BIOFERTILIZATION AND ORGANIC FARMING APPROACHES

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Abstract

Biofertilizers are considered to be low cost, ecofriendly and renewable sources of plant nutrients supplementing chemical fertilizers in sustainable agricultural systems. This refers to microorganisms, which increase crop growth through different mechanisms, i.e. biological nitrogen fixation (BNF), growth-promoting or hormonal substances increased availability of soil nutrients. Their importance lies in their ability to supplement/ mobilize soil nutrients with minimal use of non-renewable resources and as components of integrated plant nutrient systems. The most important group of biofertilizers that have played vital role of maintaining soil fertility in agriculture is up till now via BNF process. Contributions of BNF through the application of different nitrogen fixing microorganisms (biofertilizers groups) were estimated under different environmental conditions given using isotopic (^{15}N isotope dilution) and non-isotopic (N difference) methods. Symbiotic plant-microbe interactions such as Rice-*Azolla*, Legume-*Rhizobium* either prennial crops or fixing trees were examined on field and greenhouse experiments. Similarly, free-living or associative N_2 fixing microorganisms were evaluated for potential N_2 fixation with non-legumes, i.e. rice, maize, barely and wheat. Also, growth-promoting effect was considered for plants, particularly cereal crops inoculated with diazotrophs and/or arbuscular mycorrhiza fungi (VAM). Such microflora have the ability to provide considerable amounts of sparing nutrients especially P in rhizoplane of inoculated plants. Application of ^{15}N tracer techniques gave us a chance to confirm some of the mechanisms responsible for enhancement of plant growth and nutrient acquisition. From our viewpoint, it is important to encourage the use of biofertilizers especially under circumstances of lacks in soil and water

resources like we have in our region and in the same time, to spread out the concept of low input agriculture. In this respect, the recycling of organic wastes was also considered. Therefore, there is a need to develop reliable biofertilizers with scientifically defined modes of action and incorporating BNF to maximize their efficacy.

INTRODUCTION

Beneficial plant-microbe interactions in the rhizosphere are primary determinants of plant health and soil fertility. Various soil microorganisms that are capable of exerting beneficial effects on plants have a potential for use in agriculture and can lead to increasing yields of a wide variety of crops. Soil-plant-microbe interactions are complex and there are many ways in which the outcomes can influence plant health and productivity (Kennedy 1998). Microbial groups that affect plants by supplying combined nitrogen include the symbiotic N_2-fixing rhizobia in legumes, actinomycetes in non-leguminous trees, and blue-green algae in symbiosis with water ferns. Additionally, free-living fixing bacteria of the genus *Azospirillum* affect the development and function of grass and legume roots, thereby improving minerals and water uptake (Okon *et al.*, 1998). Other microorganisms that are known to be beneficial to plants are the phosphate solubilizers (*Pesudomonas spp.* and *Bacillus megatherium*), plant-growth-promoting pesudomonads and mycorrhizal fungi.

These different types of microorganisms are of economic importance in improving crop productivity and can replace costly chemical fertilizers, improving water utilization, lowering production costs, and reducing environmental pollution, while ensuring high yields. Some groups of beneficial rhizosphere microorganisms are engaged in well-developed symbiotic interactions in which particular organs are formed, such as mycorrhizas and root nodules, whilst others develop from fairly loose associations with the root. The interaction between rhizobial bacteria and the roots of leguminous crops has been well studied (Brockwell et al., 1995), while mycorrhizal relationship has only recently become a significant topic of research (Smith and Read 1997). Other plant root-microbe interactions arise from specific interactions between groups of bacteria or fungi that are adapted to live in the rhizosphere. Such rhizobacteria or rhizofungi are adapted to exploit this niche and often act synergistically in combination with mycorrhiza. Both the plant-growth-promoting rhizobacteria (PGPR) and plant-growth-promoting fungi (PGPF) affects the plant health through interactions with potential phytopathogens (Azcon-Aguilar and Barea 1996). Others produce compounds that directly stimulate plant growth, such as vitamins or plant hormones (Barea 1997, 2000). Others, such as the fungi *Trichoderma*, may stimulate plant growth by more than one mechanism (Ousley et al., 1994).

Advanced methodologies, such as ^{15}N techniques applied in such topics of biofertilization offers reliable techniques for verifying the mechanisms involved in plant-growth promotion and consequently gave an exact estimation of biologically fixed nitrogen.

In this context, we will overview the situation and contribution of different biofertilizers systems to plant development, nutrient cycling, N_2-fixation and soil fertility. Thus, the conventional and isotopic methods were applied for quantification of BNF. So, the biofertilizers and organic agriculture effects on plant production and soil fertility, as a most cheap source of nutrients, as well as the need for inoculation and inoculant production will be discussed.

Part I. Biofertilization Approach

I. Soil fertility management

This concept was documented by Katyal and Vlek (2000) as one of the amelioration techniques used to overcome the desertification problem in arid and semi-arid regions. Soil organic matter improves soil physical conditions and fertility due to an enhancement of the biological community that functions efficiently. Soil biota is diverse and impacts ecosystem functioning in many ways. Diverse species teamed together can break up recalcitrant fractions present in an organic residue (Rupela 1997). Individual organisms may play more specific roles. For instance, mycorrhizal fungi benefit the plant by mobilizing immobilized nutrients, and help in controlling pests and diseases. Earthworms can take part in composting and modifying soil structure.

The problem of soil fertility decline is so serious (Smaling *et al.* 1997) to be unable to be covered totally with organic approaches alone. Thus, fertilizers have a definite role in soil fertility management, although dryland farmers often consider this to be risky investments. However, research findings over the last several years have confirmed that fertilizer application across diverse dryland environments imparts greater yield stability with favorable economics. Further, the response to fertilizers was found to be more sustainable when their application was integrated with organic manures/biofertilizers (Katyal *et al.* 2001). The integrated use of mineral fertilizers, organic manures, and soil biological support lessens the reliance on fertilizers and better matches the economic limitations faced by the dryland farmers. Simultaneous application of other standard agronomic practices are necessary to maximize the benefits of integrated soil fertility-management systems.

Soil microbes

Soil is not just a matrix to hold plants, but is a living entity in itself. A healthy soil, full of active microorganisms in correct balance, is essential to productive agriculture. Microorganisms are responsible for many transformations in soil related to plant nutrition and health. One of the most known benefit is biological nitrogen fixation. N_2-fixing bacteria form nodules on plant roots and transform N_2 gas to plant-available nitrogen. Mycorrhizae are usually nonpathogenic fungi that form symbiotic associations with plant roots. Microbes also plays a major role in the formation of good soil structure. Bacterial mucigel and hyphal threads produced by fungi and actinomycetes bind the soil particles together. Microbial activity helps to aggregate the soil, which reduces erosion, allows for good water infiltration, and maintains adequate aeration of the soil. Soil microbes also affect the persistence of organic compounds applied in the soil. Table 1, summarizes some of such beneficial activities of soil microorganisms. Many of these activities are particularly important and significant in the plant rhizosphere and rhizoplane sites where microbial populations and activity are high.

In conclusion, the fertile soil produces a healthy plant efficient in the accumulation of nutrients, the suppression of weed growth, and erosion control through extensive root systems. The key to such a healthy soil is the microbial population. A high quality soil is that which are biologically active and contains a balanced population of microorganisms.

Plant-Microbe Systems

***Rhizobium*-Legume symbiosis**

Sustainable agriculture relies greatly on renewable resources and on-farm nitrogen contributions are achieved largely through biological nitrogen fixation (BNF). Biological nitrogen fixation helps in maintaining and/or improving soil fertility by using N_2, which is abundant in the atmosphere. Annually, BNF is estimated to be around 175 million tones N of which close to 79 % is accounted for by terrestrial fixation. In this respect, Fig 1 illustrates the distribution of N_2-fixed in various terrestrial systems and recognize the importance of BNF in the context of the global N cycle. The BNF offers an economically attractive and ecologically sound means of reducing external N inputs and improving the quality and quantity of internal resources (Wani et al., 1995). Experimental estimates of the proportion of plant N derived from N_2-fixation ($P_{fix.}$) and the amounts of N_2-fixed by important tropical and cool season crop legumes are presented in Table 2. Available data of N_2-fixed in forage legumes, cover crops and N_2-fixing trees indicates similar values to that of crop legumes (Tables 3, 4).

Table 1. Beneficial activities of microorganisms in the soil, rhizosphere, or rhizoplane.
Source, Kennedy and Papendick (1995)

Decomposition of plant residues, manures, and organic wastes
Humus synthesis
Mineralization of organic N, S, and P
Improved soil aggregation
Increase in the availability of plant nutrients (P, Mn, Fe, Zn, Cu ...etc.)
Symbiotic mycorrhizal association
Production of organic chelating agents
Oxidation-reduction reactions
Phosphate solubilization
Biological nitrogen fixation
Free-living bacteria and bluegreen algae
Associative microorganisms
Symbiotic- legume and nonlegume
Plant growth promotion: changes in seed germination, floral development, root and shoot biomass
Production of plant growth hormones
Protection against root pathogens and pseudopathogens
Enhanced nutrient use efficiency

Legumes have been an important component of agriculture since ancient times because of its role in improving soil fertility via their N_2-fixing ability (Wani et al., 1995). Review made by those investigators showed different proportions of N_2-fixed ranged from low to moderate and high levels. For example, pigeon pea cultivars fixed 4 - 53 kg N ha^{-1} $season^{-1}$ while depleting 20 - 49 kg N ha^{-1} from the soil pool. In the case of chickpea, different cultivars fixed 23 - 40 kg N ha^{-1} $season^{-1}$ and removed 63 - 77 kg N ha^{-1} $season^{-1}$ from soil.

