Cultivation of Medicinal and Aromatic Plants in India - a Commercial Approach

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Abstract

India (8°-30° N and 68-97.5° E) exhibits a wide range in topography and climate, which has a bearing on its vegetation and floristic composition. This subcontinent is one of the World's 12 leading Biodiversity Centres, encompassing 16 different agro-climatic zones, 10 vegetation zones, 25 biotic provinces and about 426 habitats of specific species. It has been estimated that about 45,000 plant species (nearly 20% of the global species) occurs in the Indian Sub-continent. About 3,500 species of both higher and lower plant groups are of medicinal values. More than 80 percent of medicinal and aromatic plants (MAP) are collected from 17 million hectares of Indian forest land. However, many of these, due to over-exploitation have become rare (*Rheum emodi, Aconitum deinorrhizum*), threatened (*Rauvolfia serpentina, Berberis artistata*), or endangered ones (*Sassurea lappa, Dioscorea deltoidea*). Problems arising out of rapid genetic loss of medicinal plants forced the need for international co-operation and co-ordination to undertake programmes for conservation of medicinal plants to ensure that adequate quantities are available for future generations.

Cultivation of medicinal and aromatic species gives scope to improve the quality of the drugs. Merits of commercial cultivation of MAP is the outcome of implementation of number of critical factors like locate-selection; good genetically stable planting materials; good agrotechnological practices; nutrient input; harvesting management and implementation of suitable post harvesting techniques to preserve the end product till smart and effective marketing arrangements are made.

There is a growing demand today for plant-based medicines, health products, pharmaceuticals, food supplements, cosmetics etc. in the international market. The international market of medicinal plants is over 60 billion US dollar per year, which is growing at the rate of 7 percent per annum. The present export of herbal raw materials and medicines from India is about US dollar 100-114 million approximately per year. India is one of the major exporter of crude drugs mainly to six developed countries viz. USA, Germany, France, Switzerland, U.K. and Japan, who share between them 75-80 per cent of the total export market.

CULTIVATION OF MEDICINAL AND AROMATIC PLANTS (MAP) IN INDIA

Techno-economical Considerations for Cultivation of MAP in India

Loss of genetic diversity, particularly related to potential medicinal species has taken place; more so in the Worlds' tropical rain forests and its conservation aspect has, of late, captured the attention of herbal scientists and experts (Duke, 1985). With emphasis it can be stated that the ultimate solution of medicinal plant conservation is medicinal plant cultivation in a scientific way (Foster, 1993).

Botanical producer will desire to optimise yield from production; whereas user or entrepreneur will want to manufacture a product of uniform quality. Environmental factors play dramatic roles on biomass yield and composition, and also on its consistency.

The process of selection of geographical site is very important and will have to be tailor-made to meet the requirement of a particular botanical or a group of botanicals with ecological homogeneity.

Elevation of the region has a profound bearing on successful cultivation of MAP. Indian cultivation of *Datura innoxia, Atropa belladona, Catharanthus roseus, Rauvolfia serpentina, Cepecacuanha* spp. and *Hyoscyamus niger* are appropriate examples (Table 1). Slope face is another factor, which determines variations of diurnal light intensity and temperature necessary for better growth and development of MAP. Latitude also have pronounced effect on biomass composition e.g. *Atropa belladona*.

Adequate soil moisture and moderate nutrient status generally meet the requirements for growing MAP in India. However in some cases (e.g. *Psyllium, Cassia, Catharanthus, Withania, Rauvolfia, Cymbopogon*), the plantation can profitably thrive on low fertility soils of warmer regions. *Pyrethrum, Solanum* spp., *Jasminium* and *Ocimum* spp. can be economically grown over medium fertility soils. In case of *Papaver, Dioscorea* spp., *Mentha* spp. and *Cymbopogon* spp., high fertility soil and liberal irrigation will be necessary for successful growth of plantation. Rained cultivation in India is widely followed in *Withania, Cassia, Vetiveria* and *Eucalyptus citriodora*.

