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ENVIRONMENTAL IMPACTS OF INTENSIVE CARDAMOM (SMALL) CULTIVATION IN INDIAN CARDAMOM HILLS: THE NEED FOR SUSTAINABLE AND EFFICIENT PRACTICES

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Abstract
The recent intensification of small cardamom (*Elettaria cardamomum* Maton) farming, and the prospects of intensification, will have the major detrimental impacts on the Indian cardamom hills (ICH) ecosystem. The increased (4 fold) cardamom production during the past 30 years was associated with a several fold increase in the consumption of fertilizers and pesticides as well as drastic reduction in erstwhile rainforest land and canopy cover. Based on simple linear extension of past trends, and the anticipated future demand of cardamom would be associated with approximately 3 fold increase in both nitrogen and phosphorus fertilizer rates as well as pesticides (4-5 fold increase in number of spray rounds) and further reduction in forest canopy cover (40%). These projected changes would have dramatic impacts on the functioning of the cardamom ecosystem because of complete loss of biodiversity and land and forest degradation. The largest impacts would be on fresh water ecosystem, which would be greatly eutrophied by high rates of nitrogen and phosphorus release from cardamom and tea plantations, and contaminated with various toxic pesticides. These detrimental environmental impacts of intensive cardamom agriculture can be minimized only if there is much more efficient use and recycling of nutrients between forest and soil.

Keywords: Ecosystem services, Environmental impact, Indian cardamom hills, Intensive cardamom agriculture

Introduction

WORLDWIDE the agricultural productions of the past 35 years have been impressive. Grain production, mainly from wheat, rice, and maize, has increased at a rate greater than the human population[1]. Productivity of cardamom in Indian cardamom hills has been spectacular for the last 20 years (1990-2009) period with 4 fold increase from 200 kg to 800 kg ha^{-1} .This increase was envisaged from nutrient poor marginal soils of tropical hills where the biodiversity was the highest until intensification of cardamom agriculture was started. Interestingly, the area under cardamom (Fig.3) cultivation has been declined significantly (by 40%) during the last 35 years. The continued increase in Indian population and its strong correlation with domestic demand would demand for production of cardamom to double. Considering the improved economic conditions of the planters as well as market price of cardamom in the Indian market, and their positive attitude towards the higher levels of pesticides and fertilizer use, further increase in productivity could demand for more chemicalized cardamom agriculture. This raises several important questions. If it is possible for cardamom production to double, again, what impacts would this doubling have on the cardamom hills ecosystem? What routes might be used to decrease such negative impacts on the ecosystem? Exploration of these questions for ecological impacts of intensive agriculture might be, and consideration of practices that might decrease such impacts. In particular, insights are sought in the parallels between ecological intensive agriculture and chemicalized intensive agriculture. Truly, a new long-term, multidisciplinary research program is needed to develop agricultural methods that can lead to at least agricultural sustainability in Indian cardamom hills (ICH) if not environmental sustainability.

Current agricultural practices for intensive cardamom production involve deliberately maintaining ecosystems in a highly simplified, disturbed, and nutrient rich state. To maximize cardamom yields, varieties are carefully selected by planters to suit to altered local growing conditions created by pruning and lopping of forest canopy on regular basis (Plate 1). Limiting factors, such as, plant nutrients (nitrogen, phosphorus etc.), are supplied in excess (6-7 fold increase in the last 30 years), and insect pests and diseases are actively controlled (650 tones of pesticide active ingredients applied during 2009 season). Sufficient sun shine is provided to cardamom plants by felling select forest trees and lopping of tree canopy severely. These are the current features (data are based on recent survey and historical records) of intensively managed cardamom plantations in ICH.