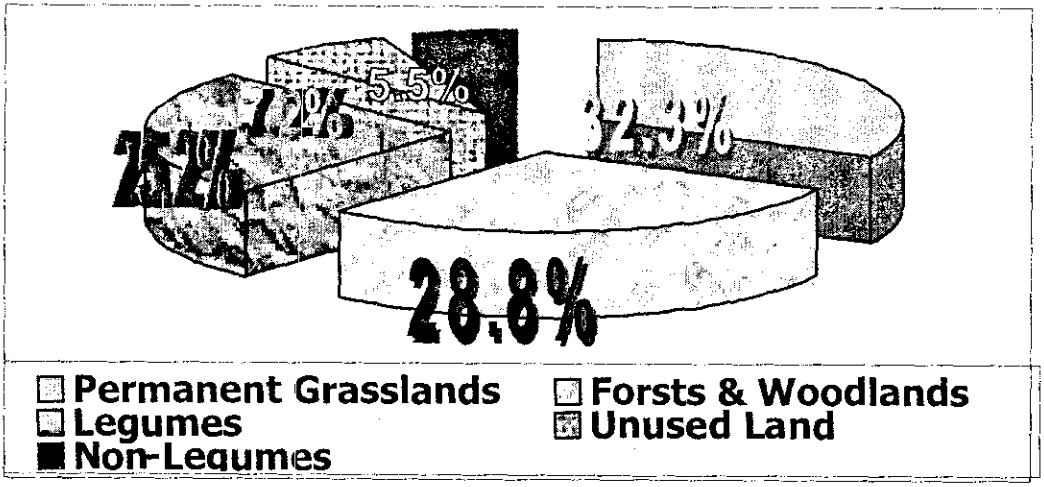

Figure 1 .Distribution of 139 million tones of N_2 fixed in terrestrial systems.

Source: Burns and Hardy (1975)

Table .2 Range of experimental estimates of the proportion (P_{fix}) and amount of N_2 fixed by important pulses and legume oilseeds. *Source: Peoples et al. (1995)*

Species	P_{fix} (%)	Amount N_2 fixed (kg N ha^{-1})
Cool-season legumes		
Chickpea (Cicer arietinum)	8 –82	3–141
Lentil (Lins culinaris)	39 –87	10 – 192
Pea (Pisum sativum)	23 – 73	17 – 244
Faba bean (Vicia faba)	64 – 92	53 – 330
Lupin (Lupinus angustifolius)	29 –97	32 – 288
Warm season legumes		
Soybean (Glycine max)	0 – 95	0 – 450
Groundnut (Arachis hypogaea)	22 – 92	37 – 206
Common bean (Phaseolus vulgaris)	0 – 73	0 – 125
Pigeon pea (Cajanus cajan)	10 – 81	7 – 235
Green gram (Vigna radiata)	15 – 63	9 – 112
Cowpea (V. unguiculata)	32 – 89	9–201

Groundnut fixed 190 kg N ha^{-1} $season^{-1}$ when pod yields were around 3.5 t ha^{1} (Nambiar *et al.*, 1986), however, it relies for its 20 - 40 % (47 - 127 kg N ha^{-1} $season^{1}$) of the N requirement on soil or from fertilizer (Giller *et al.*, 1987). Our results, in this regard, showed that N_2-fixation in groundnut was vigorous with *Bradyrhizobium* inoculation either solely or in combination with mycorrhizal fungi (El-Ghandour *et al.*, 1997), and the values of N derived from air, as estimated using ^{15}N isotope dilution, were on line with those reported by Giller *et al.*, (1987). Residual effect of ^{15}N-labelled urea or ammonium sulfate on growth and N_2-fixation by nodulating soybean was examined (Galal and El-Ghandour 1997), and the data of N derived from air was ranged from 42 to 65 % as affected by *Bradyrhizobium* inoculation either solely or in combination with *Azotobacter chroococcum* strain. Similar, dual inoculation with *B. japonicum* and *Azospirillum brasilense* enhanced growth and N_2-fixation of nodulating soybean cultivated in sterilized and/or non-sterilized soils. It seems that *A. brasilense* act as helper bacteria for developing *B. japonicum* performance in the rhizosphere of nodulating soybean (Galal 1997).

Table .3 Range of experimental estimates of the proportion (P_{fix}) and amount of N_2 fixed by important forage legumes. *Modified after: Peoples et al. (1995)*

Species	P_{fix} (%)	Amount N_2 fixed (kg N ha^{-1})	Period of measurement
Temperate forages			
Lucerne/ alfalfa (Medicago sativa)	46 - 92	90 - 386	Annual
White clover (Trifoliumrepens)	62 - 93	54 - 291	Annual
Subterranean clover (T. Subterranean)	50 - 93	2 - 206	Annual
Vech (Vicia sativa)	75	106	Not available

In a pot experiment, El-Ghandour and Galal (1997) reported that more than 80 % of the nitrogen requirement of faba bean plants (different genotypes) was gained from air (% Ndfa). Thus, the addition of ^{15}N rice straw enhanced the N_2-fixation potential as compared to ^{15}N-ammonium nitrate fertilizer. Combined inocula of rhizobia and mycorrhizae fungi had enhanced growth and N_2-fixation of inoculated faba bean comparable to single inocula.

Faba bean grown in farmer's fields responded well to inoculation with *Rhizobium* applied in two ways (liquid culture or peat-based) under gradual increase of nitrogen fertilizer up to 40 kg N ha^{-1}. In this field experiment (Table 5), nitrogen fixation estimated by N difference method was negatively affected by the high level of applied fertilizer (40 kg N ha^{-1}). In this respect, the inoculant types were slightly differentiated (El-Ghandour *et al.* 2001). Similar field trial with mungbean (*Vigna radiata* L. *Wilczek*) was conducted under drip irrigation system to investigate the effect of rhizobial inoculants either applied in peat based inoculum or through the irrigation water (inocugation). Nodulation was excellently performed with both types of inoculum (Table 6). Application of isotope dilution approach showed the superiority of inocugation method over the peat-based inoculum since the percentages of N derived from air and utilized by seeds were 73% and 50%, respectively (Thabet and Galal 2001).

Table 4. Range of experimental estimates of the proportion (P_{fix}) and amount of N_2 fixed by important N_2-fixing trees, green manures and cover crops. *Modified after: Peoples et al. (1995)*

Species	P_{fix} (%)	Amount N_2 fixed (kg N ha^{-1})	Period of measurement
Trees			
Acacia holosericea	30	3 - 6	6.5 months
Casuarina equisetifolia	39 – 65	9 - 440	6 – 12 months
Gliricidia (Gliricidia sepium)	52 – 64	86 - 309	Annual
- hedgerow for forage	69 – 75	99 - 185	3 – 6 months
- alley crop hedgerow	43	170	Annual
Leucaena (Leucaena leucocephala)	34 – 78	98 - 230	3 – 6 months
Green manures and cover crops			
Azolla spp.	52 – 99	22 - 40	30 days
Sesbania cannabina	70 – 93	126 - 141	Seasonal average
Sesbania rostrata	68 – 94	70 - 324	45 – 65 days
Sesbania sesban	13 – 18	7 - 18	2 months

Table 5. Contribution of N_2 fixed (kg plot^{-1*}) and utilized by either shoots or grains of faba bean inoculated with different inocula under gradient N levels

Inoculation	Shoot				Grains			
	Fertilizer nitrogen applied (kg ha^{-1})							
	0	10	20	40	0	10	20	40
Liquid culture	0.121	0.011	0.115	-0.009	0.252	0.224	0.213	-0.195
Peat based	0.140	0.085	0.121	-0.022	0.37	0.18	0.009	-0.123
Mixture	0.130	0.033	0.134	-0.027	0.235	0.257	0.373	-0.082

Table 6. Nodulation of mungbean roots as affected by Rhizobiun inoculation methods

Root length	Nodule number plant^{-1}		Nodule dry weight (g plant^{-1})	
	Peat-based	Inocugation	Peat-based	Inocugation
5 cm	22	25	3.1	3.6
Below	13	7	2.1	1.8

Diazotrophic bacteria and Azolla

Several groups of asymbiotic N_2-fixing bacteria have been identified in soils and flooded systems and those genera which include N_2-fixing species were reviewed by Roper and Ladha (1995). The heterotrophic diazotrophs depend on carbon, e.g. from crop residues, for energy. The most common isolates from soils were *Azotobacter, Azomonas, Beijerinckia* and *Derxia, Clostridium* and *Bacillus, Klebsiella* and *Enterobacter*, and *Azospirillum, Desulfovibrio* and *Desulfotomaculum* (Roper and Halsall 1986).