Medicinal and aromatic crops are generally adapted to a wide range of soil texture and pH. *Plantago, Cassia, Cymbopogon* growing over light soils become high yielding when grown over loam and clay loam (nearly 80% increase in yield in case of *Plantago ovata*). *Vetiveria* is unique for its tolerance to soil alkalinity and periodic flooding and water logging of fields; conditions however producing no adverse effect on total oil yield and its composition. *Cinchona, Cephalis* and *Coptis* have preference for acidic soils (5-6 pH); whereas species like *Aloe, Pandanus, Urginea, Commiphora* are grown in soils of higher pH.

Day length have been found to influence growth and development of certain medicinal and aromatic crops in India. Commercial cultivation of *Mentha, Glycyrrhiza, Coptis, Humulus* prefer more than 14 hours of day length for high crop yield whereas citronella, *Pelargonium* and *Pogostemon* are short-day plants and essential oil production can be increased by nearly 25% by satisfying appropriate light requirements to these crops.

Senna is a day-neutral plant and cultivation success is independent of prevalent day-light duration. In crops *like Solanum, Digitalis, Rauvolfia* and *Dioscorea*, effects of photoperiodic cycles (long days) have also been clearly established (Chatterjee, 1986).

Regulatory role of light intensity on improvement of performance of a number of medicinally important crops has been established. In *Mentha*, ample sunshine is necessary at maturity for higher content of oil and menthol content. Economics of cultivation of this species is very much affected if crops are harvested in rainy or cloudy days due to the fact that higher conversion of menthol into menthone. Amongst other plantation crops, low light intensity favours production like *Cephalis*; thereby necessitating artificial shading during commercial cultivation. Only 20-25 percent day light intensity is recommended for optimum productivity performance. Berberine content is nearly 10-15 percent higher in roots of *Coptis japonica*, when on average, 70 percent of incident light is intercepted. Additional light promotes the AP accumulation in *Digitalis* spp. and *Solanum khasianum* (Table 2.). Reduced light intensity (nearly 40 %) by growing *Cinchona* under shade tree increases percentage of quinine and related alkaloids by more than 30 percent; as well as bark yield by 30-40 % (Table 3).

Role of atmospheric temperature on success of medicinal and aromatic plant cultivation can also be well exemplified. *Pyrethrum* growing in southern hills is favoured by lower minimum temperature increasing the yield of dry matter and total pyrethrin contents. In general increasing temperature up to a maximum (prior to physiological damage) favour increased secondary metabolite production in many alkaloid and terpene producing medicinal plants. Composition of secondary metabolite may also be changed. Low temperature favours morphine increase in poppy and decreases the total principle content.

Nutrient Uptake and Use of PGR (Plant Growth Regulator)/Micronutrients

Fertiliser management is a key factor in the success of MAP cultivation. Productive fertiliser management varies from crop to crop; taking into consideration that other regulatory factors for a good plantation are optimally provided. Higher productivity in respect of biomass as well as AP contents has been obtained in a variety of medicinal and aromatic crops by application of NPK. Nitrogen fertilisers augmented alkaloid yield in *Rauvolfia* and *Atropa*; diosgenin in *Dioscorea* spp. and *Costus;* sennosides in *Cassia* and essential oils in *Cymbopogon* grasses, *Vetiveria* and *Mentha*. In general it can be suggested that medium levels of N, P and K are nearly optimum for secondary metabolite production. By increasing nutrients, biomass as well as accumulation of active principle may change. On some MAP, active principle accumulation remains unchanged (*Andographis*); while in still others (*Costus*), AP decreases. In other words, each medicinal plant has its own specific requirements of NPK and other nutrition elements (Table 4). Remarkable advantages in growth and development by use of bio-fertilisers in MAP cultivation in India has also been obtained.

PGR like herbal-origin n-triacontanol (saturated fatty alcohol used commercially) has in recent years, been profitably utilised in cultivation of MAP (Chatterjee, 1996); effects being more pronounced in repairing the production damages, caused by moisture and temperature stresses (Table 5. and Table 6).

