ORGANIC FARMING IN MEDICINAL AND AROMATIC PLANTS

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INTRODUCTION

Organic farming, ecological farming and biodynamic farming are the components of natural way of farming. Natural farming is self-sustaining but it is difficult to meet our requirement to feed the increasing population. On the other hand, chemical farming yields much but posses the serious problems for soil, environment and human health. There is a path in between aforementioned two type of systems of farming, that is organic farming and its aim is to create integrated, humane, environmentally and economically sustainable agricultural production systems, which maximize reliance on farm-derived renewable resources and the management of ecological and biological processes and interactions, so as to provide acceptable level of crop, livestock and human nutrition, protection from pests and diseases and an appropriate return to the human and other resources employed (Lampkin, 1990; Neuerburg and Padel, 1992).

In the modern agriculture, major inputs are- fertilizer, insecticide, pesticide and farm operation with heavy machinery developed by the middle of 20th century in Europe and USA. In India, it was on peak in late sixties or seventies with the green revolution. The fertilizer consumption (N, P_2O_5 and K_2O) was above 500kg ha^{-1} in European countries and it started creating environmental problems such as enrichment of nitrate in underground water (Aishwath, 2005b), eutrofication of lakes and release of substantial amount of ammonia to the atmosphere, salinization, pesticides contamination in under ground water, genetic and soil erosion etc. (Dahama, 1996). People also perceived that organically grown food is good as that of produced with fertilizers. These problems and issues drawn the attention to the scientific community of various fields and at the end of this century organically produced agricultural products have received the global attention. During last few years, the global market for organically produced food was about US $ 26 billion in 2003 and estimated to reach up to 102 billion by the 2020. India’s share in this market for organic food was 0.76%

(Anonymous, 2004b). In the last year (2005-2006), export of only three important medicinal plants; senna, isabgol and opium poppy were the worth of 47.21 million US $.

According to World Health Organization (WHO) more than one billion people rely on herbal medicines to some extent. The WHO has listed 21,000 plants that have reported medicinal uses around the world. India is a rich country in terms of medicinal plants flora of some 2500 species. Among them, 2000 to 2300 species are used in traditional medicines, while about 150 species are used commercially on a fairly large scale. India and Brazil are the largest exporters of medicinal plants in world market. Medicinal plants in India are estimated to be worth Rs. 550 crores. India has a wealth of 2500 aromatic plants among the 20,000 species occurring in the world (Rajeswara Rao and Rajput, 2005). Ayurvedic ethical formulations contribute the remaining sum. Cosmetic industry as well as aroma therapy are two important areas where Indian medicinal plants and their extracts, essential oil can contribute globally. Medicinal and aromatic plants have a high market potential with the world demand of herbal products growing of the rate of 7 per cent annum.

Annually, India’s medicinal plants export is worth of Rs.1250 crores and essential oil amounts Rs 260 crores. Organically grown medicinal and aromatic plants have an excellent global market and India can exploit this market to its advantage (Rajeswara Rao and Rajput, 2005). Results on application of organic manures on medicinal and aromatic plants revealed that enhancement of yield and uptake of nutrients. However, quality of the essential oil did not influenced by them. Not only organic manures, biofertilizers (*Azotobacter* and *Azospirillum*), arbuscular mycorrhizal (AM) fungi and phosphorus solubilizing bacteria, organic mulches and crop rotations are also play an important role for the enhancement of yield and nutrients utilization.

DEFINITION OF MEDICINAL AND AROMATIC PLANTS

Whole plant or individual plant part such as root, stem, leaves, bark, flower, fruits, seeds etc. or the chemicals derived from these parts are used in different system of medicines (Allopathy, Ayurveda, Homeopathy, Siddha, Unani, Herbomineral, Folklore etc.) to cure the disease are known as medicinal plants. The utilization of medicinal plants are: direct utilization in the form of plant parts (root, stem, leaf, seed and bark), powder, extracts, medicinal chemicals (alkaloids, glycosides) and plant drugs.

Table 1a. Some important medicinal plants with their useful part and medicinal uses

Scientific name	*Common name*	*Useful parts*	*Chemical constituents*	*Uses*
Acorus calamus	sweet flag	rhizomes	β-asarone	nervine tonic, speech therapy
Aloe babadensis	Aloe vera	Leaves	aloin, A and B, Aloe-emodin	cosmetics, purgative, vermifuge
Andrographis paniculata	king of bitters	herb	andrographolides	antipyretic, anti-inflammatory
Artemisia annua	anti-malarial plant	leaves	artemisinin arteether	anti-malarial
Bacopa monnieri	bacopa	whole plant	bacosides	improves memory
Calviceps purpurea	ergot of rye	sclerotia	ergotamine, ergometrine, ergotoxine	vasodilator, oxytocic, vasoconstrictor
Cassia senna	Senna	leaves and pods	sennosides	Laxative
Catharanthus roseus	periwinkle	leaves, roots	vinblastine, vincristine, ajmalicine	anti-cancer, hypotensive
Chlorophytum borivilianum	safed musli	tubers	saponins	nervine tonic aphrodisiac
Chrysanthemum cinerariaefolium	pyrethrum	flowers	pyrethroids	insecticides
Coomiphora wightii	Indian bdellium	oleo-gum-resin exudes from trunk	Guggalsterone-e and z	stringent, diuretic antiseptic, arthritis, pyorrhoea

Table 1b. Some important medicinal plants with their useful part and medicinal uses

Scientific name	*Common name*	*Useful parts*	*Chemical constituents*	*Uses*
Glycyrrhiza glabra	liquorice	under ground root & stem	Glycoside glycyrrhizin	peptic ulcers, cough, analgesic
Mucuna pruriens	itching bean	seeds	L-dopa	parkinson's disease
Papaver somnifera	opium poppy	latex	papaverine, codeine, morphine	sedative, smooth muscle relaxant
Phyllanthus amarus	phyllanthus	herb	phyllanthin	hepatoprotective
Piper longum	long pepper	seeds, roots	piperine, piplarine	Cure repiratory disease, digestive
Plantago ovata	Psyllium	Constipation & laxative	Mucilage containing fatty acids	Seed and husk
Rauvolfia serpentine	rauvolfia	roots	reserpine, serpentine	hypotensive, sedative
Solanum khasianum	medicinal brinjal	berries	solasodine	steroidal drugs
Sylibum marianum	sylibum	seeds	sylimarin	Hepatoprotective
Tinospora cordifolia	tinospora	stem	bitters	antipyretic
Withania somnifera	Indian ginseng	roots	withanolides	adaptogenic, aphrodisiac