Nitrogen fixation by asymbiotic bacteria has been observed in greenhouse and field experiments under dry land cropping systems. Biological N_2 fixation associated with crop residues (legumes or cereals) was investigated in pot experiments with wheat (Galal 2002) and chickpea cultivars (El-Ghandour and Galal 2002). In these experiments (Tables 7,8), both residues of wheat and rice were labelled with ^{15}N and used as organic N sources in comparison with either ^{15}N-labelled ammonium sulfate or ammonium nitrate as chemical nitrogen fertilizers. Dual inoculation with *Rhizobium* and mycorrhizae fungi significantly affected nodulation and colonization percentages of chickpea cultivars (El-Ghandour and Galal 2002). *Rhizobium* inoculation extended to be used with wheat gave the best results of growth parameters and N_2 fixation when combined with *Azospirillum brasilense* as heterotrophic diazotrophs (Galal 2002). The economical return of *Azospirillum brasilense* (as liquid media or commercial product) was estimated with maize crop grown under field conditions. The obtained data showed that inoculation combined with the half dose of recommended N fertilizer rates was the most effective and low cost agricultural inputs (Abdel Monem et al. 2001). The nitrogen uptake by wheat plants was significantly increased by application of soybean residues and inoculation with *Azospirillum brasilense* (Galal and Thabet 2002). This field trial concluded that soybean residue as enriched N material, and *Azospirillum brasilense* inoculation enhanced growth, grain and N yields of wheat cultivars grown in poor fertile sandy soil.

Galal and El-Ghandour (2000) examined the effect of inoculation of *Azospirillum brasilense* on grain yield, biological nitrogen fixation and NPK uptake by two rice cultivars (Giza 172 and IR 28), grown under greenhouse conditions (pot experiment). ^{15}N data confirmed the enhancement of N derived from fertilizer and ^{15}N recovery due to inoculation with *Azospirillum* as compared to the uninoculated treatment. The proportion of N derived from air not exceeds 28% indicating that the effective mechanism is the promotion of plant growth and nutrients uptake was more rather than BNF. Similar findings were observed when comparative study was held between *Azospirillum brasilense*, *Azolla pinnata* and arbuscular mycorrhizae fungi, as individual inoculum, using ^{15}N tracer technique in pot experiment with japonica rice variety, Giza 171 (Galal; 2000).

Table 7. Nitrogen derived from air (Ndfa) and utilized by inoculated wheat plants amended with ^{15}N- ammonium nitrate or ^{15}N labelled rice straw.

sInoculation	^{15}N-ammonium nitrate Ndfa (%)	(mg pot^{-1})	^{15}N – rice straw Ndfa (%)	(mg pot^{-1})
		Shoots		
Azospirillum	19.4b	1.32b	22.3b	1.07b
Rhizobium	23.0a	2.57a	24.3b	1.63b
Azosp. + Rhiz.	23.6a	3.07a	32.0a	2.46a
LSD (0.05)	2.74	0.94	2.58	0.84
C.V(%) .	6.31	18.03	4.97	21.62
		Grains		
Azospirillum	20.9c	1.46b	29.9c	1.52b
Rhizobium	34.9a	3.52a	35.0b	2.06b
Azosp. + Rhiz.	30.2b	3.23a	39.2a	4.82a
LSD (0.05)	5.45	0.73	2.14	0.73
C.V(%) .	9.58	11.80	3.10	11.52

Means in each column followed by the same letter are not significantly different at $P \leq 0.05$.

Table 8. Nitrogen derived from organic residues (Ndfr) and air (NdfA) and uptake by shoot and seeds of chickpea cultivars as affected by inoculation treatments in soil amended with ^{15}N-wheat straw.s

Treatment	Nitrogen derived from residue mg pot^{-1}			Nitrogen derived from air mg pot^{-1}		
	Shoot	Seed	Total	Shoot	Seed	Total
Giza 2						
Uninoculated	4.1 b	2.2 b	6.3 b	-	-	-
Rhizobium (Rh)	3.7 b	2.6 b	6.3 b	39.3 b	33.3 b	72.6 b
AM fungi	5.1 a	10.9 a	16.0 a	-	-	-
Rh + AMF	4.5 a	3.6 b	8.1 b	54.3 a	48.6 a	102.9 a
Giza 195						
Uninoculated	3.4 d	1.8 d	5.2 d	-	-	-
Rhizobium (Rh)	7.0 c	2.4 d	9.4 c	88.2 b	33.0 b	121.2 b
AM fungi	21.3 a	9.8 a	31.1 a	-	-	-
Rh + AMF	6.8 c	2.5 d	9.3 c	113.2 a	50.0 a	163.2 a

Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$.

Table 9. Amounts of nitrogen derived from air (Ndfa) and uptaken by shoot and grain of wheat varieties as affected by inoculation and organic residue addition. *Values are means of three replicates per plot area 3.6 m^2*

Treatment	Soil with organic residues				Soil without organic residues			
	Shoot		Grain		Shoot		Grain	
	%	kg	%	kg	%	kg	%	Kg
Giza 163								
Inoculated	39.3	0.9 b	32.6	0.69 b	40.2	0.76 b	41.2	0.59 b
Giza 164								
Inoculated	64.5	1.17 a	52.3	1.19 a	55.8	1.07 a	63.5	1.19 a

Means in the same column for each portion followed by the same letter are not significantly different at $P \leq 0.05$

Phosphate-solubilizing bacteria

Phosphorus production for plant growth promotion is considered as one mechanism of plant growth regulation induced by P-solubilizing rhizobacteria such as *Agrobacterium, Bacillus,* and *Pseudomonas* species. P-solubilizing *Pseudomonas* and *Enterobacter spp.*, have the ability to solubilize P and produce sidrophores and auxins which promoted the growth of maize plants (Chabot *et al.* 1996). Mungbean cultivated in P-deficient soil amended with rock phosphate was positively responded to inoculation with *Bacillus subtilis* (Gaind and Gaur 1991). Similarly, *Azotobacter chroococcum* showed an efficient role on solubilizing tricalcium phosphate and rock-P (Kumar and Narula 1999).

The phosphorus requirement for chickpeas has been estimated to be from 8-14 kg ha^{-1}. Its deficiency in the soil prevents good symbiotic nitrogen fixation, and hence a crop suffering from phosphorus deficiency may give the appearance of nitrogen deficiency. The presence of 3-5 mg available P per kg soil is enough to meet the phosphorus requirements of chickpea, as it is better than other crops in extracting phosphorus from the soil (Singh and Saxena, 1999). Application of phosphorus at increased rates in combination with inoculants promoted nodulation and increased seed yield, N and P uptake and N_2 fixation (Idris *et al.*, 1989; Parihar and Tripathi, 1989; Raju *et al.*, 1991; Subba Rao et al., 1986; Yahia *et al.*, 1995). It is of practical importance to study the effect of phosphate-solubilizing bacteria in association with other organisms on chickpea growth and N_2 fixation potential. While the single inoculation with *Rhizobium* increased the nodulation and nitrogenase activity, the phosphate-solubilizers increased the availability of phosphorus in soil. Combined inoculation of *Rhizobium* and *Pseudomonas striata* or *Bacillus polymyxa* had increased chickpea seed yield, dry matter content and N and P uptake significantly over the uninoculated control. These increments were more pronounced in the presence of either N or P added fertilizers (Alagawadi and Gaur, 1988). Also, Arbuscular mycorrhizal fungi (VAM) are known to increase nutrient uptake, particularly P to the host plant (Daft and Nicolson, 1969; El Ghandour *et al*, 1996a,b). Synergistic effect of VAM inoculation with *Rhizobium* was recognized for peanut (El-Ghandour *et al.*, 1997; Ishac *et al.*, 1988) and chickpea (El Ghandour *et al*, 1996b; Subba Rao *et al.*, 1986) in either sandy or alluvial soils. For instance, the nodulation criteria and BNF by chickpea were positively affected by rhizobial inoculation combined with phosphate-solubilizing bacteria and mycorrhizea as affected by P-fertilizer sources and doses (Tables 10,11 after Soliman *et al.* 2003).

Table 10. Nodule number per plant and dry weight (g $plant^{-1}$) of chickpea treated with *Rhizobium*, VAM and phosphorin as affected by levels of P fertilizers. *Values are means of triplicate pots*

Treatment	Phosphate fertilizers added mg P kg^{-1} soil						
	Control	Superphosphate		Rock-P_1		Rock-P_2	
	0	25	50	25	50	25	50
Nodule no.							
Uninoculated	25	47	52	50	56	54	56
Phosphorin (PSB)	31	65	59	70	72	71	78
VAM	30	51	53	71	72	75	77
VAM+PSB	33	70	55	76	78	81	84
Dry weight							
Uninoculated	0.04	0.3	0.34	0.3	0.4	0.4	0.4
Phosphorin (PSB)	0.05	0.36	0.31	0.5	0.42	0.4	0.52
VAM	0.04	0.3	0.3	0.5	0.4	0.41	0.5
VAM+PSB	0.06	0.4	0.3	0.52	0.43	0.53	0.53

LSD (nodule no) for inoculation effect (A), 1.18; fertilizer effect (B), 1.02; fertilizer levels effect (C), 1.02; AxB effect, 2.04; AxC effect, 2.04; BxC effect, 1.8; AxBxC effect, 3.54.

LSD (nodule DW) for inoculation effect (A), 0.02; fertilizer effect (B), 0.01; fertilizer levels effect (C), 0.01; AxB effect, 0.03; AxC effect, 0.03; BxC effect, 0.02; AxBxC effect, 0.05.