Water Stress Condition

Relationship between water availability and optimum production of MAP is rather complex. Differences exist in adaptation of specific plant species to environmental water stress and water management. Consideration of per-plant response vis-à-vis a whole field response is quite critical. In general, water-stress to botanicals might not be productive; although, a stress correctly timed and of appropriate duration and intensity might be beneficial (Simon, 1999). In *Cinchona,* increased availability of water during heavy rainy season in Eastern Himalayan region suppresses secondary metabolite accumulation, leading sometimes to ‘zero’ alkaloids; in others in tropical region, it stimulates secondary metabolite accumulation (*Costus*). Again moisture stress under certain conditions in *Rauvolfia* and *Catharanthus* produce improved root, root-shoot ratio and higher total alkaloid contents and root yield (Table 5). Moisture stress also profitably increases alkaloids in several solanaceous crops like *Atropa, Hyoscyamus, Datura* and in other species like *Rauvolfia* and *Catharanthus.*

Localisation of Secondary Metabolites and Role of Developmental Factors in Cultivation of MAP

Most of the botanicals keep confined the bio-active compounds in specialised structures due to the toxicity of these secondary metabolite products. The knowledge of location of such compounds in plants is of paramount importance to ensure proper harvesting and collection of the botanical. It varies crop to crop; some having maximum in particular stage and position of leaves (*Digitalis, Mentha*); some during particular stage of development of leaves (*Andrographis*); some during particular growth period (*Taxus, Uragoga*). There is no point of harvesting a prospective crop of *Rauvolfia (*say about 2,500 kg dry roots per hectare after three years during fruiting when total alkaloid content is about 2.4-2.5% in contrast to about 2.8-3.0% total alkaloid during flowering, when yield of dry root is 2,300-2,400 kg per hectare). In actual practice, *Rauvolfia* roots are harvested, generally during late-flowering stage of plants, from about two and half years plantation (Table 7).

Developmental stages on MAP monitor active principle synthesis. Concentration of AP in botanical is of paramount importance when commercial avenues of the harvest is explored. One important aspect is impact of growth and development on the biomass and on its composition. This happens due to the changes in biosynthetic capability because of changes in the state of differentiation of the biomass and tissues associated with active principle production and accumulation. Success in commercial cultivation depends on appropriate period of harvest (Table 8. and Table 9). In *Catharanthus, Datura, Solanum* and *Dioscorea* AP becomes maximum during reproductive phase and harvests are generally made when nearly 60-70 percent of the reproductive phase is completed. In *Costus speciosus* initiation of reproductive phase registers maximum diosgenin content. In most perennially grown medicinal plant species, maximum attainment of AP takes place after 3-4 years (in some cases like *Cinchona* during 7-8th year) and optimum period of harvest is determined accordingly.

Formation of AP is also correlated with certain other physiological growth parameters like formation of laminar area, flowers, fruits as also rate of linear growth. Application of such factors in determination of harvesting time, though beset with other growth considerations in MAP, in case of *Digitalis lanata* and *Mentha citrata*, the knowledge has been profitably utilised in prevalent cultural practices followed in India.

DOMESTICATION OF SOME IMPORTANT EXOTIC MEDICINAL PLANTS FOR CULTIVATION IN INDIA

Domestication of medicinal and aromatic plants is a crucial phenomena that ensures uniformity and consistency in the yield factor of secondary metabolite. Whether plants are high or low in secondary metabolite content is not really the question; though high levels are often desirable and required. Rather it is the genuine assurance of the genetic material that allows more consistency in the quality of the raw material and contents of the bioactive compounds; providing greater opportunity to meet future quality standards.

In India domestication of MAP has given a lead in commercial exploitation of desirable medicinal and aromatic plant and a number of species, having a natural abode and facing threats in the forest by over-exploitation, has been brought to organised cultivation in different regions of India (*Andrographis, Gymnema*).

The same is true for exotic species also. *Cephalis ipecacuanha* plants are originally from Brazil and the clones that have been acclimated under Indian conditions show augmented growth, higher root quantity and alkaloids as compared to Brazilian and Nicaraguan species, in lower foothills of E. Himalayan. *Catharanthus roseus*, originally from Madagascar, has been domesticated freely under Indian conditions. Plants prefer plains than hills and region wise trials show South Indian conditions to be more conducive for growth and development of the crop. *Dioscorea composita*, known to be Mexican species has also been successfully acclimated under conditions of South and Eastern Indian plains with optimum growth and yield of diosgenin. *Solanum laciniatum* is an Australian species of relatively recent introduction and has also shown to be very promising at relatively higher altitudes of Himalayas and thus successfully domesticated . Such instances of successful domestication of medicinal crops in India have been studied in details (Chatterjee, 1996).