Table 2. Some important aromatic plants with useful plant part and uses

Scientific name	*Common name*	*Useful parts*	*Chemical constituents*	*Uses*
Artemisia pallens	davana	Flower, shoot	davanone, davana furans	flavouring
Coriandrum sativum	coriander	seeds	linalool	flavouring
Cinnamomum zeylanicum	cinnamon	leaves, bark	eugenol, cinnemaldehyde	flavouring
Cymbopogon flexuosus	lemongrass	leaves	citral	perfumery, pharmaceutical
Cymbopogon martinii var. motia	palmarosa	flowering shoot	geraniol, geranyl acetate	perfumery
Cymbopogon winterianus	citronella	leaves	citronellal, geraniol, citronellol	perfumery
Eucalyptus citriodora	eucalyptus	leaves	citronellal isopulegol	perfumery
Jasminum grandiflorum	jasmine	flowers	linalool, benzyl acetate, benzyl benzoate	perfumery
Mentha arvensis	menthol mint	shoot	menthol, menthone	perfumery, flavouring, pharmaceutical
Ocimum basilicum	basil	flowering shoot	linalool, methyl chavicol, eugenol	perfumery, flavouring, pharmaceutical
Pelargonium species	geranium	shoot	citronellol, geraniol	perfumery, aromatherapy
Pogostemon patchouli	patchouli	leaves	patchoulol	perfumery
Polianthus tuberosa	tuberose	flowers	methyl isoeugenol, benzyl benzoate	perfumery
Posa damascena	rose	flowers	citronellol, geraniol	perfumery, flavouring
Vetiveria zizanioides	vetiver	roots	vetiverol	flavouring, pharmaceutical

Plants containing aromatic essential oil that is extracted for perfumery, cosmetics, flavouring, medicinal and other human uses are known as aromatic plants. We also can say that aromatic plants, those possessing odoriferous and steam volatile substances occurred as essential oils, gum exudates, balsam etc. obtained from various plant parts. Most of these are essential oils and volatile at room temperature. The aromatic products are: essential oils, aroma chemicals, absolutes, balsams, concentrates, gums, hydrosols, mosses, perfumed water, pomades, resins and resinoids. Some important medicinal and aromatic plants are listed in Table 1 and 2 and Fig. 1 with their active principles and uses.

Cymbopogon flexuosus (lemongrass) clump

Asparagus adscendens Willd. (Satavar)

Reuvolfia serpentina (Sarpgandha)

Fig. 1. Some common medical and aromatic plants

EXPORT POTENTIAL OF MEDICINAL AROMATIC PLANTS IN INDIAN PERSPECTIVE

Department of commerce (DOC) exported all commodities including medicinal plants and extracts. The annual export of India DOC are not based on the calendar year, but rather on the April through March season. The selected Indian medicinal herbs and extracts and their export potential presented in Table 3.

Table 3. Selected high demand herb export (kg) from India

Name of the herb	*2002-2003*	*2003-2004*	*2004-2005*	*2005-2006*
Ajowan fruit (*Trachyspermum ammi*)	222,110	1,070,680	1,101,470	355,170
Asafetida gum resin (*Ferula assa-foetida*)	473,910	744,210	731,640	287,460
Black tea leaf (*Camellia sinensis*)	180,719,300	172,861,050	172,866,870	69,339,910
Garcinia fruit & rind (*Garcinia cambogia*)	63,330	137,790	107,230	24,540
Garcina extract	867,850	920,160	541,690	150,420

(*Garcinia cambogia*)				
Greater galangal rhizome (*Alpinia galanga*)	364,400	119,360	323,400	56,400
Green tea leaf (*Camellia sinensis*)	897,470	1,384,920	1,860,680	772,410
Gymnema leaf powder (*Gymnema sylvestre*)	278,960	88,180	118,530	10,600
Gymnema leaf extract (*Gymnema sylvestre*)	43,060	56,970	19,740	11,590
Henna leaves & powder (*Lawsonia inermis*)	2,537,500	3,123,380	3,924,600	1,686,750
Indian frankincense gum (*Boswellia serrata*)	57,620	7,990	12,080	7,910
Myrrh oleo gum resin (*Commiphora* spp.)	---	11,860	11,700	---
Neem leaf (*Azadirachta indica*)	---	42,690	155,650	91,450
Opium exudates (*Papaver somniferum*)	250,050	258,010	216,280	1,46
Psyllium husk (*Plantago ovata*)	682,550	7,235,620	18,814,840	12,301,980
Psyllium seed (*Plantago ovata*)	1,114,740	3,520,040	1,131,390	207,210
Senna leaves & pods (*Cassia angustifolia*)	9,638,470	10,973,690	10,571,780	5,143,400
Sickle-pod senna seed (*Cassia tora*)	2,366,910	1,881,090	1,131,060	1,090,180
Turmeric rhizome (*Curcuma longa*)	32,444,010	37,042,260	37,322,140	25,844,340

Source: Government of India Ministry of Commerce and Industry, Department of Commerce, Export Import Data Bank, March 2006.

NECESSITY OF ORGANIC FARMING IN MEDICINAL AND AROMATIC PLANTS

India is a global leader in the production of medicinal and aromatic plants. The National Medicinal Plants Board and the Food and Agriculture Organization recommended that all the medicinal and aromatic plants to be cultivated organically. Organically grown medicinal and aromatic products are not only readily acceptable in global market but also fetch premium prices than those grown with conventional farming. For example, during March, 2006 the rate of organically grown Psyllium (*Plantago ovata*) husk was more than six times higher than the unclean/conventional produce. However, organically produce senna (*Cassia* *angustifolia*) leaf rate was approximately double over the conventional. Similarly, organically produced senna (*Cassia angustifolia*) pods rated approximately 40% higher over conventional. Hence the future global market is bright for organically grown products. Therefore, it is essential that India has to initiate pace to move from chemical or conventional farming to organic farming in the medicinal and aromatic plant sector. Based on the ecological significance of medicinal and aromatic plants, these are very specific for soil, water and climatic requirement. To introduce in new areas, the soil should have appreciable amount of organic matter, which can provide buffer action in the soil so that plant can withstand properly otherwise very small quantity of individual ion present in the soil and in irrigation water may leaves adverse impact on plant growth. Many of the medicinal and aromatic plants showed cholorosis (Table 4 & 5), when soil poor in organic matter and having high residual sodium carbonate in soil or in irrigation water (Aishwath, 2004a; Aishwath, 2005a).