Table 11. Biological N fixed in shoots (mg pot^{-1} and percent) of chickpea plants as affected by inoculation and phosphatic fertilization. *Values are means of triplicate pots.*

Treatment	Phosphate fertilizers added mg P kg^{-1} soil						
	Control	Superphosphate		Rock-P_1		Rock-P_2	
	0	25	50	25	50	25	50
Mg pot^{-1}							
Uninoculated	100.9	228.1	218.9	198.9	210.4	221.3	205.9
Phosphorin (PSB)	123.8	237.7	226.5	237.3	232.8	234.9	233.6
VAM	134.9	245.7	234.8	250.1	241.9	255.2	247.6
VAM+PSB	151.4	299.9	287.9	312.9	287.0	302.7	262.5
% Ndfa							
Uninoculated	23.9	43.0	39.9	39.0	40.0	40.9	39.0
Phosphorin (PSB)	24.9	42.9	40.9	41.9	40.0	40.0	40.0
VAM	26.9	44.0	40.9	42.9	41.0	42.9	41.9
VAM+PSB	29.0	52.9	49.9	52.0	47.9	49.9	44.0

LSD for inoculation effect (A), 0.19; fertilizer effect (B), 0.17; fertilizer levels effect (C), 0.17; AxB effect, 0.34; AxC effect, 0.34; BxC effect, 0.29; AxBxC effect, 0.59.

The contribution of Mycorrhizae

Mycorrhizae are fungi so closely connected to the roots that they are considered an extension of the root system. The vesicular-arbuscular mycorrhizal fungi (VAM), which are members of the class *Zygomycetes* order *Glomales*, form mycorrhizae with plant roots. These fungi are obligate symbionts and are not host-specific. They occur in about 80% of plants (Bonfante-Fasolo, 1987). The VA mycorrhizal fungi grow primarily inside the root, but the network of extraradical fungal hyphae form an extension of the effective root area of the plant, which increases the absorption and translocation of immobile nutrients.

Mycorrhizal technology is aimed at restoring the inoculum potential of AMF in problem soils. This may be achieved through bioaugmentation, by inoculating soils with AMF or by using transplanted seedlings that already have the appropriate AMF in their roots. Contribution of AMF to soil health and fertility is one of topics reviewed recently (Jeffries et al. 2003). It is considered as essential components of soil biota; they can be found in nearly all ecological situations, both in natural ecosystems, particularly in those supporting plant communities with a high species diversity, and also in normal cropping systems, especially if managed with sustainable practices (Gianinazzi and Schüepp 1994). Phosphorus is the key element obtained by plants through the symbiosis and the evidence to support this is extensive (Smith and Read 1997). In exchange, mycorrhizal plants provide the fungus with photosynthetic C, which in turn is delivered to the soil via fungal hyphae. Therefore, the extraradical hyphae of AMF act as a direct conduit for host C into the soil and contribute directly to its C pools, by passing the decomposition process. As a consequence of this, the amount and activity of other soil biota are stimulated; however, this seems to be a selective phenomenon, since it stimulates in particular the microbes having antagonistic activity against soil-borne pathogens (Linderman 2000). This indicates that AMF could be useful biological tools for maintaining healthy soil systems.

Arbuscular mycorrhizal fungi changes plant physiology and certain nutritional and physical properties of the rhizosphere soil. In turn, these changes may affect colonization patterns of this region by soil microorganisms by the so-called mycorrhizosphere effect (Gryndler 2000). Arbuscular mycorrhizal fungi thus interact with natural and introduced microorganisms in the mycorrhizosphere, hence affecting soil properties and soil quality (Fig 2). Conversely, soil organisms are known to affect AM formation and functioning markedly (Barea et al. 2002). Some of the literature cited in this review reported either antagonistic or synergistic effects of complex rhizoshpere microflora on AM formation, nutrient cycling and plant growth and biological control of plant pathogens (Barea *et al.* 2002; Gryndler 2000; Vosátka and Gryndler 1999; Jeffries 1997; Nehl *et al.* 1996).

Soil microorganisms can produce compounds that increase root cell permeability, thereby increasing the rates of root exudation that stimulates the growth of hyphae of AMF in the rhizosphere and facilitate root penetration by the fungus. Amino acids, plant hormones, vitamins, other organic compounds and volatile substances (CO_2), produced by soil microorganisms, can stimulate the growth rates of AMF (Azcón-Aguilar and Barea 1995; Barea 1997, 2000). The contribution of AMF can be stimulated by interacting with dinitrogen-fixing bacteria and phosphate-solubilizing microorganisms that have activities in improving the bioavailability of the major plant nutrients such N and P (Barea *et al.* 2002; Galal and Soliman, unpublished data).

Management of such interactions is a promising approach either for low-input agricultural technologies or for the re-establishment of natural vegetation in a degraded area (Bethlenfalvay and Linderman 1992; Gianinazzi and Schüepp 1994; Jeffries and Barea 2001; Galal 2000; Galal and El-Ghandour 2000; Miller and Jastrow 2000).

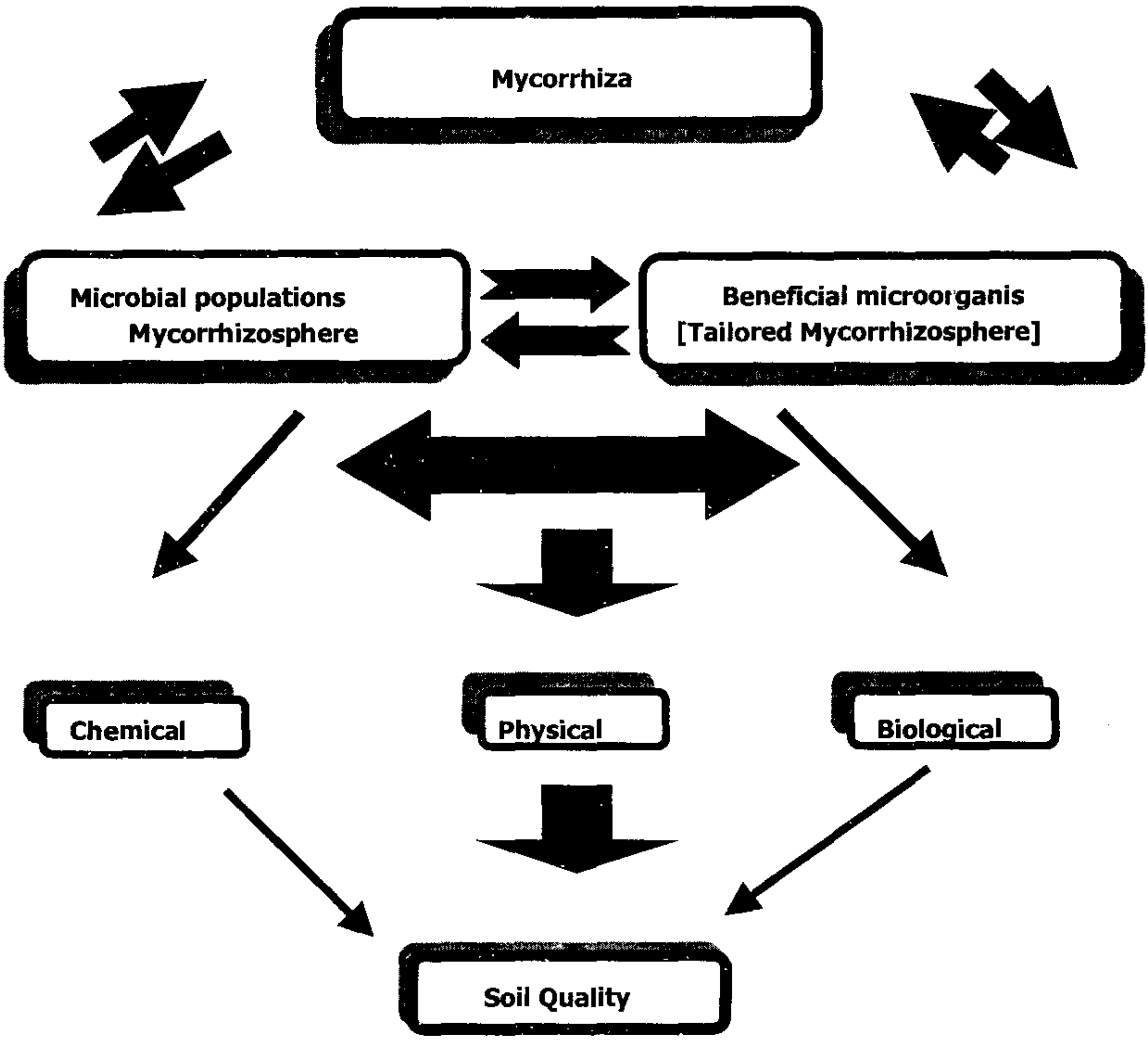

Figure 2. Arbuscular mycorrhizal fungi interact with natural and introduced microorganisms in the mycorrhizosphere, thus affecting soil properties and quality. Jeffries *et al.* (2003).

Measurements of the $^{15}N/^{14}N$ ratio in plant shoots indicated enhancement of N_2-fixation rates in Rhizobium-inoculated mycorrhizal plants, as compared to the non-mycorrhizal plants (El-Ghandour and Galal 2002; Toro et al. 1998; El-Ghandour and Galal 1997; El-Ghandour *et al.* 1997). Several microbial combinations were effective in improving plant development, nutrient uptake, N_2-fixation (^{15}N) or root system quality, showing that selective and specific functional compatibility relationships among the microbial inoculants were evident with respect to plant response (Jeffries *et al.* 2003). Promotion of AMF interacted with associative microbes like *Azospirillum* was also demonstrated (Galal and El-Ghandour 2000; Volpin and Kapulnik 1994).

The interactive effect of phosphate solubilizing rhizobacteria (PSB) and AMF on plant use of soil-P sources of low bioavailability (native or added as rock phosphate) had been evaluated in soil using ^{32}P isotopic dilution approach (Toro *et al.* 1998), and ^{15}N techniques to examine the effect of *Rhizobium*, PSB/ AMF associations on chickpea improvement, N_2-fixation and bioavailability of P from two different rock phosphate sources (Soliman *et al.* 2003).