GENETIC IMPROVEMENT AND BIOTECHNOLOGY OF MAP IN INDIA

Genetic Improvement

In India considerable emphasis has been given on genetic resource management in medicinal and aromatic crops. Field gene banks have been created which provides variants in form and active principle contents; serving as parent materials to breed new desirable varieties. In most cultivation new, high yielding and disease resistant varieties, released through selection are being used for higher productivity with economic gains. Some of the crops deserve special mention in this connection viz. *Plantago ovata, Papaver somniferum, Rauvolfia serpentina, Hyoscyamus niger, Mentha arvensis, Glycyrrhiza glabra, Cassia angustifolia and Catharanthus roseus.* Regular breeding work in many corps have yielded new varieties (Gupta and Chadha 1995).

Mutation breeding has also produced success in crops like *Hyoscyamus, Plantago, Jasminium* and to some extent limited success in *Rauvolfia, Dioscorea, Datura, Catharanthus* and *Papaver.*

Biotechnology in MAP

Biotechnology has become important in three ways :

(i) as a tool for mass multiplication of plantlets having high precision in uniformity, freedom for pathogens. In India, limited success has been obtained in botanical crops like *Aconitum, Podophyllum, Dioscorea, Ferula,* where plantation areas are limited due to scarcity of planting materials.

(ii) possibilities of biotransformation and bioconversion of phytochemicals to a more valuable derivative in plant cell culture which is difficult to achieve by chemical synthesis e.g. high valued phytochemicals like diosgenin from steroidal *Dioscorea spp.;* indole alkaloids (ajmalicine) from *Catharanthus*; glycosides from *Digitalis* for commercial gains.

(iii) besides, it has become an efficient means of in-vitro conservation of genetic resources of MAP at extremely low temperature for long term storage.

Micropropagation: In India success has been achieved to produce high valued phytochemicals like indole alkaloids (ajmalicine) from *Catharanthus*; glycosides from *Digitalis*; podophyllotoxin from *Podophyllum* spp. A particular mention can be made of Indian *Podophyllum* (*P .emodi* var. *hexandrum*); when collected at proper season not only contains 2 and half times or even more of resin compared to *American podophyllum* but this resin has double the amount of podophyllotoxin (anticancer drug tenoposide and etoposide). Major problem in cultivation is that seeds take very long time to germinate. Micropropagation techniques need to be perfected in this area.

ECONOMICS OF CULTIVATION OF MAP IN INDIA

A cultivator of medicinal and aromatic plants wants to be sure of his investments in the cultivation programme in terms of cost benefit ratio and which is very much related to his selection of crops; its agrotechnology of growing; proper harvesting technology and vis-à-vis post harvest management and lastly the marketing prospects of his produce. The diverse nature of factors related to the success of MAP growing is very complex and proper monitoring of different factors appear to be very crucial. India’s wide ecological diversity provide successful implementation to one’s programmes but with application of proven GAP and GMP. A medicinal or aromatic crop, on proper selection of varieties/strains, often leads to an economically viable plantation. Some examples of costs involved in different MAP crops are provided in the Tables 10. and 11.

Harvesting Management and Yield of Botanicals

In commercial cultivation programmes of MAP, an in-depth knowledge of growth and development phenomenon of the botanical as well as its appropriate production and collection with the objective of receiving an uniform, consistence and rich bioactive end product, will have to be mastered. Knowledge of when the active compound is accumulated and when, plays a very deciding role in the entire process of successful botanical cultivation and harvesting. Some specific data in the Tables 12. and 13. illustrate this contention.