Table 4. Influence of residual sodium carbonate dominated irrigation water on medicinal plants under poor soil organic carbon content (0.18-0.21)

S. No.	*Name of the Plant*	*Visual changes in colour and morphology of plants*
1	*Chlorophytum borivilianum*	Leaf chlorosis during conducive weather and burning of leaf tips and margins under dry-spell or bright sunny days.
2	*Bacopa monnieri*	Regular irrigation for one year leads to death of plants.
3	*Centella asiatica*	Chlorosis leaves, rolling of leaf form the funnel shape.
4	*Barleria prionitis*	Seedlings are highly susceptible for chlorosis. Black spot on the leaves appears due to death of the tissue.
5	*Pedalium murex*	Leaf burning, chlorosis, reduced growth and early death.
6	*Rauvolfia serpentine*	Stunted growth, initially inter-venial chlorosis, leaf burning and bunchy top.
7	*Piper longum*	Chlorosis in rainy season and burning and curling of leaf margin in the dry spell.
8	*Commiphora weightii*	Prolong use of this water affect the growth of the plant and partial chlorosis in leaves during rainy season.
9	*Asparagus, Species*	Chlorosis in young leaves and bunchy top of plants.
10	*Alpinia calcarata & speciosa*	Chlorosis in young leaves with green midribs, burning and inward rolling of leaf margin and dwarfism.

11	*Cassia tora*	Inter-venial chlorosis in leaves with pale yellow colour.
13	*Murraya paniculata*	Reduction of inter-nodal distance and chlorosis in leaves.
14	*Plumbago zeyilanica*	Cap shape of leaf, reduction in size, and chlorosis in leaf.
15	*Elettaria cardamomum*	Growth reduction, inter-venial chlorosis occurs with pale yellow colour to white.
16	*Catharenthus species*	Inter-venial chlorosis appears in the leaves. Inter-nodal distance reduced resultant bunchy top of plants.
17	*Citrus medica*	Young leaves showed inter-venial chlorosis and curling.
18	*Andrographis paniculata*	Reduced plant growth, inter-venial chlorosis, plant shape become pyramidal type.
19	*Hibiscus subdariffa*	Seedlings are highly susceptible for chlorosis

Source: Aishwath, 2005a

Table 5. Influence of residual sodium carbonate dominated irrigation water on Aromatic plants under poor soil organic carbon content (≈ 0.21%)

S. No.	*Name of the Plant*	*Visual changes in colour and morphology of plants*
1	*Cymbopogon winterianus*	Initial establishment of plant is problematic with this water. Initially inter-venial and then leaves turn into complete white. Plant mortality occurs at the severity of chlorosis.
2	*Cymbopogon flexuosus*	The irrigated plants showed inter-venial chlorosis. Reduction of growth, biomass production and oil yield.
3	*Cymbopogon martinii*	Seedlings are susceptible for chlorosis to this irrigation water.
4	*Other Cymbipogon species*	Some local selections of this area, which are having high potential of biomass and oil yield production, highly susceptible for the chlorosis caused by this irrigation water resultant lower growth and yield.
5	*Hibiscus abelmoschus*	Reduced growth and yield was observed due to chlorosis in plants. Chlorosis observed in all the three seasons

		(winter, summer and rainy). However, high degree of chlorosis found in the rainy season.
6	*Pandanus odoratissimus*	It shows stunted growth and chlorosis in leaves at the initial stage and after establishment of 3-4 years bushes did not showed any adverse impact on growth and development of plants.
7	*Cestrum nocturnum*	By the use of this water, midribs of the leaves remain in the chlorotic leaves. The leaf surface becomes uneven and shows depressions and indentations on the leaf surface. Leaf turn into boat shape by curling inward.

Source: Aishwath, 2005a

MEDICINAL AND AROMATIC PLANTS AS A COMPONENT OF ORGANIC FARMING FOR SOIL FERTILITY AND ENVIRONMENT CONCERN

Aromatic crop spent grass and spent wash are good organic source of nutrient supply of to the other crop and in nutrient recycling for fertilizer economy. The spent by product can also used as mulch for moisture conservation and weed control. Incorporation of palmarosa distilled grass at the rate of 5 t ha^{-1} along with N decreased weed biomass, conserved soil moisture and increased the rainfed palmarosa biomass and oil yield (Prakasa Rao *et al.*, 2001). Application of citronella spent grass @ 6 t ha^{-1} along with N reduced the N losses and saved 150 kg N by giving yield equivalent to 450 kg N ha^{-1} without affecting oil quality of citronella (Puttanna and Prakasa Rao, 1997). The neem cake (Prasad *et al.*, 1971) and pongamia cake (Sahrawat, 1981) possess nitrification inhibitory action, which helps in check the loss of nitrogen in the soil by leaching. The distilled waste of menthol mint and pyrethrum (*Chrysanthemum cinerariaefolium*) flowers showed significant nitrification inhibitory properties as compared to neem cake (Ram *et al.*, 1993). These organic product and by-product can be used for enhancing nitrogen use efficiency in integrated nutrient management of crops. Nitrification inhibition prolongs the N supply to the long duration crops without loss by leaching of nitrate and check the underground water pollution. Citronella spent grass and menthol mint used for mulching along with 180 kg N after the sprout of menthol mint rhizomes enhanced the yield of main and ratoon mint crop (Ram and Kumar, 1997). *Pongamia glabra* leaf mulch used @ 20 t ha^{-1} in citronella crop, reduced the

72% weed biomass, conserved the 45% soil moisture and enhanced the herb and oil yield of citronella, that was comparable to the 200 kg N application (Prakasa Rao and Puttanna, 2000).