Jeffries *et al.* (2003), in excellent review, demonstrated that the rhizobacteria behaved as mycorrhiza-helper bacteria (MHB), promoting AM establishment by either the indigenous or inoculated AMF, while AMF formation increased the size of the PSB population. Because the bacteria did not change root weight, length or specific root length, they probably acted by improving the pre-colonization stages of AMF establishment. The dual inoculation treatment significantly increased microbial biomass and N and P accumulation in plant tissues and these dual-inoculated plants displayed lower specific activity ($^{32}P/^{31}P$) than their comparable controls, suggesting that the mycorrhizal and bacterized plants were using P sources which are unavailable to the uninoculated plant. It therefore appears that these rhizosphere / mycorrhizosphere interactions contributed to the biogeochemical cycling of P, and promoted plant fitness.

Egyptian Desert Soils

The Arab Republic of Egypt occupies the northeast corner of Africa and the Sinai Peninsula of southwest Asia. The country has a total area of about 1001450 km^2. Its maximum length from north to south is about 1085 km. Egypt has 2900 km of coastline, two-thirds of which is on the Red Sea. Less than 4 per cent or about 35 600 km^2 of the land area of Egypt is settled or is under cultivation. This territory consists of the valley and delta of the Nile and a number of oases. The remaining 96 per cent of the country consists of desert. Egypt has the following physiographic regions (Plate 1).

- **The Nile Valley and Delta .**The Nile enters Egypt from Sudan and flows north for about 1545 km to the Mediterranean Sea. The width of Nile Valley is not uniform, and varies from 0.3 to 24 km from south to north. The Delta is about 160 km long, 250 km wide and has an area of about 22 000 km2. The Nile Valley and Delta cover an area of about 30 000 km^2 and have fertile soils, formed by deposits carried down by the Nile. In the Nile Valley the cultivated area mostly consists of a narrow strip of land surrounded by desert on both sides.
- **The Western Desert or Libyan Desert.** Is part of the Sahara and includes a vast sandy expanse called the Great Sand Sea. This desert makes up more than two-thirds of Egypt. It has an average elevation of 180 m above mean sea-level, with the highest point at 1082 m, and several depressions. The Qattara Depression has an area of about 18100 km2 and reaches a depth of 133 m below sea-level, the lowest point in Africa. The Oases of Siwa, Kharga, Bahariya, Dakhla and the large lake of Qarun to the north of Fayoum town are located in this region.
- **The Eastern or Arbian Desert .**Rises gradually from the Nile Valley to a mountains range bordering the Red Sea. The highest peak of this range is about 2187 m above mean sea level.
- **The Sinai Peninsula.** Consists of sandy desert in the north and rugged mountains in the south with a peak of 2642 m, which is the highest point in Egypt

Nowadays, the critical problem facing the Egyptians is the rapid population growth where the projections suggested that the population would be 86 million by the year 2025. In this respect, new and alternative technologies should be put into consideration, i.e. reclaiming and conserving the desert soils and in the same time, promoting its productivity. Biofertilizers and organic farming technologies are the most promising techniques, as cheap and environmental saver, could be used for development of such soils and to combat the desertification problem. (for more details about the physiographical features of Egypt also, see Ghassemi *et al.* (1995).

MAIN PHYSIOGRAPHIC FEATURES OF EGYPT

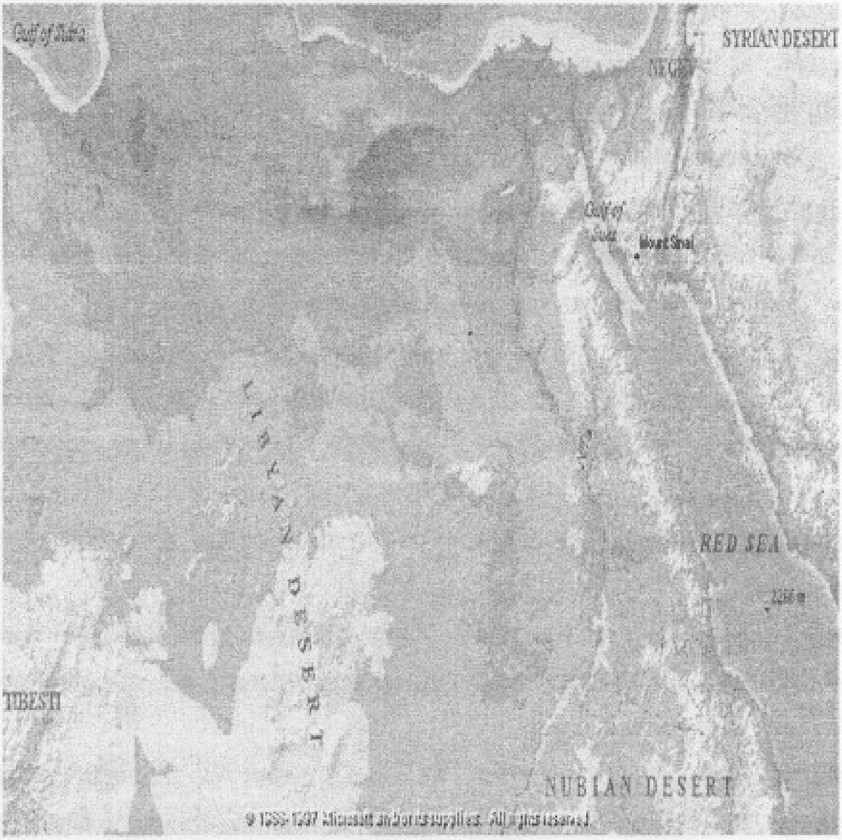

Plate 1. Main physiographic features of Egypt

Role of AM Fungi in alleviating desertification

Ecosystem degradation processes in desertification-threatened areas resulted in disturbance of natural plant communities accompanied by loss of physico-chemical and biological soil properties, such as soil structure, plant nutrient availability, organic matter content and microbial activity. These physical, chemical and biological properties are descriptive measurements of the soil quality concept. Minor differences in these components may be early warning signals of soil degradation and can be used as indicators so that degrading effects can be remedied and soil-building practices can be implemented. Also, the soil quality is defined as the end product of soil degradative and conserving processes (Fig 3) acting on the soil (Kennedy and Papendick 1995). Therefore, it is becoming critical to recover not only the vegetation but also these biological and physico-chemical soil qualities (Miller and Jastrow 2000; Jeffries and Barea 2001).

There is an increasing interest in using AMF to improve revegetation processes for desertified ecosystems, particularly those developed under Mediterranean environments, based on the use of shrub plants belonging to the natural succession (Herrera et al. 1993). A proposed approach to combat desertification is shown by figure 4, which includes inoculation with symbiotic microorganisms including AMF (Jeffries et al. 2003).

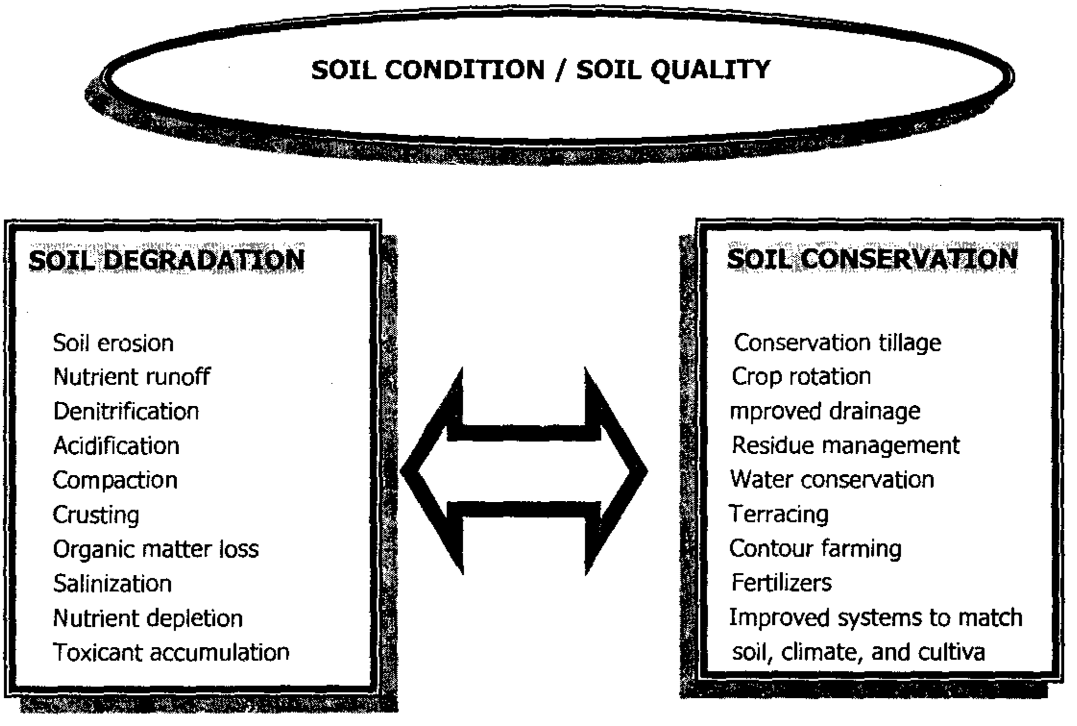

Figure 3. Soil quality as a sum of soil degradative and soil conserving processes (Parr *et al.* 1992).