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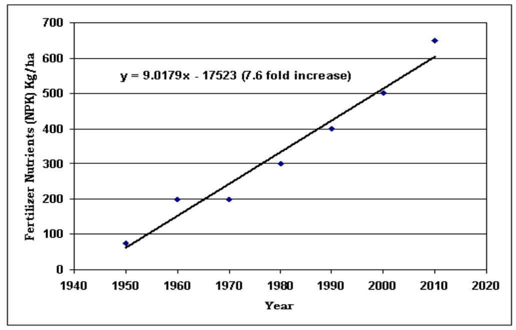
Cardamom was once shade loving rare medicinal plant scattered throughout the tropical rainforest of India and Malaysia, now, it is no more a shade loving crop and occupies every two meters of ICH soils. The monoculture cardamom with fewer types and varieties has replaced that once tropical rainforest ecosystem that contained highest level of biodiversity including thousands of plant and insect species, and many species of vertebrates[2]. Thus cardamom agriculture in Indian cardamom hills has caused a significant simplification and homogenization. Worlwide, intensification of agriculture has caused four once rare crop plants (barely, maize, rice and wheat) to become dominant plants on the earth as humans became the dominant animal[3]. Therefore entire regions of the world now are dominated by virtual monocultures of a given crop. Although it is difficult to predict the future of the cardamom agriculture because of global and local change, some insights can be obtained by an analysis of the broad trends that occurred during the recent increase in cardamom productivity. These trends may give some insights into the local environmental impacts that the further increase of cardamom productivity may have in the marginal soils of ICH. Next, I consider the science of cardamom ecology, which can offer solutions to these environmental problems. Finally, I pose the major environmental challenges that ICH face as local population pressure on land and demand for more cardamom production continue to increase.

The ecology of intensive cardamom production practices in ICH

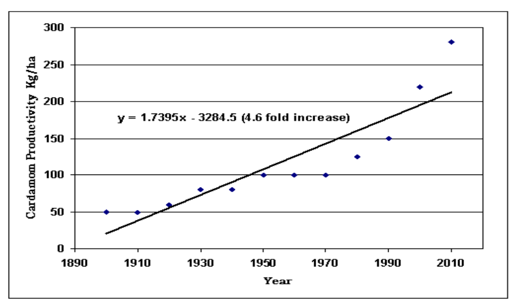
Based on the historical records and recent survey data one can analyze the trends of intensification in ICH during the past three–four decades and the factors that allowed cardamom production to several fold. Majority of the area (25000 ha) under yielding cardamom plantation has been maintained intensively at least for the last 15 years (1995-2009). The productivity of cardamom has tripled mainly because of intensification. Many factors have contributed to the recent jump of cardamom productivity. The use of high yielding varieties like *Njallani* since its induction in the mid 1990's, along with better agricultural practices were important, and were increased use of plant production and protection chemicals for better pest control and yield. Besides, there were marked increases in the amounts of plant nutrient fertilizers and manures applied each month as well as plantation (Fig.1), in the proportion of land that was irrigated, and in the loss of forest canopy. It was the combined effects of all of these factors, and more, that allowed cardamom production to triple in the last 15 years.

Figure 1 Application of plant nutrients for cardamom in CHR (Source: Cardamom Board and Kerala Agricultural University)



The survey and historical data show that this recent increase in cardamom production and productivity was accompanied by several fold increase in fertilization, irrigation and by decrease in land in cultivation. Other agronomic aspects like clean cultivation and shade regulation also played significant role for enhanced productivity. What might be required to further doubling the cardamom productivity? An optimistic scenario might assume that, during the future periods, all of the relationships (Fig.2) would remain linear and gains in crop genetics, pest control, and cultivation practices would continue at their previous rates. The assumption of the linearity and extrapolation can be used to predict the rates of fertilization and pesticide application to increase the productivity of cardamom that can meet our future demand. These changes represent tripling of fertilization and pesticide application, and doubling of irrigation.

Figure 2 Cardamom productivity (India) decadal trend from 1900-2009 (Source: Spices Board, Govt. of India, Ministry of Commerce and Historic records)



Such projections of yields of cardamom may be overly optimistic for several reasons. First, the yield of a crop is a saturating function of supply of its limiting source. Adding higher levels of fertilizers to already marginal tropical hill soils which can hold lesser nutrients comparatively will have good impact on cardamom yields, but have lesser fertilizer use efficiency and more environmental implications.

