during the same period; and after a year of vegetative phase, they enter reproductive phase and produces panicles, flowers and capsules. Thus, its yielding pattern smacks more that of a biennial crop. The essential oil content varies between 5 to 8% in seeds. Drying of harvested seeds is highly specialized job, mainly aimed to reduce the loss of volatile oil for which it is valued and to enhance the appearance of capsules for marketing. As the vegetative phase of new tillers for next year crop and the reproductive phase of previous year tillers occur at the same period, adequate supply of nutrients for both vegetative growth and seed development are to be met all through the year for sustaining the productivity and quality of the capsules

Cardamom Soils

Cardamom grows in acidic soils in the pH range 4-7. But it is sensitive to manganese and prefers soils low in available manganese content as in volcanic soils of Guatemala or in soils with high organic matter which reduce the activity of manganese by chelate binding with complex organic acids as in ever green forest ecosystems preferably with alternate wet and dry conditions like in latosols of Western Ghats of south India and in other cardamom growing areas.

It prefers loams with good water permeability for rhizomes' growth under the soil surface. As for other crops it requires all essential nutrients, major and micro ones, for biomass production for productivity and bio-synthesis of aromatic oils thru bio-cycles supported by micronutrients acting as co-enzymes.

Corresponding Author: V. Ranganathan,
Retired Scientist
Block-12,Flat H-1, Jains green acres, 91 Darga Road Pallavaram
Chennai 600043 Tamil Nadu, India.
E-mail: vedantarangan@yahoo.com

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Extensive research in Pampadumpara, Appangala, Mudigere and other research stations have exposed the need for inclusive nutrient packages blended for sustainable productivity and quality of capsules which are updated now and again and released thru extension wings of IISR of ICAR, India for the benefit of cardamom growers.

Climate

Cardamom thrives well in hot humid tropical and sub-tropical zones with a rainfall between 1000 to 4000 mm and temperature ranging from 10 to 35^0C. It grows well at around 75% humidity. Such suitable climate for Cardamom is seen in humid tropical and sub-tropical ever green forest eco systems at elevations between 600 to 1500 m MSL.

Productivity Algorithm

Growth is defined in terms of a) height of plant (cm), b) total number of tillers, bearing tillers and non-bearing ones per clump. Productive parameters are number of panicles per clump, panicle length (cm) and number of capsules per panicle. Cardamom responds to nutrient applications and irrigation as revealed by extensive research carried out in the recent years – nutrients application to a targeted yield, light intensity penetration, and irrigation resources accessible. To get optimum leaf area index from the time of transplanting to achieve high productivity from second year onwards, high density planting is resorted in replanting areas and new openings. Some Important yield and productivity parameters are given in Table 1. The yield potential of cardamom as revealed in research studies are lent in Table 2.

Harvest Index

Harvest index of cardamom clones vary from 0.060 to 0.091 and the factors that affect them are light intensity under adequate supply of nutrients, water and favorable climatic conditions. Studies on shade regulations have shown that cardamom performs its physiological functions optimally at about 50 to 70% light intensity. Pollination is entomophily and honey bees play a major role and constitute about 98% of flower visitors. Hence great care is warranted tomaintainthe eco system for their comfortable habitat by judicious pests and disease control measures. The forest eco-system bestows a comfortable habitat for honey bees. Pollination, by honey bees, is reported to help 64 to 66% fruit set as against 1 to 3% in control

Table 1: Growth and yield parameters

Attribute	Mean	Range
Total Tillers per Clump, no	40	30 to 60
Productive Tillers per clump, no.	20	10 to 40
Non_Productive Tillers per clump, no	20	10 to 40
Lenght of Panicle, cm	50	40 to 60
Panicles, per clump	20	15 to 30
Fresh Capsules, per clump, no.	600	300 to 1000
Dry capsuless (8 to 12 % moisture) per clump, g	210	100 to 350
Flowers per panicle, no.	100	80to120
Pollination efficiency, entomophily	64%	64 to 66%
Pollination efficiency other modes	2%	1 to 3%
Fruit set	40%	30 to 50
Fruit drop	40%	20 to 60
Moisture Content, fresh capsules	68%	65 to 75
Moisture Content, dry (Curred) capsules	9%	8 to 12 %
Fresh Weight of 100 Capsules, g	74	64 to84
Dry Weight of 100 Capsules, g	26	16 to36