MEDICINAL AND AROMATIC PLANTS AS BIO-PESTICIDES FOR OTHER CROPS

Some of the medicinal and aromatic plants exhibited pesticidal and antimicrobial properties can be used as biopesticide in organic farming. All the plant parts of pink and white periwinkle (*Catharanthus sps*.) can be used in control of nematodes and this crop is also used as a trap crop for the controlling of root knot nematodes (*Meloidogyne incognita*) and (*Meloidogyne javanica*) in many a crops and reduces infection in Okra (Patel *et al.*, 1991). Pyrethrum contains pyrethrins in its leaves, which has natural insecticidal properties (Head, 1967). The neem oil and cake are well known for the insecticidal properties and pyrethrum flower for mosquito repellents. *Calotropis spp.* and *Tebernamotena corneria* are also having good insecticidal properties to control the pests and diseases in many of the crops. Some essential oils (citronella, lemon-scented gum etc.) have mosquito repellent properties. Farmers are also using custard apple seed and leaf extracts and decoctions, *Vitex negundo* leaf extract, garlic and chilli extracts, distillation water of aromatic crops and plant extracts for controlling pests and as a pest repellent, and these needs scientific validation (Rao and Rajput, 2005). *Calotropis procera* leaf and AM fungi significantly reduced *Meloidogyne incognita* infection and improved the tomato seedlings (Rao *et al.*, 1996). Shoot and root extracts of *Cannabis sativa*, *Chenopodium ambrosioides*, *Malea azadirachita* and *Solanum hispidum* had killing action on nematodes like *Haplolimus indicus* and *Rotylenchulus reniformis* (Haseeb *et al.*, 1978). Ovi-positional deterrence activity against *Phthorimea opeculella* was reported by Deshpande *et al.* (1990) with the combine use of acetone extract of *Glycosmis pentaphyllum*, *Catharanthus roseus*, *Salvodora oleododesh* and *Breneya species*. *Andrographis paniculata* crude extracts and adrographoloid posses anti-feeding activity against the rice pest *Nephotettix cincticeps* (Wadiarta *et al.*, 1997) and aqueous extract inhibited 78.6% of aflatoxin production by *Aspergillus flavus* (Kumar and Prasad, 1992). Leaf extracts of periwinkle, *Tribulus terrestris*, *Vitex negundo* var. Purpurascens and *Aloe vera* showed antiviral effect against rice tungro virus (Selvaraj and Narayanaswamy, 1991).

Essential oil of cymbopogon species (*C. Martinii, C. flexuousus* and *C. winterianus*) their major constituents geraniol, citrol and citronellol were toxic to nematode species like *Anguina tritici*, *Tylenchulus semipenetrans, Meloidogyne javanica* and *Heterodera avenae* (Sangwan *et al.*, 1985). Essential oil of cymbopogons tested against activity of 18 bacteria (Pattnaik *et al.*, 1996). Lemongrass (*Cymbopogon citratus*) oil reported insecticidal against the cotton leaf worm (*Spodoptera exigua*) for ovicidal and larvicidal (Sharaby, 1988). Tomato root dipped in water extract of lemongrass (*Cymbopogon flexuousus*) at the time of transplanting effectively controlled the root knot developed on tomato caused by *Meloidogyne incognita* (Tiyagi *et al.*, 1990).

MAJOR COMPONENTS OF ORGANIC FARMING IMPLYING TO MEDICINAL AND AROMATIC PLANTS

The major components are: Green manure and farmyard manure, city and farm waste compost, vermi-compost and vermi-wash, crop residue management, cover crops and mulching, concentrated manures (oil cakes, meat and blood, fish, horn and hoof meal etc.), microbial fertilizers and crop rotations and crop management. All the above soil inputs are major source of organic matter, which provides the humus in the soil after decomposition. The decomposition of organic matter helps in alteration of physical, chemical (Aishwath *et al.*, 2003) and biological properties of the soil (Pettersson *et al.*, 1992). It provides the substrate to the microbial population as well as the improved habitat for macro fauna (worms, millipedes, spiders etc.), which helps in soil aeration. The improved physical conditions alter the inoculum’s potential (density and capacity) of pathogens and host. The improvement in the physico-chemical properties promotes the roots growth (Chandra *et al.*, 2003) and nutrient absorption of crop plants. These conditions made the plant vigorous and develop the capacity to avoid or tolerate the disease. Ultimately, better yield mask the effect of disease.

Green manure and farmyard manures

The green manuring crops are important where sufficient water is available for raising them. Green manuring crops are generally leguminous crops helps in tapping of atmospheric nitrogen and restore nitrogen in soil and also enhance the availability of other nutrients. The nutrients lying beneath the surface soil are also come out on the surface and utilized by the crop. Most of the experiments conducted on organic manures are with integrated nutrient management in response to medicinal and aromatic plants. Safed musli (*Chlorophytum borivilianum*) responded well with sole application of 10-15 t ha^{-1} of FYM with respect to root yield (Chandra *et al.*, 2003). The macro and micro nutrients uptake by safed musli as well as soil properties also improved due to application of 10-15t FYM (Aishwath *et al.*, 2003). Thimmarayappa *et al.* (2000) obtained higher yield with farmyard manure alone or in combination with inorganic fertilizers in cardamom (*Elettaria cardamomum* Maton). The per cent yield increased (Table 6) of ambrette, bacopa, perivinkle, king of bitters, winter cherry with farm yard manure was ranged between 30.4 to 308.7% (Prakasa Rao *et al.*, 1988; Prakasa Rao *et al.*, 2003; Rajeswara Rao *et al.*, 2004; Rajeswara Rao and Rajput, 2005). Use of farmyard manure on turmeric (*Curcuma longa* L) gave encouraging result with respect to growth and rhizome yield (Balashanmugam *et al.*, 1989; Gopalkrishna *et al.*, 1997 and Gill *et al.*, 1999). Impact of FYM was additive when these applied with N, P and K fertilizers (Shaha, 1988 and Vishwanath *et al.*, 2004). Application of distillery effluent @ 100 cubic meter ha^{-1} encouraged the growth aonla budlings and improved properties of the soil (Singh and Gaur, 2004).

Table 6. Response of medicinal and aromatic plants to farmyard manure (t ha^{-1})

Medicinal crops			Aromatic crops		
Crop	Farmyard manure	Yield increase (%)	Crop	Farmyard manure	Yield increase (%)
Ambrette	20	308.7	Davana	30	36.7
Bacopa	20	33.8	Jamrosa	24	22.8
Periwinkle	15	ns	Menthol mint	20	37.7
King of bitters	10	150.0	Palmarosa	15	10.3
Winter cherry	7.5	53.8	South American marigold	10	ns

Similarly, in aromatic crops (Table 6), like davana, *jamarosa*, menthol mint, palmarosa and South American marigold application of farmyard manure enhanced the herb and oil yield (Prakasa Rao *et al.*, 1997; Chand *et al.*, 1996; Ram and Kumar, 1997; Patra *et al.*, 2000; Rajeswara Rao, 2001; Prakasa Rao *et al.*, 2001). The application of 15 t FYM ha^{-1} in palmarosa, mean herb and oil yield increased 8% and 10%, respectively. However, there was no significant effect observed on geraniol content with FYM application (Maheshwari *et al.*, 1991).