Second, yield benefits from genetic potentials have already occurred especially for *Vazhukka* types[1]. Since cardamom is a cross pollinated crop, once most of the original genetic variance preserved within crop landraces and wild relatives has been exploited, future breeding based yield gains are likely to be small or difficult to obtain from the present variety *Njallani* whose close optimum morphological and physiology trade off surface point would yield little from further selection and breeding from the variety[1].

Cardamom farming has occupied already the best soils and locations (although these cardamom hills have low soil fertility and productivity). The soil physical texture (loamy) of cardamom soils (A horizon) would not allow to hold more nutrients and is highly prone to erosion. The sand, silt and clay fractions ranges from 34-25%, 30-20% and 36-55% respectively. Therefore any further expansion of cardamom cultivation in cardamom hills is unlikely and may not be productive. A doubling of cardamom production may require a much greater increase in forest lands dedicated for its farming, this is highly unlikely to get continuous high yields. The resulting cardamom ecosystem destruction would vastly increase the proportion of the species threatened with extinction. It also would cause a massive release of CO_2 from land clearing and intensive cardamom farming practices. Because high diversity ecosystems generally occur on less fertile soils[1], the conversion of less fertile ecosystem to agriculture would disproportionately impact biodiversity. Cardamom is highly sensitive to moisture and air temperature. Even short period of drought and excess rainfall will affect growth and yield of cardamom. Under fast changing mountain climate in ICH intensive cardamom farming would pose enormous risks and challenges.

Ecological impacts of intensive cardamom production

Clean cultivation (Plate 2) and earthing up, severe pruning and shade lopping (Plate 1) as well as forest under growth clearing were the major causes for complete elimination of biodiversity including waysides or roadsides in the ICH. The ICH were part of the once a biodiversity hot spot (4 Pascal) where continuous monoculture farming of cardamom and tea has been taken up for centuries. Selective tree felling and degradation (1.6%) of cardamom hills go fast than other places in southern India[4]. Regeneration of pruned trees is very slow in cardamom hills for various reasons like changes in the local climatic and environmental conditions and improved soil fertility status. The ongoing deforestation in cardamom hills has accelerated local warming, resulting in higher loss of soil organic carbon[5]. Significant reduction in night time temperature minima has been envisaged in severely lopped cardamom areas, resulting greater diurnal temperature variations. Application of lime materials to cardamom plantations common to increase soil pH and to decrease pathogenic infection during rainy season, which also contributes to soil carbon loss as CO_2 because lime materials with moist soil ultimately gives off carbonic acid which is highly unstable in soil system, disassociates into CO_2 and water. Thus lime addition contributes more CO2 into ICH atmosphere.

Plate 1. Severity of shade lopping in cardamom plantation in ICH

Plate 2. Loss of biodiversity due to clean cultivation and clearing of undergrowth in fresh cardamom plantations in ICH

Continuous cultivation of cardamom for centuries in ICH has ended up with soil degradation which is irreversible at least for few decades from present. Soil environmental degradation in terms of increased acidity, accumulation of heavy and rare metals (Cu, Pb and Zn) and pesticide residues (endosulfan, chlorpyriphos, DDT), leaching of N and P through run off and surface waters are significant and require special attention. Manures are more likely to contribute to poor water quality by the addition of material with a high chemical oxygen demand. These environmental problems arise in ICH because of very high application of manures (including slurry prepared from the dung and urine of cattle and poultry) and fertilizers to maximize the yield of cardamom. A tripling of phosphorus supply rates is likely to adversely impact many aquatic systems, especially those that have significant inputs of eroded cardamom hill soils or phosphorus rich wastes livestock and poultry[6].The long-term ecological impacts of increased rates of agricultural nitrogen and phosphorus input will depend on the levels to which these nutrients are accumulated in various pools of ICH and non agricultural systems. These levels are uncertain with in an ecosystem because of complexities of the local biogeochemistry of nitrogen and phosphorus. As emphasized by[7], scientific effort comparable to that on the global carbon cycle will be needed to understand the impacts on biogeochemistry of elevated rates of agricultural nitrogen and phosphorus application.