Table 2: Productivity Potential in Cardamom

Details	Yield	Harvest index
Yield at 9000 plants /ha		
40 to 50 % light intensity	1875 kg/ha	0.066
65-70 % light intensity	1928 kg/ha	0.073
Comparative study of12 clones in trench system1.8 m x 0.6 m (1.08 m^{-2})		
total dry matter /plant	2759 to 4853 g	0.06 to 0.091
Dry matter in capsules	133 to243 g	

plots. Honey bee keeping in areas going in for less shade or artificial shade has become a necessity to ensure viable productivity by promoting fruit set and production of more number of capsules. Four bee colonies per hectare during the flowering season is the general recommendation to optimize pollination. Exposure of panicles from a layer of mulch also helps to improve pollination by 14 times. Thus creating a favorable environment for maximum fruit setting is a must for optimizing Harvest index.

In crops grown under shade, solar energy incident on the surface is shared by shade trees and cardamom. In natural habitat of Cardamom, the ratio of distribution of incident solar radiations between shade trees and cardamom is around 60:40. With shade regulations allowing 50 to 70% light intensity in space between adjacent shade tree rows, it is almost reversed. Hence a) shade regulation in old cardamom fields existing under natural forest eco-systems and b) adoption of proper spacing of shade trees and cardamom plants in new plantings to ensure 50 to 70% light penetration are some of the focal points to be tailed in the cultivation system to chase the productivity to a targeted level.

Economic Planting Cycle

Under traditional planting systems, it takes 3 to 4 years to reach productivity levels of 300 to 1000 kg / ha and thereafter the yield declines due to debilitation of plants by MOSAIC disease locally known as Katte disease meaning a disorder which nails the economic age of plantation at 12 to 15 years. If the infection is early, the loss is total; but if it is delayed the decline occurs over the span of 3 to 5 years with crop reduction up to 70%. Replanting is carried out when the productivity level dips to uneconomical levels. The virus is disseminated by the aphid vector (*Pentaloniacaladii*) and also through infected rhizomes. The average yield for the cycle is brought down to 200 to 300 kg /ha though the yield levels around 1000 kg /ha are not uncommon at 3 to 5 years after planting. Since there is no known remedy to control the propagation of infection except roughing them out, a system of 10 to 15 year replanting cycle with high density planting, high nutritional inputs and irrigation with drip and sprinkler techniques have been standardized to get a mean yield of 600 kg /ha / year or above for the planting cycle which is under successful adoption in many cardamom areas particularly in Karnataka. This system also takes care of other virus diseases of recent history for whom roughing out the diseased plants is the only remedy. During non-flowering season other pest and diseases are controlled with chemicals cleared by ICAR and Ministry of Agriculture, taking care not to adversely disturb honey bee habitat.

Soil OM and Nutrients

Maintenance of organic matter and soil mulching are important for soil tilth and to reduce run-off during rainy season and soil erosion. Soil disturbance practices like kokra weeding, forking the soil around the clumps with the belief to aerate the soil during dry months and digging trenches for water conservation except in marginal rain fall areas should be carried out to a possible minimum and all crop residues such as cardamom trashes, leaf fall from shade trees are to be retained in the field itself; to be brief nothing other than the picked capsules will be allowed to leave the field. Weeds should be scorched with cleared chemicals and stubbles left in situ to act as soil mulch during dry months and, allow a live mulch of soft weeds untouched during rainy months to tame the run-off water and to reduce soil disturbance. Zero or minimum tillage cultivation helps in maintaining soil tilth on the long run.