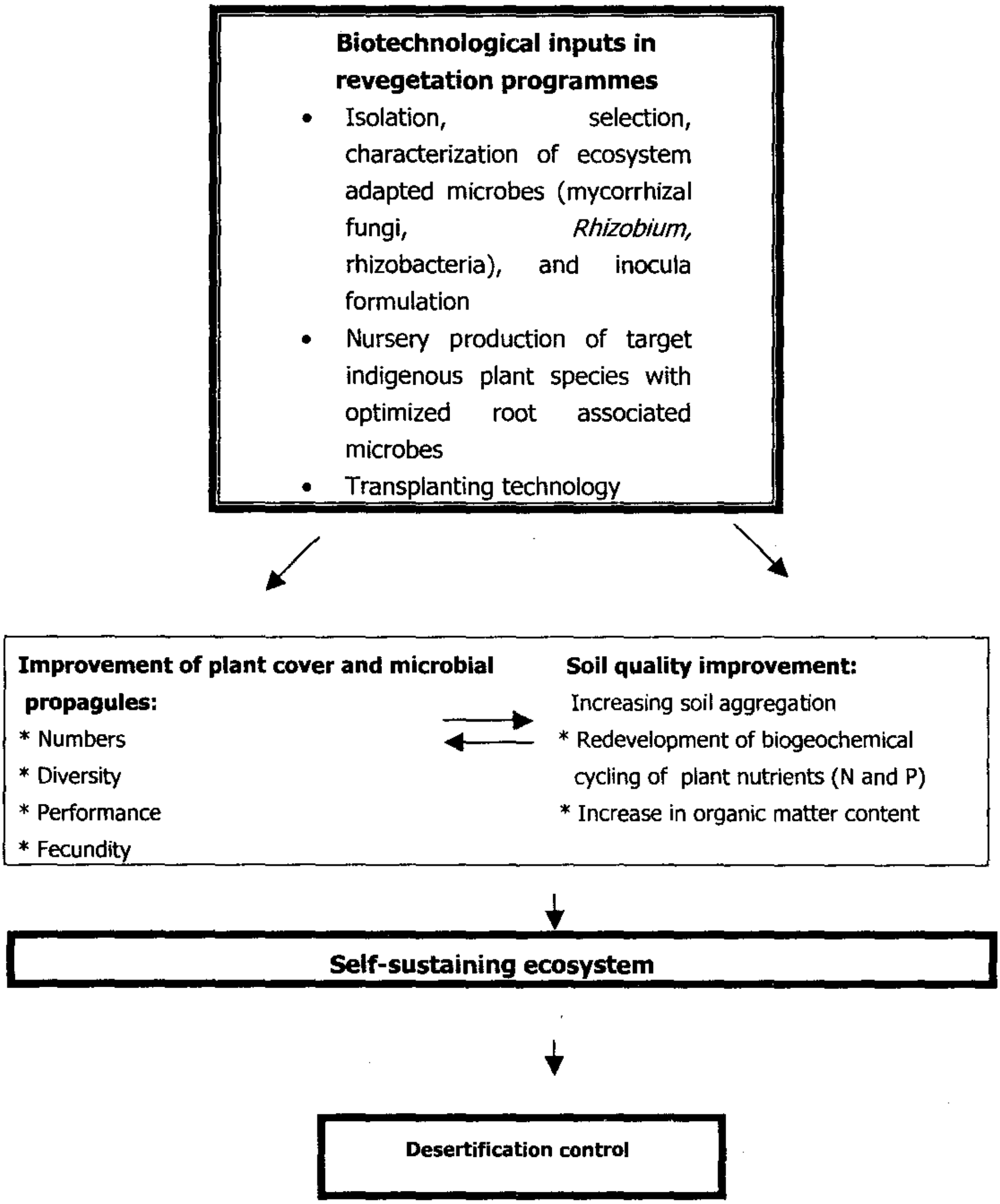

Figure 4. Proposed approaches to help plant establishment and to improve physical, chemical and biological soil properties essential to redevelop a self-sustaining ecosystem and combat desertification

Experiments had been carried out to assess the long-term benefits of inoculation of shrub legumes with rhizobia and AMF. This had included improving the establishment of target legume species as well as the benefits induced by the symbiotically tailored seedlings in key physico-chemical soil properties (Requena *et al.* 2001). The desertified semi-arid ecosystem in southeastern Spain with natural vegetation of degraded shrubland (*Anthyllis cytisoides*) was investigated (Requena *et al.* 1997). This drought-tolerant legume is able to form symbioses with both rhizobia and AMF. Improvement of seedling establishment, survival rates, growth, N-fixation, and N-transfer from N-fixing to non-fixing species associated in the natural succession was detected (Requena *et al.* 2001). The possible improvement of soil quality in terms of N content, levels of organic matter, and hydrostable soil aggregates in the rhizosphere of the target plants were also evaluated. A long-term improvement in the physico-chemical properties was evident in the soil around the *Anthyllis cytisoides* plants inoculated with an inoculum of AMF based on indigenous taxa. The benefits included an increased N content, and higher amounts of organic matter and soil aggregation in the soil around the roots. It can be assumed that the increase in N content in the rhizosphere of the legume can be accounted for by an improvement in nodulation and N-fixation rates resulting from inoculation of nodulated plants with AMF (Brea *et al.* 1992). The improvement of soil aggregation will maintain good water infiltration rates, good tilth and adequate aeration for plant growth, thus improving soil quality (Wright and Upadhyaya 1998).

Inoculation with native AMF also benefited plant growth, N_2 fixation and P acquisition by plants. Improved N status of non-leguminous plants grown in association with legumes had been previously described for agricultural crops (Azcón-Aguilar *et al.* 1979), but this was the first demonstration of this phenomenon for natural plant communities in a semi-arid ecosystem. The results support the general conclusion that the introduction of target indigenous species of plants, associated with a managed community of microbial symbionts, is a successful biotechnological tool to aid the recovery of desertified ecosystems, suggesting that this represents the initial steps in the restoration of a self-sustaining ecosystem (Requena *et al.* 2001).

Biological Nitrogen Fixation in Sustainable Agro-ecosystems

The demand for fixed nitrogen as a nutrient for world crop and pasture production has increased rapidly during this century. The dual discoveries of symbiotic biological nitrogen fixation in legumes just over 100 years ago and of the Haber-Bosch process for industrial nitrogen fixation by the reduction of atmospheric nitrogen to ammonia in the early decades of the 20^{th} century were essential for this increased production The growth of the human population would have been impossible without these progress. It is estimated that twice as much fixed nitrogen will be needed for cereal crop production by 2020 to meet the food requirements of increasing human populations. This dramatic increase in the requirement for fixed nitrogen will need to be increasingly satisfied by biological nitrogen fixation rather than industrial nitrogen fixation. Compared with industrial nitrogen fixation, BNF is sustainable and can be less polluting and cheaper.

This process is considered one of the beneficial ways which soil microorganisms positively influence plant growth and development. Table 1 summarizes some of such beneficial activities of soil microorganisms. Many of these activities are particularly important and significant in the plant rhizosphere and rhizoplane sites where microbial populations and activity are high.

Techniques for quantifying nitrogen fixation

There is no single correct way of measuring biological N_2 fixation. It is unrealistic to expect one technique to provide accurate field measures of N_2 fixation for all of the diverse organisms, which have the potential to fix N_2 in symbiotic or associative relationships, or in the free-living state. Each methodology has its own unique advantages and limitations, which make it more or less suitable for particular species and environments (Ledgard and Peoples 1988).

Procedures that have commonly been used for measuring symbiotic N_2 fixation will be discussed briefly in this section.

- Nitrogen difference method

This method needs a companion non-fixing reference crop to be grown under the same conditions where the legume plant can grow. The difference in nitrogen uptake and yield between legume and reference crop is regarded as the contribution of symbiotic fixation to the legume. In this method, we assumed that the legume and reference crop assimilate the same amount of soil and fertilizer nitrogen. However, identical usage of soil nitrogen does not always occur (**limitation**) in the field and results may often be **inaccurate.** The N difference method is a **relatively simple** procedure and is often used when only **total nitrogen analysis** is available. This method may give most reliable estimates of N_2 fixation in soils low in available nitrogen.

- Acetylene Reduction Assay (ARA)

The ARA is a useful diagnostic tool for detecting nitrogenase activity and has been widely used in all areas of N_2 fixation research. However, it is now considered to be of limited use for even comparative studies with legumes. Because ARA provides only an instantaneous measure, its accuracy has always been restricted by the requirement for many repeated determinations to adjust for marked diurnal and seasonal changes in N_2-fixing activity. But further errors in field estimations with legumes may arise from the use of inappropriate calibration factors to relate ethylene production to N_2 fixation, incomplete recovery, disturbance and damage of nodules or from an acetylene-induced decline in nitrogenase activity during assay.

- ^{15}N-Isotopic Techniques

Principles

Nitrogen tracer technique has been applied for tracing the fate of different forms of nitrogen in the biological-plant-soil relationship. By exploiting the stable nitrogen isotope ^{15}N, it has been possible to reliably measure rates of N_2 fixation in a wide range of agro-ecological field situations involving many leguminous and non-leguminous species.

The stable isotope of nitrogen, ^{15}N, occurs in atmospheric N, at a constant abundance of 0.3663 atoms %. If the ^{15}N abundance is different in plant- available soil nitrogen from that of atmospheric N, measurements of the proportions of legume nitrogen derived from each source can be calculated from measurements of the isotopic abundance in the nodulated legume and in non-fixing reference plants which are totally dependent on the same soil nitrogen.