Composts and vermicomposts

A pot experiment was conducted to test the growth of 9 plant species of medicinal value (*Andrographis paniculata*, *Abelmoschus moschatus*, *Plumbago zeylanica*, *Psoralea corylifolia*, *Plantago ovata*, *Ruta graveolens*, *Solanum xanthocarpum*, *Withania somnifera* and *Hyoscyamus niger* on skeletal (degraded) soil of Madhya Pradesh, India and it has been concluded that during rehabilitation/afforestation of skeletal and similar degraded lands low in organic matter and nutrients, compost should be mixed in the surface soil in 1:2 proportion before sowing (Singh *et al.*, 1998). Galangal (*Kaempferia galanga* L.) intercropped with coconut were treated with FYM (24 and 32 t ha^{-1}), composted coir pith (CCP, 29 and 39 t ha^{-1}), vermicompost (VC, 21 and 28 t ha^{-1}), 20 t FYM ha^{-1} + 50:50:50 kg NPK ha^{-1}, NPK alone and control (without any manure). The nutrient content did not differ significantly in both planting materials and plant population levels. N content was significantly higher in plants treated with FYM, VC and FYM + NPK as compared with CCP and NPK alone, and the control (Maheswarappa *et al.*, 2000). In greenhouse pot experiments on chamomile (*Chamomilla flowerrecutita*) grown with the treatments of no fertilizer, 6 kg controlled release fertilizer (CRF, 15:9:12 NPK) m^{-3} + 2 kg vermicompost (VC) m^{-3}, 4 kg CRF m^{-3} + 4 kg VC m^{-3}, 2 kg CRF m^{-3} + 6 kg VC m^{-3}, or 8 kg CRF m^{-3}. Flower production was best with 4 kg CRF m^{-3} + 4 kg VC m^{-3} and 2 kg CRF m^{-3} + 6 kg VC m^{-3} (Aguilera *et al.*, 2000). In velvet bean vermicompost applied @ 5 t ha^{-1} gave 30.4% more yield over control (Rajeswara Rao and Rajput, 2005). In aloevera, Saha *et al.* (2005) used organic and inorganic sources of fertilizer on performance of Aloe vera at Kharagpur, India. They found N and K fertilizers significant increase in biological and gel yields, plant height, number of leaves per plant and chlorophyll content with application of fertilizer as compared to no fertilizer treatment. However, vermicompost and vermin-wash was found to be effective and comparable with inorganic source of fertilizer in increasing content of gel, moisture, gel ash and aloin. In turmeric (*Curcuma longa*), application of vermicompost enhanced the fresh and dry weight of rhizomes and the impact was higher when it applied along with N, P and K fertilizer than in isolation (Vishwanath *et al.*, 2004).

Response of biofertilizers

Some of the microbes are useful as a biological nitrogen fixation. These are two types: Symbiotic nitrogen fixer like – *Rhizobium spp*., Non symbiotic nitrogen fixer lilke - *Azotobacter*, *Azospirillum*, *Clostridium*, blue green algae and Azolla. Tricalcium phosphate which is water insoluble and it could be solublized by phospho-bacteria. *Bacillus siliceous* degrades silicate minerals and make K available to plants. Some other microbes affect the solubility of boron, sulfur, iron etc. and make them available to the crops. In the rhizosphere soil of 25 medicinal and 20 aromatic plants, palmarosa had highest *Azotobacter* population, whereas *Rauvolfia serpentiana* and *Plantago ovata* found lowest population (Rao *et al*., 1987). The *Datura stramonium* inoculated simultaneously with *Azotobacter*, *Azospirillum* and AM fungi enhanced the dry matter accumulation and alkaloid content (Saleh *et al*., 1998). *Azospirillum* seed treatment enhanced root growth and weight, which lead to increased production of dry leaf, pod and overall dry matter production of senna (*Cassia angustifolia*) as observed by Arumugam *et al*. (2001).

Azotobacter application with or without mineral fertilizers significantly increased the yield without any adverse impact on oil quality of rainfed palmarosa (Maheshwari *et al*., 1998) and vetiver (Sinkanagam *et al*., 1999). Plamarosa inoculated with *Azospirillum bresilense* along with *Glomus agregatum* showed higher growth, yield and oil content as compared to uninoculated or inoculated alone with *Azospirillum* and AM (Neelima and and Janardhanan, 1996). The 16% herbage yield and 21% oil yield increased with *Azotobater chroococcun* in palmarosa (Maheshwari *et al*., 1991). The response of *Azotobacter* on plant height, oil content and oil yield of bergamot mint (*Mentha citrata*) was inferior to herb yield and NK uptake at later stage. However, response of *Azotobacter* was highest when it used with 75% recommended doses of NPK and caster cake (Venu Madhav, 2004). Use of *Azotobacter* and phosphate solublizing bacteria (PSB) increased the growth and yield of *Material chamomile* L (German chamomile). However, application of *Azotobacter* and PSB with 15 kg each of N and P with 50 kg K yielded highest flower without the significant differences in oil content (Prasad and Kumar, 2004).

Response of arbuscular mycorrhizal (AM) fungi

AM fungi are found associated with majority of agricultural crops. They are ubiquitous in geographical distribution and occurring with plant growing in arctic, temperate and tropical regions. AM occur over broad ecological range from aquatic to desert environments. These fungi are obligate symbionts and have not been cultured on nutrient media. However, there is a report that AM fungus, *Glomus aggregatum*, was cultured axenically and maintained on a synthetic medium. AM fungi infect and spread inside the root. They have special structures known as vesicles and arbuscules. The arbuscules helps in the transfer of nutrients from fungus to the root system and vesicles, which are 'sac like' structures store P as phospholipids. There is little host specificity for AM but the competitive ability of a given species with native strains may influence the dominance of a certain endomycorrhizal fungus in root system. AM have been associated with increased plant growth and with enhanced accumulation of plant nutrients, mainly P, Zn, Cu, and S through greater soil exploration by mycorrhizal hyphae (Abbot and Robson, 1984; Cooper, 1984). It has also been reported that AM simulate plant growth by physiological effects other than by enhancement of nutrient uptake or by reducing the severity of diseases caused by soil borne pathogens (Dehne, 1982). The survival and performance of AM fungi is largely affected by the host plant, soil fertility, cropping practices, biological and environmental factors.