As 'P' requires sub-soil placement while all other nutrients can be applied broadcast, its total annual requirement can be given in one application as straight P or combined as NPK mixture in one of the NK applications before earthingup and covered with the soil and trashes. NK requirements are met in 3 to 4 broadcast applications. NK splits are applied when soils are moist so that they are retained by electrochemical forces in exchangeable sites. Thin film of water on the surface doesn't move with run-off water as the velocity drops layer by layer to zero at soil surface. Nutrient losses are negligible unless the soil moves. As the cardamom soils are rich in organic matter all micronutrients can be applied along with NPK or NK fertilizers to soil. If foliar application of micronutrients is planned, it is preferably done during non-flowering season along with pesticide sprayings. In targeted productivity systems, all nutrients are applied at rates calculated for total bio-mass production required to achieve set yield of end product for which the crop is grown based on whole plant analysis. No allowance is given for soil available nutrients so that these extra nutrients could help tosustain the minimum concentration of salts in soil solution required to support the soil physicochemical properties against their depletion by the plants' uptake for their growth. In cardamom, to produce 100 kg capsules, plants have to synthesize 1500 kg of biomass taking the average of harvest index as 0.067. Nutrient requirements are, therefore, to be calculated for total biomass production i.e.

1500 kg biomass for every 100 kg capsules targeted. Thenutrient composition of wholeplant of crops with distinctive adjustments specific to cardamom is given in Table 3.

Energy Conversion Ratio

Unlike most other crops, 'K' requirement of cardamom is very high like Tea which has also evolved under similar humid ever green forest eco-system. Potassium aided by silicon play an important role in absorption, retention and release of CO_2 for photosynthesis in"C4" photosynthetic path adopted by these crops. Therefore, in highly degraded soils low in soluble silica, they respond to application of soluble silicates. The theoretical maximum *conversion* efficiency (εc) of photo synthetically active radiation (PAR) into *plant* biomass is 12.3 % for "C4" plants. But 30 t0 40% of energy fixed is lost in dark and Photo respiration. In crops like tea grown for leaves and cardamom grown for seeds, respiration losses are more for sustaining continuous production of new growth in tea and, seed development and synthesis of aromatic oils in cardamom. These are the reasons for low harvest index seen in cardamom.

The chemical composition of whole cardamom plant is almost similar to that of others except for a higher content of Potassium and Boron. Silicon content in cardamom is comparable to Tea, Rice and sugarcane and it gives resistance to lodging besides erectness to leaves, thereby enhancing photosynthetic efficiency. In soil based system, it is unlikely to have any crops without silicon. The high silicon accumulators are mostly monocotyledons (Wheat, Sugarcane, Rice, Barley etc.,) and they contain 10 to 100 g kg^{-1} in dry weight, and medium accumulators contain between 5and10 g kg^{-1}.The di-cotyledons contain less than 5 g kg^{1} in dry matter. Dry matter of cardamom seeds contains 37g kg^{-1}silicon.

NPP (Net Primary Production)

There are several approaches to reckon the theoretical maximum productivity of a crop under unlimited supply of nutrients and water. Traditional approach is based on a) solar energy incident on earth surface (@ 400 calories cm^2d^{-1} in tropics and sub-tropics b) photosynthetic efficiency c) respirational losses, d) energy required for biomass synthesis @ 17.5 MJ kg^{1} biomass per year and, e) efficiency of natural recycling process limited to 60 to 70 % by thermodynamic laws. Recent satellite studies show that solar radiations incident on surface can fix 200 t ha^{-1} carbon per year roughly equivalent to 450 t ha^{-1} biomass per year (delucia et.al.2014). Harvest index then decides the productivity in terms of economic end product. Crops are grown in non-ideal conditions defined by agro climatic conditions (Ranganathan 2014, 2017) besides social and economic factors whichaffect the harvest index. The theoretical maximum productivity as revealed by the above approaches are shown in Tables 4 and 5. Under unlimited supply of water and nutrients, the theoretical average maximum productivity seems to be around 14 and 10 t per ha with and without irrigation respectively and is dependent on light intensity.

Table 3: Chemical composition of Whole plant biomass

A									B							
Macro - nutrients							Macro-elements		Micro - nutrients							
%							%		Ppm							%
C	O	H	N	P	Ca	S	Mg	K*	Cl	B	Fe	Mn	ZN	Cu	Mo	Si*
45	45	6	1.5	0.2	0.50	0.10	0.20	1.00	100	20	100	50	20	6	0.01	N/a

A - Elements going into chemical composition of the biomass;
B - Mineral elements present in ionic form to for biomass synthesis and hydration of tissues control bio cycles to synthesize chemicals;
K content of cardamom 2.0 to 3.0% for all.