Isotope-based methods offer the most sensitive measures of total N_2 fixation over the growth of a legume crop. Direct exposure of plants to $^{15}N_2$ with an enrichment greater than the natural abundance of the isotope in air (0.3663%) has often been applied as unambiguous proof of N_2 fixation (Peoples et al., 1989). Although useful for controlled environment or glasshouse experiments in which plants are enclosed in a chamber and exposed to the labelled gas, this method is not practical for quantifying fixed N_2 in the field. Methods which involve growing both a N_2 fixing- and a non-fixing plant in soil that has been enriched with ^{15}N by addition of labelled inorganic or organic fertilizer have been widely applied (Hardarson and Danso, 1993). Measurements of the extent to which the N_2 fixing plant dilutes the ^{15}N-enriched N taken up from the soil allows discrimination of the fixed N_2. The non-fixing plant, often called a 'reference plant' that may be a cereal, another dicotyledon or a non-fixing genotype of the legume crop under test, is used to sample the enrichment of the soil N. This provides the basis from which the contribution of fixed N_2 in the legume can be quantified (Figure 5).

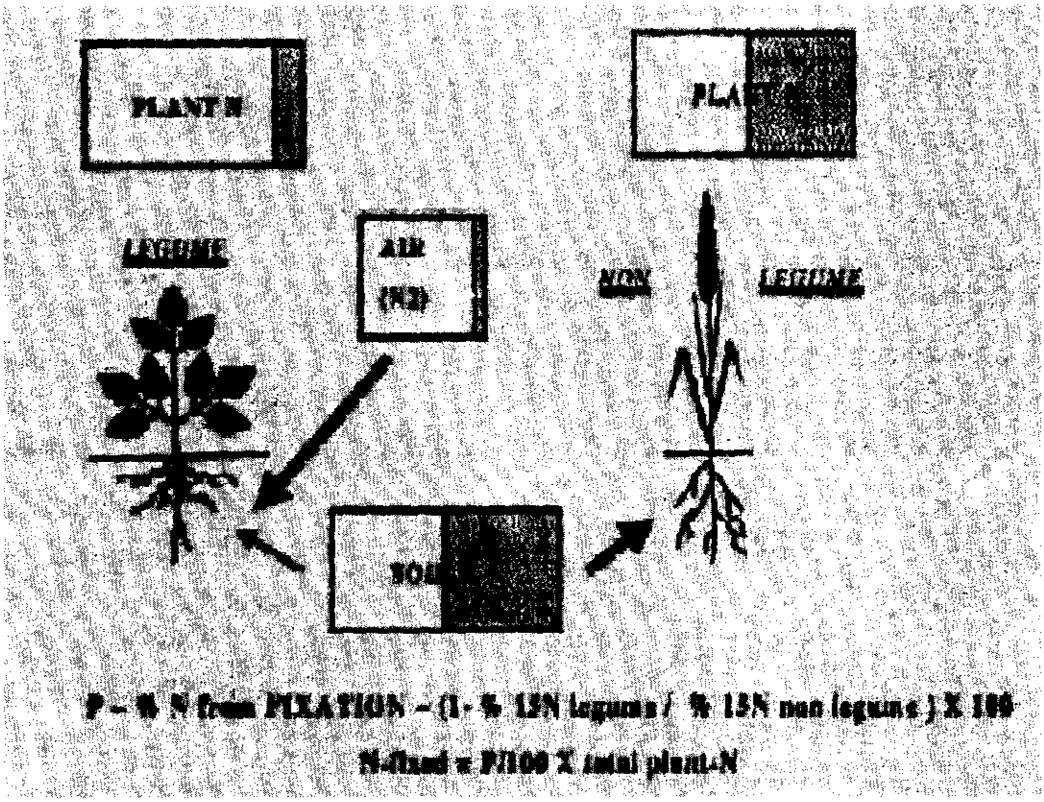

Figure 5. N_2 fixation may be quantified by applying ^{15}N labelled inorganic fertilizer to a fixing and a non-fixing reference crops by measuring the isotopic dilution of the ^{15}N by N derived from the atmosphere in the N_2 fixing crop.

^{15}N-enrichment

The use of methods involving artificial adjustment of soil ^{15}N enrichments to measure N_2 fixation have been reviewed earlier (Chalk 1985; Hauck and Weaver 1986; Danso 1988; Ledgard and Peoples 1988). A major assumption of the technique is that the legume and non-fixing reference plant absorb the same relative amounts of nitrogen from added ^{15}N and soil nitrogen. Its main advantage is that the method provides a time-averaged estimate of the proportion of legume nitrogen derived from atmospheric N_2. This represents the integral of any changes in N_2-fixing activity that may occur during the measurement period. In this respect, the choice of the appropriate reference plant is the most important single factor affecting the accuracy in estimating N_2 fixation in ^{15}N-enrichment studies.

Natural ^{15}N abundance

The small differences in the natural ^{15}N abundance of soil nitrogen compared with atmospheric N_2 has been utilized to estimate N_2 fixation by isotope-dilution. Although the principles of the technique are the same as those of ^{15}N-enrichment studies, the main limitations are quite different. A mass spectrometer capable of precisely measuring differences of 0.000037 atom % ^{15}N is necessary and sample preparation requires great care in order to avoid isotopic discrimination. The procedure is unreliable where the ^{15}N abundance of soil mineral nitrogen is low and variable, however, this is not often a problem in agricultural soils and similar estimates of N_2 fixation have been obtained with either ^{15}N-enriched or natural abundance techniques.

Isotope Dilution Approach

The use of isotope dilution concept for estimating N_2-fixation requires the application of equal nitrogen rates and ^{15}N enrichment of a given fertilizer to both the legumes and a suitable non-fixing reference or control crop. In principle, since the legume and the reference crop are absorbing N from similar zone, the $^{15}N/^{14}N$ ratio of soil-derived nitrogen is expected to the same for both crops. However, in addition to the nitrogen absorbed from soil, the N_2-fixing legume also assimilates atmospheric N_2 of lower $^{15}N/^{14}N$ ratio than the soil nitrogen. This results in a dilution of the $^{15}N/^{14}N$ ratio of soil nitrogen assessed by the reference crop. The extent to which this soil $^{15}N/^{14}N$ ratio is diluted is an indication of the magnitude or the efficiency of N_2-fixation (Danso, 1988). The following equations were used to calculate N_2 fixed using the isotope dilution technique:

$$\% \text{ Ndfa} = \left(1 - \frac{\text{Atom \% } ^{15}\text{N excess in legume}}{\text{Atom \% } ^{15}\text{N excess in reference}}\right) 100$$

$$\text{Ndfa (kg N ha-1)} = \frac{\% \text{ Ndfa}}{100} \times \text{Total N in legume}$$

The important assumption, which underlies the validity of the isotope dilution method, relates to the uptake of soil and fertiliser N by both N_2 fixing- and non-fixing plants. The assumption requires that each take up N from the same volume of soil, i.e. that the distribution of roots, and, more importantly, patterns of nutrient uptake from the soil are similar, and that they occur roughly over the same time. Much attention has been paid to the validity of this assumption, as well as the suitability of particular reference crops, by the Joint FAO/IAEA Programme (Hardarson and Atkins, 2003). The general conclusion is that where the proportion of N derived from the atmosphere is significant (more than 40%), then the impact of the reference on the validity of the measurements is small (Danso *et al.*, 1993). Where the % N derived from atmosphere is lower than 40% however, care needs to be exercised in assessing the variability of the data.

The A-Value Approach

On soils of low nitrogen status, non-fixing crops may grow poorly, while N_2-fixing plants grow well. This could be responsible for a mismatch in growth and nitrogen uptake patterns between the reference and the fixing crop. In the same time, the addition of large amounts of fertilizer nitrogen (which may be needed to promote the healthy growth of the reference crop) to legumes has been shown to inhibit N_2-fixation. The use of A-value approach however, allows the application of different nitrogen rates and ^{15}N enrichments of a given fertilizer to legume and reference crop.

The principle behind this approach is that a plant with more than one source of available nitrogen will absorb from each of these sources in proportion to their relative amounts, i.e. there will be no preference for one source of nitrogen over another. The A-soil is assessed by the reference crop as following:

$$\text{A-soil} = \frac{\%\ \text{Ndfs}}{\%\ \text{Ndff}} \times R$$

$$= \frac{100 - \%\ \text{Ndff}}{\%\ \text{Ndff}} \times R$$

Where R is the rate of fertilizer nitrogen added, % Ndfs and % Ndff are the percentages of N in the plant derived from soil and fertilizer, respectively.

For a N_2-fixing legume however, the estimated A-value includes nitrogen derived from fixation i.e., A-soil + A-fixed.

$$\text{A-soil} + \text{A-fixed} = \frac{100 - \%\ \text{Ndff}}{\%\ \text{Ndff}} \times R$$

Since A-soil is the same for both fixing and non-fixing crops,

A-soil + A-fixed – A-soil = A-fixed

Based on the A-value concept, proportional uptake may be expressed as :

$$\frac{\%\ \text{Ndfa}}{\text{A-fixed}} = \frac{\%\ \text{Ndff}}{R} = \frac{\%\ \text{Ndfs}}{\text{A- soil}}$$

Therefore,

$$\%\ \text{Ndfa} = \frac{\%\ \text{Ndff}}{R} \times \text{A-fixed}$$

However, the advantages and limitations of the abovementioned techniques are summarized as in Table (12).