It will be clear from the contents of the above mentioned data that raw material of different botanicals are to be harvested during proper time of season; at proper stage of developmental growth keeping in view its correlative relationship with plant and its organs. Tribal professional doctors, in general select the time and seasons for collection of medicinal plants depending on the parts used (Pal and Jain, 1998).

Post Harvesting Problems

Management of harvesting processes and handling of post-harvest products need to be taken very effectively and in this area, Indian cultivators face multitude of problems. More than 50 percent of botanical cultivators in India, particularly in humid regions, face challenges in short term as well as gradual drying processes and they generally take-up the process in a collective manner where other similar produces come. However, this operation also faces difficulties due to not so efficient communication system in village areas.

In India, post harvest loss significantly exists, particularly in rural areas where MAP cultivation takes place. In the Table 14. this loss is illustrated.

Costs Benefits

It will be worthwhile to examine the cultivation cost, yield of botanicals raw materials/ products and gain in financial terms of some important MAP grown in India. The expenditure figures have been arrived at on consideration of average costs on cultivation processes under condition of irrigation, fertiliser and other input costs, harvesting cost, cost of manpower and average land lease values; all taken together. Yield data of the produce has been based on production of botanicals in different growing regions of a specific crop and income reflects the prevailing selling prices of the products in India and its neighbouring countries (Table 15).

Envisaged Medicinal Plant Farm/Plantation Size and Probable Costs Involved

Economic size of cultivation is very important in case of commercially growing medicinal and aromatic plants. In India small farmers/co-operatives develop relatively smaller size cultivation plots giving much care as well as labour which does not fall in line with economic viability of large-area plantation. Costs vis-à-vis productive factors has been analysed and the Table 16. may help in determining crop growing area requirements of MAP cultivation on commercial lines in Indian subcontinent.

Present Utilisation Pattern of MAP in India and Market

Per capita annual consumption of drugs in India is about Rs. 125 which is the lowest in the world because the majorities consume medicinal plants as principal health care resources. According to the estimates of World Health Organisation (WHO), 80 per cent of population of the developing countries depend mostly on plant drugs for their primary health care. Medicinal plants occupy an important position in the socio cultural, spiritual and medical arena of rural people of India. One and a half million practitioners of Indian System of Medicine and Homeopathy (ISM and H) use medicinal plants in preventive, promotive and curative applications. There are about 4,60,000 registered practitioners of ISM and H who use medicinal plants in the codified streams. Besides there are also 7,843 registered pharmacies of ISM and 851 Homeopathy and a number of unlicensed small scale units (data up to 1999). About 3500 species are estimated to be used in human and animal health care, but the pharmaceutical industries have concentrated in about 700 plant species.

Crude drugs and dried parts of the medicinal plants form the essential raw materials, required for the production of traditional medicines like Ayurveda, Sidha, Unani, Homeopathy, Tibetan and other systems of medicines including folk, ethno- or tribal medicines. The crude drugs are also utilised for obtaining therapeutically active chemical constituents by specialised methods of extraction, isolation, fractional distillation and purification for use as phytochemicals for the production of modern allopathic medicines.

DEMAND OF BOTANICALS - AN OVERALL VIEW

International Market Scenario

Developing countries are the leading suppliers of medicinal plants (Akerele, 1991, Handa, 1993.). They are the sole producers and exporters of a number of medicinal species that does not occur elsewhere e.g. *Cinchona*, *Uragoga* and *Rauvolfia* species. In the case of other botanicals like *Chamomile* and *Glycyrrhiza*, which also occur elsewhere but are difficult to obtain in sufficient quantities from traditional suppliers owing to manpower scarcity and rising production costs, developing countries are increasingly providing new sources of supply. However the supply cycles in many countries have resulted prices to fluctuate widely and scare away, both supplies and end users from the market. A need for an orderly development of the market is of prime importance at the present scenario towards which end, other countries could seek the co-operation of India by way of initial contacts being established with large volume end-users in developed countries and also provide technical interaction and necessary financing.