Table 4: NPP- under unconstrained availability of resources- Traditional approach

	Parameters used			Total	Biomass Distribution		yield
	SR	E to B	EiCi	Biomass	Shade trees	Cardamom	Dry capsules
	TJ $ha^{-1}yr^{-1}$	MJ kg^{-1}		t $ha^{-1}yr^{-1}$	t $ha^{-1}yr^{-1}$	t $ha^{-1}yr^{-1}$	t $ha^{-1}yr^{-1}$
A (60:40)	75.256	17.5	0.06	258	155.0	103	6.9
B (40:60)	75.256	17.5	0.06	258	103	155	10.4

A; Forest association with less than 50% light intensity; solar energy sharing Shade trees: cardamom -60:40
B-Regulated shade and new openings Light intensity 50 to 70%: solar energy sharing shade trees: cardamom- 40:60
SR- Annual integral of incident solar radiation TJ $ha^{-1}yr^{-1}$
E to B-Energy to biomass, MJ kg^{-1}
EiCi- energy captured and used (Theoretical daily energy stored in biomass of C4 plants (6%)

Table 5: NPP-under unconstrained availability of resources (after delucia et.al. 2013)

Detail	Parameters used		Biomass Distribution		yield
	NPP (1) TJ $ha^{-1}yr^{-1}$	NPP (2) MJ kg^{-1}	Shade trees t ha^{-1} yr^{-1}	Cardamom t ha^{-1} yr^{-1}	Dry capsules t ha^{-1} yr^{-1}
A (60:40)	200	450	270	180	12.1
B (40:60)	200	450	180	270	18.1

A; Forest association with less than 50% light intensity; solar energy sharing Shade trees: cardamom- 60:40
B-Regulated shade and new openings Light intensity 50 to 70%: solar energy sharing shade trees: cardamom- 40:60
NPP (1)- Net Primary production as tons Carbon per ha
NPP (2)- Net Primary production as tons Biomass per ha
Harvest index- 0.067; Mean of estimates of theoretical maximum productivity- 11.875 rounded to 12 t/ha

Table 6: Water-Limiting NPP-under unconstrained supply of nutrients

Rain cm	Rain water Use efficiency	quantity water M ml ha^{-1}	Biomass kg/ha	capsules kg/ha
A-Without Irrigation Support				
100	0.6	60	24000	1608
250	0.6	150	60000	4020
400	0.6	240	96000	6432
B- With Irrigation Support				
100	0.8	800	32000	2144
250	0.8	200	80000	5360
400	0.8	320	128000	8576
C-At Full water Requirement for Theoretical Max				
840	0.8	672	268800	18010
560	0.8	480	179200	12006

Water Constraints

The main limiting factor in achieving maximum theoretical productivity is availability of Water. Physiologists have shown that an average of 250 kg water is transpired to synthesize one kg biomass mainly to keep the tissue temperature at optimum range against 10 to 15^0C rise in temperature when biosynthesis takes place using respiration energy. Besides this, water acts as nutrient carrier, medium for dispersal of bio mass in living tissues, temperature regulator, and also maintains source-*sink* gradient for continuance of metabolic processes. As slightly negative water potential is required for soil aeration and bio-activity, the water use efficiency is limited to an average maximum of 80% for the year. The water use efficiency, be it from rain or irrigation,varies between 60 and 80% during rainy months and 40 to 60% during dry months in cardamom growing areas. The annual mean of water use efficiency can be roughly taken as 60% in non-irrigated areas and 80% in irrigated areas. Under unconstrained availability of nutrients the maximum productivity achievable with the rainfall of the area, with and without irrigation support, is shown in Table 6.

Nutrient Constraints

For targeted productivity, 'N' requirement is calculated based on whole plant analysis for the total biomass required to be synthesized for the targeted yield (bio-mass- 15 times the targeted productivity at 6.7% harvest index) and, that of other nutrients are based on the ratio at which they are seen in whole plant analysis. In high productivity programs all nutrients are given to avert any one them turning to be a limiting factor in achieving the goal. The threshold productivity of an area is determined by the amount of available nutrients thru their natural recycling cycles and the rainfall. The maximum efficiency of utilization of soil nitrogen and also that of applied nitrogen is 60% in high production programs.