AM fungi association not only well known in field crops but also its presence has been reported in almost all medicinal and aromatic plants (Barthakur and Bardoloi, 1990; Rao *et al.*, 1987; Sharma and Roy 1991; Venkteswara Rao *et al.*, 2000; Gautam and Sharma 1996, Rao *et al.*, 1989). However, most of the studies were done in the pot culture and needs further investigation at field level to asses their actual contribution to the crops. The *Datura stramonium* (Saleh *et al.*, 1998) and other four medicinal plants (Camprubi *et al.*, 1990) inoculated with *Glomus mosseae* reported higher growth yield and nutrient uptake of these crops. Isabgol (*Plantago ovata*) inoculated with AM –*Glomus fasciculatum*, *G. Macrocarpus* and *G. mosseae* found better growth, yield and seed weight with all the fungal inocula. However, *G. mosseae* proved better over other inoculums (Bloss, 1982). Paprika (*Capsicum frutescens* cv. Passion) plants infected with the vesicular-arbuscular mycorrhizal fungus, *Glomus mosseae*, absorbed the greatest quantity of soil P at a soil pH of 6.8 and with the benefit of nitrate nutrition. The 53% increase for paprika-plant P acquisition may be attributable to the favourably altered bio-availability for P in the rhizosphere soil environment (Jiahnyao and Hongchi, 2000). In Mansoura, Egypt, AM fungi associated with 30 species of medicinal plants studied by Agwa (2000). The 38 to 100% colonization of AM (Table 7) was observed in *Alpinia galangal*, *Glacyrrhiza glabra*, *Fenugreek* and *Digitalis*, *Catharanthus roseus*, *Clocimum Cucuma amada*, musk, sacred basil and basil (Rao *et al.*, 1987; Sharma and Roy, 1991). The *Leptadenia reticulate* and *Withania somnifera* had better adaptability in arid desert environment with various stresses like soil alkalinity, nutrients and moisture with association of AM fungi (Panwar and Tarafdar, 2005).

Table 7. Per cent colonization of AM fungi in different medicinal and aromatic plants

Medicinal plants		Aromatic plants	
Crop	Per cent colonization	Crop	Per cent colonization
Alpinia galanga	100	Citronella	75-91
Allium cepa	38-42	*Cymbopogon citratus*	80
Basil	63	*Cymbopogon flexuosus* var. sikimensis	72
Cassia alata	69	*Cymbopogon jwarancusa*	50
Cassia fistula	94	*Cymbopogon khasianus*	76
Clocimum	92	Davana	86
Convolvulus arvensis	100	Lavender	80
Coriander	32	Lemongrass	21-75
Curcuma amada	92	*Mentha arvensis*	46
Datharanthus roseus	65	*Mentha piperita*	100
Digitalis	60	*Mentha spicata*	100
Fenugreek	92	*Mentha citrata*	40
Glycyrrhiza glabra	38	Palmarosa	41-98
Leucaena leucocephala	100	Patchouli	43
Musk	83	Rose-scented geranium	22-59
Sacred basil	77	Vanilla	57
Azadirachita indica	10	Vetiver	42

Fifteen medicinal plant species were screened for AM fungi infection in alkali soil of Uttar Pradesh, India. The highest AM colonization percentages were in *Cassia fistula*, *Cassia alata*, *Leucaena leucocephala* and *Convolvulus arvensis* (94, 69, 100 and 100%, respectively). It indicate that all medicinal plants growing on alkali soil show mycorrhizal infection, and that AM infection possibly increases the capacity of plants to accumulate phosphate as it is released by other microorganisms (Rani and Bhaduria, 2001). In arid ecosystem, the root infected of *Azadirachta indica* with AM was 75% and 61% under rainfed and irrigated conditions respectively (Pandey *et al.*, 1999). The AM fungi play an important role in the establishment and withstand of *Mitragyna pervifolia* and *Azadirachta indica* under moisture, salinity and alkalinity stress in arid ecosystem (Pandey and Tarafdar, 2002; Panwar and Tarafdar, 2005).

Lemongrass (*Cymbopogon flexuousus*) with *Glomus spp.* and with *B. sclerotica* (Jonardhanan *et al.*, 1990), palmarosa with *Glomus aggregatum* (Gupta and Jonardhanan, 1991), six mint species with *Glomus aggregatum, Glomus fasciculatum* and *Glomus mosseae* (Khaliq and Jonardhanan, 1997), rose-scented geranium with mixed inoculum (*Acajulosppora lavis*, *Gigaspora margarita*, *Glomus fasciculatum* and *Glomus mosseae*) enhanced the growth, yield and nutrient uptake of crops (Venkateshwar Rao *et al.*, 2002). The colonization of AM in *Mentha arvensis*, *Mentha piperita*, *Mentha spicata*, *Mentha citrata*, palmarosa, celery, citronella, davana, lavender, lemon scented gum, vanilla, patchouli, vetiver and lemongrass ranges from 42 to100% (Rao *et al.*, 1987; Vektaswara Rao *et al.*, 2000; Barthakur and Bordoloi, 1990; Jonardhanan *et al.*, 1990). Positive influence of mycorrhzal association in palmarosa was also reported by Kothari and Singh (1996). *Eucalyptus camaldulensis* association with AM and dehydrogenase activity was higher under rain-fed condition (64% and 10.5 p kat g^{-1}) than irrigated (52% and 9.0 p kat g^{-1}) in arid zone trees under agroforestry system (Pandey *et al.*, 1999).