The supply and price fluctuation of the natural plant products have caused the pharmaceutical industries to invest in synthesis of natural products, development of synthetics or to use more readily available natural products to ensure stability of supply. Such examples can be seen in the decline in the use of diosgenin as steroid precursors, decline in production of *Uragoga ipecacuanha* extracts; synthetic production of ephedrine and pseudoephedrine and the like. However good foreign market exists, even nowadays for species and drugs, which are as follows:

Aconite, *Aloe*, *Ammi*, *Atropa, Cinchona, Cassia*, *Dioscorea, Digitalis, Ephedra*, ergot, *Hyoscyamus*, ipecac, liquorice, opium, papain, *Podophyllum, Pyrethrum, Rauvolfia*, rhubarb, *Datura, Valeriana, Vinca, Andrographis, Lawsonia*.

The demand for plant based medicines are on the increase in both developed and developing countries because of the growing recognition that these herbal medicines are non-narcotic natural products easily available at affordable price. These medicines are also a source of health care available to the poor. Besides, the growing demand of plant based medicines, there is also a growing demand for health products, pharmaceuticals, foods supplements, cosmetics etc in international markets. The total estimated demand of herbal material is 55,780 tonnes. And only 25-30 species have a share of about 62-65 percent.

Indian Market of Botanical Products

For a country which has had easy access to herbal medicines for thousands of years, the progress made in India is very much limited. The vast herbal resources still remain largely untapped. The current market status is far from encouraging. Though allopathic companies are also joining the Ayurvedic fray, this field of medicine still remains alternative. This is evident from the fact that while the allopathic systems accounts for about 90% of the total state expenses on medicare; Ayurveda, along with other systems of alternative medicine are allocated only about 5%.

According to the Chemexcil, national pharmaceutical market is in the order of Rs. 12,500 crores (US $ 2800 million) of which Ayurvedic market is Rs. 2500 crores (US $ 560 million). The growth rate of the market is about 16-20 percent per year. It is assumed that since intensive health care is being made access in the rural areas, the industry shall be able to maintain growth rate of minimum 16 % per annum. Moreover people are getting more conscious of their health which will also favour the pharmaceutical industry as well as the domestic herbal drugs market which has been estimated to be 15% of total pharmaceutical market.

Current Scenario

The medicinal plant industry is on the verge of entering into a high growth phase; particularly in botanicals required for production of Ayurvedic medicines. There are more than 250,000 species of plants identified on world-wide basis for their medicinal value, out of which 20000 plants have been documented and approximately only 5000 species phytochemically studied. In India out of 3500 species identified, 1100 species are used in different systems of medicines and out of these nearly 650 species are used in the country, mainly by indigenous industries. About 150 species are used commercially. Many of these are exported without any value addition to various countries of the world. The market potential, of late, has become extensive and a continuous upgradation in the botanical raw materials has ushered in a state of competitiveness for the domestic industry; while globalising the international market also.

Herbal Cosmetic Market

Indian herbal cosmetic market at nearly Rs. 550 crores (US $ 125 million) constitutes nearly 30% of the total cosmetics market. Keeping in mind the wave of nature beauty and industry experts opinion, it is assumed that herbal cosmetics market, with annual growth rate of 2% shall constitute more than 50% of the total cosmetics market at the end of the decade; reaching more than Rs. 3500 crores (US $ 780 million)

India's Export Potential of Botanicals

There is a growing demand today for plant-based medicines, health products, pharmaceuticals, food supplements, cosmetics etc. in the international market. The international market of medicinal plants is over 60 billion US dollar per year, which is growing at the rate of 7 percent per annum. The present export of herbal raw materials and medicines from India is about US dollar 100-114 million approximately per year.

India is one of the major exporter of crude drugs mainly to six developed countries viz. USA, Germany, France, Switzerland, U.K. and Japan, who share between them 75-80 per cent of the total export market. An analysis of the export figure shows that following botanical drugs and aromatic crops are substantial contributors to India's performance in terms of value: opium alkaloids (their derivatives and salts), medicinal castor oil, menthol crystals, *Psyllium* husk, *Capsicum* oleoresins, peppermint oil, sandalwood oil, turnmeric oleoresins, *Cassia* leaves, mint oil.