Steady higher yield realized by cardamom planters in the recent past years is attributed to continuous higher application of manures and fertilizers to a nutrient poor soil. Such a high application always results in higher concentrations of plant nutrients in tissues and organs, which makes cardamom more susceptible to insect pests and diseases. Higher insect pest population and disease intensity will be expected always when the tissue concentrations of plant nutrients particularly N remains high. This can lead to frequent and increased application of pesticides. Nutrient addition also causes dominance by few, often formerly rare plants and animal species, and the loss of biodiversity [8-11]. Shade lopping and selective tree felling, resulting in significant change in microclimate system, which often increased pests especially white flies, thrips and soil root grubs and nematodes.

Cardamom consumed more insecticides than those of fungicides, nematicides and flowering hormones. The toxicological parameters like per capita consumption, pesticide intensity and risk weighed active ingredients are high for cardamom than tea. Tea consumed more of herbicides than others. As far as number of pesticide applications, tea requires more than 35 rounds of pesticide sprays in a year while cardamom needs 15-18 rounds of pesticide sprays per year. Higher quantities of toxic flowering hormones and soil insecticides are given for cardamom system. Considering the number of rounds of pesticide sprays and quantity of pesticides used in ICH one can rate cardamom as the highest pesticide consuming rainfed crop in the world. Therefore ICH is not only a biodiversity hot spot but also a pesticide hot spot of the world.

Almost all the planters surveyed and interviewed have serious concern about the climate change induced water problems (scarcity during dry summer) and felt that it can have negative impact on the production of cardamom. Under changing future climatic scenario, a doubling of irrigation would pose additional environmental problems unless its efficiency is increased. Additional irrigation would divert more water from aquatic ecosystem and impact ground waters and surface waters via additional leaching of agrochemicals. Other aspects of sustainability of cardamom including pesticide pollution and contamination of environment, forest degradation, labor scarcity, cost of pesticides and other inputs etc. are of less important. Planters are very particular about the price fluctuation in the national and international markets, and they want fair price always. Only a few planters have expressed mild health problems with spraying of triazophos, lambdacyhalothrin and phorate. Pesticide applicators never take safety and precautionary measures during application of pesticides. Neither planters nor applicators have had training or awareness on IPM. Planters rely only on chemicals for pest management. Upon intensive cardamom cultivation over the years cardamom soils have accumulated copper and iron and lost boron and zinc. As far primary nutrients are concerned cardamom soils have depleted its nitrogen and phosphorous levels.

Concentrations of heavy metals (Cu, Cd, Zn, Al, Si, Pb) and anions like nitrate, phosphate and fluoride may increase in surface and ground waters to levels that can cause deterioration of water quality (Table 2). Current and future warming may aggravate this problem and therefore toxicology of environmental contaminants in cardamom agroecosystems will be altered. Acidification induced degradation of ICH soils are inevitable and not recoverable until the discontinuation of the existing practice of excessive N-fertilization and heavy manuring. Hydrogen ion activity in cardamom soils has been doubled due to heavy fertilizer application. The reason being, even the minimum application of nitrate nitrogen at the rate of 50 kg N ha^{-1} can decrease soil pH by 0.3 units, which is sufficient enough to increase hydrogen ion activity to double. To neutralize this, a minimum of 500 kg of lime materials is needed per season per hectare.