The Nitrogen content of whole plant is 1.5%, and at 60% utilization efficiency an application of 2.5 kg N for every 100 kg biomass is needed. It works out to application rate of 37.5 kg N for every 100 kg of capsules targeted at a harvest index of 0.067. All other nutrients are applied at rates in proportion to nitrogen they occur in whole plant analysis. The threshold limit of productivity is pinned at 240/ha kg by the amount of soil available nutrients sustained by the natural recycling processes as

shown in Table 7, i.e. Soil with its natural resources of nutrients could support a yield 240 kg /ha.

Rain water with supportive irrigation will support a target productivity between soil threshold limit (240 kg /ha) and that limited by water availability (2143 kg capsules per 100 ha cm water), with application of supportive amounts of all nutrients. Maximum productivity achievable under various situations is recapped in Table 8.

Summary

Productivity trend of cardamom crop over the past is shown in Table 9. It has remained stagnant over the years. Recent studies have exposed the so far unexplored yield potential of cardamom (see Table 2 mentioned earlier). The holistic approach on cardamom research has shown that Cardamom responds to fertilizers and irrigation.

The interactionsof nutrients among themselves and with water and light intensity are significant indicating the need for balanced application of all nutrients with supportive irrigation wherever possible and with well-regulated shade discipline.

The rates of application of nutrients needed to approach the target inintensive programs are shown in Table 10.

There exist a large gap between present yields and that could be attainable. Besides refining cultivation practices, attempts areneededto enhance the primary productivity systems for obtaining maximum energy by developing thermophilic systems enriched with reaction centers

Table 7: Soil – Threshold limit of productivity

A	Elevation,	600 to1500 m MSL
	Equilibrium, OM	2 to 4 %
	N release by OM decomposition	90 kg per ha per year
	N application rate for target yield	37.5 kg /100kg capsules
	Threshold productivity- kg capsules /ha	(90/37.5)*100 =240 kg /ha
B	Soil N utilization efficiency	60%
	N utilized by the plants from Soil N available /ha/year	54 kg /ha/yr.(60% of90 kg)
	N content, whole plant analysis	1.50 %
	Equivalent Biomass	3600 kg/ha
	CAPSULES at harvest index of 0.067	241 kg/ha

Table 8: Threshold limits of Productivity - kg/ha:

A: NPP, unconstrained supply of water and nutrients, kg/ha (maximum at 50 to 70 % light intensity)	**kg/ha**
NPP, kg /ha	18000
water requirement to reach NPP- in rainfall units, cm	840
nutrients to reach NPP, N kg /ha along with proportional application of all other nutrients	6750
B: NPP, unconstrained supply nutrients	
uniformly distributed rainfall , capsules kg /ha per 100 cm rainfall	2143
rainfall only, with dry periods; Capsules kg /ha per 100 cm rainfall	1600
rainfall +irrigation; Capsules kg/ha, per 100 cm rainfall	2100
C: NPP, unconstrained supply of water	
soil nutrients ,only natural resources	240

Table 9: Productivity trend - Dry capsules kg/ha

Year	1971-1980	1981-1990	1991-2000	2001-2010	2011-17
Area '000ha	92	95	79	91	89
Productivity kg/ha	36	41	85	171	263

Source: Data from various issues of 'Spices statistics', Spices Board, Cochin and Agricultural production statistics, Ministry of Agriculture, Government of India, Delhi.

Table 10: Nutrients for every 100 kg Capsules targeted

A							B						
Macro - nutrients kg				Macro elements kg			Micro - nutrients g						
N	P	Ca	S	Mg	K	CL	B	Fe	Mn	ZN	Cu	Mo	Si
37.5	5	12.5	2.5	5.0	75.0	250.0	50.0	250.0	125.0	50.0	15.0	0.025	x

A - Elements going into chemical composition of the biomass ;
B - Mineral elements present in ionic form to for biomass synthesis and hydration of tissues control bio cycles to synthesize chemicals

with respect to chloroplast pigments thru selection, genetics and genetic engineering. This, with refined cultivation practices, will aid in improving the productivity of the cultivars.

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