Cosmetic industry as well as aroma therapy are two important areas where Indian botanicals or their value added extracts/essential oil can contribute globally. A names of species of great importance worth to mention are as follows: *Aloe* spp., *Rose* spp., *Chamomile* spp., *Ocimum* spp., *Lawsonia innermis*, *Mesua ferra*, *Calendula* spp., *Lavendula* spp., *Mentha arvensis*.

The total value of crude herbal drug exports has increased from Rs. 394 crores (US $ 88 million) in the year 1996-97 to Rs 466 crores (US $ 104 million) during 1999-2000. Survey study shows that India's share of the global market is nearly 2 percent and there is enormous scope to exploit the export market.

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Tables

Table 1. Effect of altitude on active principle (AP) content of different MAP species

Species	Altitude (m)			
	100	500	1000	1500
	% of active agents			
Datura innoxia	0.46	0.39	0.32	0.29
Atropa belladona	0.14	0.16	0.20	0.21
Catharanthus roseus	1.32	1.26	1.10	0.95
Rauvolfia serpentina	2.95	2.60	2.50	2.48
Cepecacuanha spp.	2.00	2.38	2.72	2.90
Hyoscyamus niger	0.63	0.66	0.70	0.82

C.D. at 5% level : 0.03 to 0.10

Table 2. Effect of additional light hours on active principle content

Add. light (hrs) for 20 days	% increase (+) of active principles over control		
	D. purpurea	*D. lanata*	*S. khasianum*
4	+10.50	+12.50	+8.50
8	+21.00	+29.00	+14.00

Table 3. Effect of light intensity on active principle content

Light intensity reduced by	% increase (+) of active principles over control		
	Cinchona	*Ipecac*	*Coptis*
40 %	+32.50	+50.20	+12.50

Table 4. Effect of NPK fertilisers and micronutrients on active principles and essential oil

Species	% increase (+) over control			
	NPK	Mg	Mn	Fe
Active principles				
Ipecacuanha	+35.50	+20.00	+18.60	+8.30
Rauvolfia	+40.50	+9.50	+11.00	+35.20
Andrographis	+15.50	+16.20	+12.50	+13.00
Dioscorea	+42.00	+17.50	+18.50	+6.50
Cassia	+2.60	+8.30	+6.25	+4.55
Essential oils				
Mentha	+50.20	+19.60	+22.55	+10.00
Palmarosa	+42.60	+16.50	+20.00	+12.55

Table 5. Effect of water stress and n-triacontanol on active principle and essential oil content

Species	% increase (+)/decrease(-) over control	
	water-stress (low)	n-triacontanol
Active principles		
Ipecacuanha	+19.55	+36.60
Rauvolfia	+20.60	+32.25
Catharanthus	+18.25	+28.45
Dioscorea	+25.00	+38.25
Essential oil		
Mentha arvensis	-20.80	+20.00

Table 6. Water stress damage recovery by n-triacontanol on essential oil on *Mentha* spp.

Species	Parameter	% increase(+)/decrease(-)	
		Oil yield	E.o. content
M. arvensis	% Damage (low w.stress)	-45.00	-10.50
	% Recovery (5 ppm n-tria)	+62.50	+4.50
M. spicata	% Damage (low w.stress)	-40.00	-15.50
	% Recovery (5 ppm n-tria)	+82.50	+7.00

Table 7. Developmental stages and active principle content

Species	Active Principle	% content during		
		Vegetative	Reproductive	Post-reproductive
Rauvolfia serpentina	total alkaloid	1.54	2.81	2.50
	reserpine	0.12	0.18	0.16
Digitalis lanata	glycosides	1.06	1.42	1.24
Digitalis purpurea	glycosides	0.75	0.88	0.75

Table 8. Optimum harvesting time : *Costus specious*

Development stage	Age (days)	% Sapogenin	Dry Tuber (t) /ha
Vegetative	120-140	0.40-0.52	5.00-5.50
Pre-flowering	180-210	0.80-1.00	7.80-10.00
Flowering	280-300	0.60-0.70	10.00-11.25
Fruiting	320-350	0.30-0.40	11.00-13.50