Weed control in medicinal and aromatic crops

There are several ways to control the weeds as hand or manual weeding, cultural means like hoeing and mulching and intercropping are widely practiced for that purpose. In medicinal yam (*Dioscorea floribunda*), organic mulch of menthol mint spent, palmarosa spent grass and inter-cropping with black gram reported superior over control and herbicides and elephant yam intercropped with black gram was most economic (Singh *et al.*, 1986). Hand weeding, mulching with spent grass and close spacing gave higher yield of citronella as compared to control. Intercropping green gram with citronella increased the essential oil content without affecting oil quality (Rajesswara Rao *et al.*, 1993). Citronella spent grass used in citronella, palmarosa and lemongrass enhanced the biomass and oil yield (Singh *et al.*, 1991), and succeeding menthol mint crop (Singh *et al.*, 1997). Rose-scented geranium intercropped with menthol mint reduced the 40% weeds growth without any adverse effect. *Mucuna pruens* can be used as cover crop and living mulch to control the weed and cut down the herbicides use. The weeds can also control through allelochemicals released by the crop (Fujii *et al.*, 2000). Organic mulch and herbicides were tested in some *Cymbopogon species* and organic mulched were found more effective and economic than herbicides. However, palmarosa followed by lemongrass had a better weed suppression potential than citronella java (Singh *et al.*, 1985). *Withania somnifera* with other crops act as trap crop for broomrape parasite of opium popy (*Papaver somniferum*) by inducing germination parasite through allelochemicals and subsequently kills it (Ramanathan, 1985).

Control of pests and diseases

Most of the medicinal plants are consumed directly or used in the preparations of various formulations in traditional system of medicine (Ayurveda, Siddh and Unani) and some of the active principles are extracted or isolated for the preparation of allopathic drug. Therefore, control of pests and diseases in medicinal and aromatic plants has to be taken seriously to avoid the adverse impact of pesticide residues or other chemicals.

In general, medicinal and aromatic plants are very resistant to pests and diseases. However, organic farming is self sustaining system provides the natural strength in plants to avoid, tolerate and resist against the disease and pests, reason being the medicinal and aromatic plants have wide adaptability. However, under conventional farming, the control of these pests and diseases should be implying the principles of organic farming to avoid above - mentioned consequences.

In isabgol (*Plantago ovata*) various neem spray available in the market were tested to control the aphid and the crude extract of neem-seed karnel was more effective and economical (Upadhyay and MIshra, 1999). In cinchona, crickets cuts the young seed lings can be controlled by tobacco decoction spray and leaf curl caused by tea-fly (*Helopeltis atonii*) could be checked by molasses spray of @11g in 9 litres. Neem karnel extracts (@ 25%) checks the infestation of mealy bug in long pepper (Farooqi and Sreeramu, 2001). Seedling mortality of *Withania somnifera* is physiological rather pathogenic due to partial root anoxia and can be controlled by deep hoeing (Aishwath, 2002). The soil borne diseases and insects can be controlled by using suitable crop rotations and also by selecting inter cropping. Many other cultural practices could replace the use of chemicals as insecticide and pesticides i.e., spacing, irrigation, drainage, hoeing etc. In isabgol close spacing and more irrigations invites the high infestation of aphid.

Intercropping and crop rotations

Intercropping refers to growing two or more generally dissimilar crops simultaneously on the same piece of land and base crop should be in distinct raw arrangement. The recommended optimum plant population of the base crop is suitably combined with appropriate additional plant density of the associated crop and there is crop intensification in both time and space dimensions. The principles involved in management of inter-cropping is to get additional yield through an inter crop as a bonus and to avoid the risk of crop failure. However, crop rotation is a sequence of growing crop on a piece of land in preplanned succession for effective utilization of resources with minimum input. Crop rotations manage the soil fertility and conservation of soil water and soil loss. Out of that intercropping and crop rotations are very much useful for the control of pests and diseases and in organic farming principles.

In aloe, during the first year of planting more than 40% land remains unutilized, hence suitable leguminous or less competitive inter crop like clusterbean, groundnut sesame, isabgol, coriander, cumin etc. could be grown successfully (Maiti and Chandra, 2002). In various combinations of inter cropping of isabgol (*Plantago ovata*) were tested and *P. ovata* + *Saccharum officinarum* was most profitable (Neema *et al.*, 1995; Sharma *et al.*, 1997). The suitable crop rotations for *P. ovata* are groundnut-isabgol, black gram-isabgol and green gram-isabgol (Maiti and Mandal, 2000). Ashwagandh + Babchi (1:1) and Ashwagandh + Babchi (3:1) proved better over the other intercropping of ashwagandh (*Withania somnifera*) and the crop rotation are clusterbean – ashwagandh, *Andrographis paniculata*- ashwagandh, fodder sorghum- ashwagandh. The suitable crop rotations for senna (*Cassia angutifolia*) are paddy-senna, senna-mustard and senna-coriander (Maiti and Aishwath, 2002). In Maharastra, farmers are practicing intercropping very successful in multi-tire system i.e. pigeonpea (*Cajanus cajan*) + safed musli *(Chlorophytum borivilianum)* + Termeric (*Curcuma longa*) with limited resources. Intercropping of rose scented (*Pelargonium species*) with corn mint (*Mentha arvensis*) gave significant result on yield of both crops (Rajeswara Rao, 2002).

Response of organic mulches

Mulches of any material applied on the soil surface to check the evaporation, weed infestation, regulation of temperature and conserve the moisture and soil loss. However, organic mulches have additional benefit in addition to above aspects that is the conditioning of physical, chemical and biological properties of soil after decomposition and improvement the soil health (Fig. 2). About 60 to 70 per cent of the rainfall lost through evaporation can be reduced by the mulches. In general mulches are two types, (1) Non- organic mulches i.e. plastic, soil or dust, vertical or sub-soiling etc. (2) Organic mulches- stubble, straw, spent grass, trashes, green leaves or biomass etc. The organic mulches may be leguminous with narrow C: N ratio and non-leguminous with wide C: N ratio. The leguminous mulches are beneficial to the annual crops and provide the nutrients to the plant by their fast decomposition and are rich in nitrogen. However, non leguminous mulches are most suited to the perennials like trees and bushes.