Table 1. Species that can be used for breeding and biotechnological program of cultivated cardamom types in ICH

Sl.No.	Scientific Name	Common Name
1.	Amomum sublatum	Black cardamom
2.	Amomum aromaticum	Bengal cardamom
3.	Amomum maximum	Java cardamom
4.	Amomum xanthioides	Thai cardamom
5.	Amomum globosum	Chinese cardamom
6.	Amomum tsao-co	Chinese cardamom
7.	Amomum krervanh	Cambodian cardamom
8.	Amomum kapulaks	Thai cardamom
9.	Aframomum korarims	Ethiopian cardamom
10.	Aframomum mala	Kenyen cardamom
11.	Aframomum melegueta	Guinea cardamom
12.	Aframomum danielli	Cameroon cardamom
13.	Aframomum angustifolium	Madagascar cardamom

Table 2. Concentration (ppm) of anions, cations and heavy metals in the water samples of agroecosystems of Indian cardamom hills (n=8).

Water quality parameters	Cardamom		Tea	
	Openwell	Borewell	Openwell	Borewell
Al	0.22	n.d	0.01	n.d
B	0.01	0.01	0.01	n.d
Ca	17.53	15.73	22	27.96
Cd	0.013	0.2	0.02	0.02
Cl	53.82	16.8	64.33	18
CO_3	1.2	0	15.6	0.96
Cu	0.01	0.01	0.01	0.01
EC, μs/cm	329.17	463.67	432.67	441
F	0.06	0.88	0.24	0.37
Fe	3.31	1.07	3.3	1.05
HCO_3	27.98	179.33	47.47	201
K	7.22	1.73	15.73	1.94
Mg	4.77	8.77	9.83	10.74
Na	29	56.23	34.67	45.88
NO_3	37.74	0.4	49.87	0.24
Pb	0.04	0.03	0.01	n.d
pH	9.26	7.77	9.68	7.69
Si	5.32	1.09	5.23	1.07
SO_4	11.53	33.07	9.47	36.92
Zn	0.06	0.01	0.05	n.d

n.d = not detectable

Cardamom yield, quality and Loss of ecosystem services

Crop production depends on soil fertility, fertility created by ecosystem is destroyed when lands are converted to intensive farming especially marginal tropical hill soils. Cardamom is a cross pollinated crop, and pollination is effected by honey bees. The honey bee activity is very much reduced because of heavy application of toxic pesticides and disturbance and degradation caused to cardamom hills. Quality of cardamom particularly the number of seeds per capsule and its concentration of essential oil as well as weight of cardamom capsules per unit volume (liter weight) has been reduced. Apart from this, honey is an important income source for tribal communities in cardamom hills. During the last 15 years avian fauna diversity has reduced significantly, and now, hearing the voices of birds is a surprise. Natural enemy population for major insect pests and diseases over the last 10 years has been declined owing to increased number of pesticide sprays irrespective of climate seasons (Fig.4). Existing natural ecosystems provide, at no cost, pure drinkable water. In contrast, the ground and surface water associated with intensive cardamom ecosystem contains sufficiently higher amounts of anions and cations that cause health problems as to be unfit for human consumption. Cardamom hills once had lots of wet lands and thick forest on the slopes, which helped meter the release of water into the steams and rivers thus helped in flood control. The current situation is uncontrollable during both extreme events of severe drought and flood or water logging. In future, cardamom will be subjected to frequent extreme climatic events that can offset cardamom productivity. The ICH and Periyar Tiger Reserves (PTR) are the major attraction of international tourists. The loss of biodiversity and environmental contamination with chemicals will have tremendous impacts on tourism industry in Kerala.

Figure 3. Changes in the area under cardamom cultivation during the last six decades in ICH

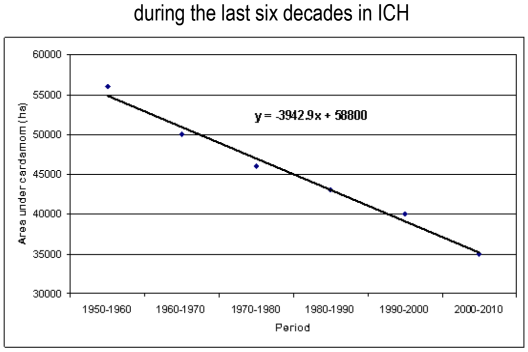
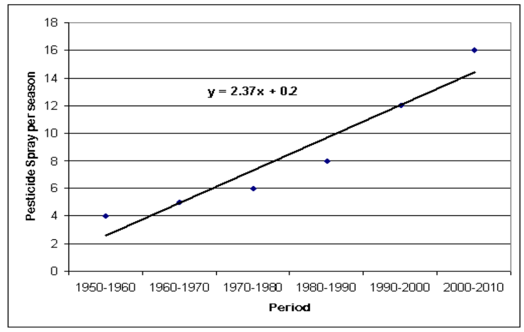