Table 9. Optimum harvesting time : *Catharanthus roseus*

Development stage (days)	Age Roots	alkaloid % Leaves	Yield (t)/ha Stem
Early reproductive	210-240	1.05-1.25	0.65 0.75 1.00
Post reproductive	300-330	1.00-1.10	0.70 0.70 1.50

Table 10. Cost of *Dioscorea* cultivation in India

Species	Yield (t)/ha	Diosgenin %	Cost of IRS'000/ha/3Yr (Av US $)
D. deltoidea	7.0-9.0	6.0-7.2	1000-1200 (25,000)
D .composita	8.0-12.0	3.0-3.5	900-1100 (23,000)
D. floribunda	11.0-14.0	3.3-5.5	850-1100 (23,000)

Table 11. Cost of *Catharanthus* and *Rauvolfia* cultivation in India

Species	Yield (t)/ha	Alkaloid %	Cost of IRS'000/ha/Yr (Av US $)
Catharanthus	leaves 2.00 root 0.75	1.75-2.00	30-35 (750)
Rauvolfia	root 2.00	1.80-2.20	50-60 (1250)

Table 12. Active agent content of *Digitalis purpurea* leaves depending on age and the time of harvest

Age of plants	% Total glycosides (leaves)		Yield kg/ha
	Morning	Afternoon	
Pre-flowering (5-6 Months)	0-90-1.00 1.	00-1.40	250-300
Flowering * (9-10 Months)	0.80-0.90	1.00-1.20	600-650
Post flowering (12-13 months)	0.70-0.80	0.85-1.00	775-815

* Optimum harvesting stage

Table 13. Active agent content of *Andrographis paniculata* depending on age

Stages	Days	Andrographolide %	Yield (t)/ha
Early vegetative	60-70	1.70-1.75	0.80-0.85
Late vegetative	90-100	2.80-3.00	1.40-1.50
*Early reproductive	160-180	2.95-3.20	1.88-2.00
Reproductive	190-200	2.50-2.75	1.75-1.85
Post reproductive	210-240	2.10-2.20	1.60-1.68

* Optimum harvesting stage

Table 14. Characteristic loss of drugs quality occur frequently in post-harvest processing in India

Crops	Organ and AP	Post-harvest loss %
Rauvolfia	Roots; indole alkaloid	30-40% loss due to imperfect drying, toxin accumulation
Gymnema	Leaves, glycosides	20-25% loss to morphological distortion and conversion of AP
Cassia	Leaves and pods, glycosides	40-50% loss due changed pigmentation & broken consistency
Glycyrrhiza	Roots, flavonoids	20-25% loss due to degradation of AP
Ocimum	Leaves, linalool	20-25% deterioration of leaf texture and reduction of linalool.
Mentha	Shoots, E. oil	20-25% deterioration of leaf; menthol quality affected.

Table 15. Average costs and income of some medicinal plants cultivated in India and neighbouring countries (on hectare basis)

Species	Yield t/ha	Input costs US$	Income US$	Anticipated profit US$
Rauvolfia	1.90	2940.00	14250.00	11310.00
Cassia	2.15	2680.00	5400.00	2720.00
Psyllium	1.60	2480.00	4000.00	1520.00
Andrographis	3.00	2730.00	5250.00	2520.00
Withania	0.70	1630.00	2450.00	820.00
Catharanthus	5.10	2130.00	6225.00	4095.00

Table 16. Growing area requirements of medicinal and aromatic plant cultivation on commercial lines in India

Type of medicinal plant	Plantation/cultivation size (hectare)	Expenditure USD/hect.
Root yielding plant (herb, shrubs and climbers)	25-30	8200
Bark yielding plant (tree)	75-85	5300
Leaf/whole plant yielding plant (herb, shrubs)	20-25	4500
Leaf and/or wood yielding plant (tree)	80-85	4800

Note: Land cost not included, rent factor included

The above farm/plantation sizes are considered viable under the following yield consideration.

1. Dry bark yield from trees : 2000-3200 kg/hectare
2. Dry root yield from herb/shrubs : 2200-2500 kg/hectare
3. Dry tuber yield from shrubs/climbers : 46-58 t/hectare
4. Green aromatic leaf yield from herb : 10-25 t/hectare (crop specific)