Chlorophytum borivilianum (with asalio-stra mulch)

Chlorophytum borivilianum (with neem-leaf mulch)

Chlorophytum borivilianum (with lemongrass mulch)

Chlorophytum borivilianum [with dhaincha (Sasbania aculeate) mulch]

Chlorophytum borivilianum (without mulch)

Green neem leaf mulch and asalio straw mulch applied in the safed musli (*Chlorophytum borivilianum*) enhanced the growth and tuberous-root yield (Anonymous 2004a). The neem mulch proved better over asalio-straw mulch with respect to growth and yield of musli, soil available nutrients and also decomposed faster than asalio straw. In preliminary trial with musli and leguminous or non leguminous mulches, (Dhaincha, sunhemp, green gram, moth bean, cow pea, guar, sesbania and lemongrass), it has been observed that leguminous mulches better than non-leguminous mulches for musli crop (Fig. 2). Dhaincha (*Sasbania aculeata*) mulch has highest N content and decomposed faster, resulting more availability of nutrients and ultimately better growth and yield of musli. In aonla (*Emblica officinalis* Gaertn) and guava based cropping systems under salt affected soil, mulching improved the growth and yield of both crops. However, sugarcane trash mulch reduced weed intensity, and irrigation with paddy straw improved the soil properties as compared to other mulches (Rao and Pathak, 1998; Prasad *et al.*, 2004). Mulches of maize straw and paddy straw, grasses, subabool lopping, rice husk and black polythene used in aonla (cv NA-7). Among the organic mulches, paddy straw showed better response for plant growth, soil moisture retention and regulation of soil temperature (Singh and Singh, 2004). Some of the organic and inorganic mulches tested in aonla (Rao, 1995; Rao and Pathak, 1998), aonla + ber (Shukla, 1996) and aonla + guava (Mishra *et al.*, 2004) based cropping systems in sodic soil, paddy straw and sugarcane trash mulch maximized the growth of aonla, improved the soil properties and proved cheaper to maintain soil energy as compared to black plythene. *Citronella java* spent grass mulch used in menthol mint enhanced the yield of main and ratoon crops (Ram and Kumar, 1997). Leaf mulch of *Pongamia glabra* increased the herb and oil yield of *Citronella* and conserved the 45% soil moisture and 72% reduction in weed biomass (Prakash Rao and Puttanna, 2000).

Nutrient requirement

The nutrient requirement of the many medicinal and aromatic crops are still not known. In most of the cases, the nature of medicinal and aromatic plants is not as that of other field crops. These plants are very specific for nutrition and soil requirement and some of them perform well even in poor and degraded soils (Aishwath, 2004b). Many a times nutrient requirement ratio is very wide within the macro and micro nutrients (Aishwath, 2005c). Nutrient requirement of some medicinal and aromatic plants are given in Table 8. Some of the medicinal plants (guggal) are performed well in mineral soil and addition of organic manures exhibits adverse impact on growth, establishment and also gummosis.

Table 8. Nutrient removal by some medicinal and aromatic crops

Crop	*N uptake (kg ha^{-1})*	*P uptake (kg ha^{-1})*	*K uptake (kg ha^{-1})*
	Medicinal crops		
Periwinkle	24	5	24
Psyllium	68	7	60
Opium poppy	51	--	--
Safed musli	4	1	2
Winter cherry	44	8	30
	Aromatic crops		
Menthol mint	109	28	129
Citronella	181	33	255
Lemongrass	160	32	194
Palmarosa	430	62	339
Geranium	180	24	137
Coriander	30	4	36
Davana	179	26	171
Japanese mint	109	28	129
Pappermint	42	--	--

Source: Prakasa Rao, 1992; Aishewath *et al.*, 2003; Aishwath, 2004a, Aishwath *et al.*, 2005c

CONCLUSION

Medicinal and aromatic plants perform better with organic manures, biofertilizers and mycorrhizal association. Weeds, insects-pests could be managed effectively with mulches and bio-pesticides, respectively. Crop rotations and intercropping also adds value per unit area and helpful for control of disease, pests and weeds. Organic manures and mulches not only improve the yield and controls weeds but also provides the organic matter and nutrients to the soil, ultimately improves the soil health. However, switching over from modern farming to organic farming in Indian perspective is not so feasible at present. Many of the studies were carried out with biofertilizers in pot culture and organic or biopesticides tested in the laboratory. These need to be confirmed at field level in natural environment for the comparable results. It has been provoked that quality of medicinal and aromatic plants deteriorates with chemical fertilizers. However, there is no conclusive report available with comparison of organic manures and fertilizers with respect to quantity and quality of the produce. In some studies, application of micronutrients as chemical fertilizer improved the yield without alteration of quality. Even there are some reports that physical root quality of *Withania somnifera* adversely affected by application of FYM; it is because of branching of roots and fiber development in them also in *Plantago ovata* chemical fertilizers do not affect the quality and enhances the total husk production. Some of the plant directly consumed or formulation prepared directly may have much significance for organic farming. Therefore, assumption in medicinal and aromatic plants based on other crops may not be proved. Most of the medicinal and aromatic crop response with manures and fertilizers is not on soil test basis. Therefore, results are not comparable with various locations, and some times it misled for recommendations of manures doses and that has to be taken care with proven facts.

Let thy food be thy medicine,
and thy medicine be thy food.
(Hippocrates, 400 B.C.)

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DIVERSITY AND POTENTIALS OF SOIL FAUNA IN RECYCLING OF ORGANIC MATTER

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INTRODUCTION

Soil is a community and seat of biological activity. Soil biota imparts in various physiochemical and biological activities and improve soil health on a sustainable basis. Soil fauna can be divided into three groups viz., microfauna, mesofauna and macrofauna. Microfauna includes Protozoa, smaller Turbellaria, Rotifera, Nematoda and Tardigrada. Mesofauna covers Enchytraeidae, most Arachnida, some Myriapoda and the smaller insects. Macrofauna includes Mollusca, earthworms and the larger arthropods.

Soil animals act as buffer energy source for soil and plant both. They act as indicator of soil condition and can be used for soil diagnosis. Soil biota constitutes the driving force of terrestrial ecosystems because it controls the rate of turnover and mineralization of organic substrates. The significant effects of soil fauna on the nutrient dynamics of ecosystem have been documented (Moore *et al.*, 1988; Verhoeff and Brussaard, 1990; Tripathi *et al.*, 2003). Soil fauna favour microbial activity, increase enzymatic activity, stimulate root development and maintain a control over plant damaging species. Hence, the importance of soil fauna at this juncture can not be ignored.

Wood (1991) considered the biological quality of the soil in terms of population of soil organisms or of the processes accomplished by the organisms. When plants die, the above ground plant parts are distributed within the soil by gravity, water movement and by soil organisms. Root growth distributes carbon through the movement of dead plant parts by animals or water movement. In agroecosystems soil fauna play an important role in distribution and flow of carbon within the soil system by creating galleries, chambers, burrows, mounds and nests and producing faecal matters. Intensive efforts are required to restore biological health, biodiversity and the physical and chemical properties of soil. It is becoming increasingly evident that the soil animals are the major contributors to soil fertility