Figure 4. Changes in number of pesticide sprays during the last six decades in ICH



Ecological insights into agricultural impacts and sustainability

The intensification of cardamom farming is passing a threshold and became the major sources of nitrogen and phosphorus as well as metal nutrients (Fe, Al, Si, Zn and Cu) loading to terrestrial and fresh water ecosystems. If this loading increases as projected, cardamom agriculture will adversely transform majority of the adjoining areas as well. What might be done to decrease the environmental impacts of high intensity cardamom farming while maintaining or improving its productivity, stability, or sustainability? This major challenge will have no single, easy solution because forest is one of the important components in cardamom farming. Partial solutions will come from increases in the precision and efficiency of nutrient and pesticide use, from advances in crop breeding and biotechnology, and variety of solutions from agroforestry and ecosystem function. Functioning of cardamom agroecosystem is known to depend on traits of cardamom (both composition and diversity), and the composition and diversity of forest species, and the degree of physical disturbances they experience. If we consider this, and the impacts on the current level of intensification, the cardamom ecosystem is considered highly unsustainable. Cardamom is farmed under high density and intensity, paving way for contagious spread of epidemics, resulting in higher consumption of pesticides. Up to 20 years ago, the plantations had several cultivars from major cardamom types, and used to get infested with few insect pests and diseases, resulting very low pesticide consumption. This is due to higher cardamom diversity causing slow spread of epidemics throughout the population. The monoculture single variety (*Njallani*) cardamom under intensive fertilization could be more susceptible to pathogenic organisms and insect pests because of higher nutritional status of its tissues and organs. Important cardamom relatives of Asian and African types that can be used for modern breeding and crop improvement program is given in Table 1. Same approach of current intensification practices will have significant environmental costs that could be lowered by reestablishing the nutrient cycling system between forest and soils. In cardamom hills, other agronomic practices (incorporation of green manure and cover crops etc.) will not work owing to the uniqueness of cardamom ecosystem.

Regulations are needed now for manures and city wastes that are major sources of nutrient loading in soils and water systems. In the present scenario of intensification, *Njallani* is the best cardamom variety which has very high nutrient absorption capacity owing to its high root cation exchange capacity than the past popular varieties like PV-1. The environmental benefits of the ruling variety (*Njallani*) come from higher consumption of soil nitrate and ammonium that would be lost via leaching and vitalization. This would decrease impacts on off-site ecosystems. Improved varieties and selections of cardamom that would have higher yield potentials can decrease some of the future environmental impacts; such varieties should be brought into future cardamom farming to attain stability of cardamom ecosystem. The greater stability of more diverse cardamom system means that the cardamom diversity has an insurance value by minimizing year to year variance in yields therefore a mixture of appropriately chosen genotypes of high yielding cardamom can make cardamom ecosystem more stable than mono variety system.

Conclusions

Intensive monoculture single variety (*Njallani*) cardamom farming in low fertile marginal soils of ICH brought about several environmental problems despite continuous higher yields. Ecological principles suggest that such systems will be relatively unstable, will have high leaching loss of nutrients, will be susceptible to invasion by weedy species, and will have high incidences of insect pests and diseases-all of which do occur in ICH. It is critical that current practices of intensive cardamom farming be modified to minimize environmental impacts even though many such practices are likely to increase the cost of production of cardamom which is already extremely high for an Indian farmer. Considering all of the above, ecologically intensive cardamom farming could be the appropriate one for the sustainability of cardamom farming and ICH.

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