Reference plant selection criteria

Several factors affecting the suitability of a non-fixing reference plant were outlined earlier (Vose and Victoria, 1986). These factors have been modified and presented as reference plant selection criteria (Danso 1988). Reference plants are deemed to be suitable if they do not fix N_2 and have the following characteristics in common with the legume: (i) rooting zone (ii) relative N uptake pattern (iii) growth duration (Danso 1988). These criteria appear to recognize the effects that temporal and spatial variations in the distribution of isotope have on estimates of P_{atm}. A major problem with these so-called 'selection criteria' apart from the lack of precise definitions for (i) and (ii) in particular, is that verification cannot be attempted until the experiment is completed. Even then, they are little more than qualitative indices of plant behaviour, and provide no direct evidence that the basic assumption of the methodology has been met (Chalk and Ladha 1999). Nevertheless, Danso *et al.* (1993) used these criteria to justify their argument that reference plants are not a limitation of the methodology, citing several studies in which these so-called 'essential requirements' were ostensibly met.

Table 12. Advantages and limitations of methods for estimating biological nitrogen fixation by legumes in the field. *Source: Ledgard and People 1988.*

Advantages	Limitations
N-Solute method	
*inexpensive *simple *analysis done by simple colorimetric assays *need not be totally destructive *may be done on an individual plant basis *assesses plant dependence on atmospheric N_2 and soil N	*indirect (must established calibration with plant N_2 fixing status) *short-term estimate *cannot be used for interspecific comparisons without calibrating each species *calibrations may be influenced by developmental stage in some species *cannot be used on some amide-producers
N Difference method	
*direct *relatively simple *adjusts for soil-derived N	*requires suitable non N_2 fixing reference plant *legume and reference plant must absorb the same amount of soil N
Isotope dilution techniques	
*direct *give time-integrated estimate of %N fixed *assesses plant dependence on atmospheric N_2 and soil N	*requires suitable non-N_2 fixing reference
(a)^{15}N enrichment method	
*potentially accurate	*instrumentation and ^{15}N enriched materials expensive *requires addition of ^{15}N-labelled compound *legume and reference plant must absorb the same relative amounts of N from the soil and added ^{15}N *^{15}N enrichment of plant-available soil N can change with depth and time
(b) Natural ^{15}N abundance method	
*No ^{15}N addition required * δ^{15}N of plant-available soil N can be relatively constant with depth and time *choice of reference plant may be less important than ^{15}N enrichment studies	*requires a precise mass spectrometer and meticulous analytical procedures *insensitive if δ ^{15}N(soil) nears δ ^{15}N (air) *field variability may be large in some cases *may have to allow for isotopic fractionation during N_2 fixation

Part II. Organic Farming

Organic Farming Approach

Organic agriculture creates productive landscapes: it successfully reconciles food production and environmental conservation. Organic management relies on local human resources and knowledge to enhance natural resource processes, respecting ecological carrying capacities. By reducing dependence on off-farm inputs and creating more balanced nutrient and energy flows, ecosystem resilience is strengthened, food security is increased and additional incomes are generated. Hence, organic agriculture responds positively to all Sustainable Agriculture and Rural Development (SARD) objectives.

The term "organic agriculture" refers to a process that uses methods respectful of the environment from the production stages through handling and processing. Organic production is not merely concerned with a product, but also with the whole system used to produce and deliver the product to the ultimate consumer.

Organic agriculture is a holistic production management system, which promotes and enhances ecosystem health, including biological cycles and soil biological activity. Organic agriculture is based on minimizing the use of external inputs, avoiding the use of synthetic fertilizers and pesticides. Organic agriculture practices cannot ensure that products are completely free of residues, due to general environmental pollution. However, methods are used to minimize pollution of air, soil and water. Organic food handlers, processors and retailers adhere to standards to maintain the integrity of organic agriculture products. The primary goal of organic agriculture is to optimize the health and productivity of interdependent communities of soil life, plants, animals and people.

"Organic agriculture" is not limited to certified organic farms and products but includes all productive agricultural systems that use natural processes, rather than external inputs, to enhance agricultural productivity. Organic farmers adopt practices to conserve resources, enhance biodiversity, and maintain the ecosystem for sustainable production. This practice is often but not always oriented towards the market for food labelled as organic. Those who seek to label and market their foods as organic will usually seek certification - almost certainly if they grow to export. However, many farmers practise organic techniques without seeking or receiving the premium price given to organic food in some markets. This includes many traditional farming systems found in developing countries.

Importance of Organic Farming (FAO, 2003)

The organic production system is designed to:

- Enhance biological diversity within the whole system
- Increase soil biological activity
- Maintain long-term soil fertility
- Recycle wastes of plant and animal origin in order to return nutrients to the soil, thus minimizing the use of non-renewable resources
- Rely on renewable resources in locally organized agricultural systems
- Promote the healthy use of soil, water and air as well as minimize all forms of pollution that may result from agricultural practices
- Handle agricultural products with emphasis on careful processing methods in order to maintain the organic integrity and vital qualities of the product at all stages
- Become established on any existing farm through a period of conversion, the appropriate length of which is determined by site-specific factors such as the history of the land and the type of crops and livestock to be produced

Case study of SEKEM and the Egyptian Society for Cultural Development

Established in 1977, the SEKEM initiative began by using biodynamic methods on 70 hectares of desert land, 60 km north of Cairo. The secret to SEKEM's success however, is not to be found in the company's agricultural practices alone but rather in its efforts to bring about integration between the economic, the social and the cultural spheres of life in all aspects of its work. Employees are therefore empowered to realise their full potential not only as employees but also as responsible and capable members of society.

The initial success of the SEKEM biodynamic farm in the production of fresh fruits, vegetables and herbs lead other farmers to cooperate with the initiative. Today around 180 farms cultivating approximately 2 700 hectares all over Egypt, from Aswan to Alexandria, are applying the international guidelines for biodynamic agriculture. Complementing this is an initiation for economic and cultural development, a program which has led to 1 200 direct jobs in SEKEM projects and an estimated further 2 500 related jobs.

ECONOMIC DEVELOPMENT

In the economic sphere, SEKEM established a new form of management for the added value chain from the farmer to the consumer, promoting partnership and transparency, and ensuring high quality products and justified prices, bearing in mind the welfare of humankind and earth. In order to ensure the proper production and marketing of its products, SEKEM established several specialized companies.

- Isis: In 1981 SEKEM started its first shipments of active ingredients of medicinal herbs to the United States. By 1983, SEKEM was producing its first line of herbal medicines for the local market under the brand name of SEKEM Herbs, and the Isis Company was formed. Isis was responsible for producing and packing bread, dairy products, oils spices, different varieties of teas and conservable food items for local supermarkets under the Isis brand name. In 1985, the Isis product line was expanded to include eight herbal drinks and different spices, which are now also sold though SEKEM shops throughout Egypt.
- Atos: Atos was established in 1986 as a joint venture between SEKEM, Deutsche Investitions und Entwicklungsgesellschaft (DEG) and Dr. Schaette in order to develop the Egyptian phytopharmaceutical market. A group of physicians and pharmacists work together in the research and development of new products from natural sources for different illnesses and conditions. In 1992 Atos secured a

licence agreement with Weleda, a leading phytopharmaceutical producer in Germany, to manufacture and market natural remedies in Egypt. In 1993, Atos launched Tomex 200 mg, a standardized concentrated garlic powder tablet shortly followed by other phytopharmaceuticals in 1995. In 1997, the group of companies developed a quality manual and was awarded the ISO 9001 certification.

- ☐ Libra Egypt: Libra Egypt, founded in 1988, supplies the raw materials from the farmers and producers to the various companies of SEKEM for further processing and production. In 1990, Libra Egypt, in cooperation with Eosta (Netherlands) and Organic Farm Foods (United Kingdom), started exportation of organic fresh fruits and vegetables to Europe. In 1993, Libra for Organic Cultivation was established, growing cotton and other crops organically in Egypt and in 1994, 1 000 acres of cotton were planted biodynamically.
- ☐ Hator: Established in 1996, the Hator Company produces and packs fresh fruit and vegetables for both the local and export markets. The products are marketed through Organic Farm Food in England and Eosta in Holland.
- ☐ Sekem Shops: Since 1996, 7 SEKEM shops have been set up, offering the public the complete range of products from the SEKEM initiative. An effective marketing system ensures efficient distribution of the products in cooperation with wholesale, retail and consumer representatives. It creates a living interaction between the farmer, producer and trader, providing the consumer with the highest possible quality at the fairest prices. The products now sold include children's and baby wear under the name of "COTTON PEOPLE organic", using SEKEM's biodynamically grown cotton transformed into textiles at SEKEM's textile factory "CONYTEX". These garments are also exported through Alnatura, supplying wholesalers in Austria, Germany and Switzerland, and Oskri in the United States which began sales through e-commerce (also, see below).

Biodynamic agriculture for reclamation and cotton production in Egypt

This programme has been extremely successful in reclaiming desert land for agriculture. Through regional cooperation among many actors, farmers and agricultural engineers receive training on the importance of micro-organisms for developing soil fertility. Farmers experience the importance of organic matter and compost (referred to as 'black gold') for organic farming and receive training in organic matter management and compost preparation (from small-scale to industrial systems) using agricultural waste and animal manure. Results include over 2 200 ha of biodynamically certified desert locations at the margins of the Nile Valley and elsewhere. The approach is strongly market oriented for the production of organic cotton, medicinal herbs and vegetables. Cotton has recently been intercropped successfully with basil and lemon grass. The project and connected smallholders are following international standards for organic agriculture (the European Community (EC), National Organic Program and Demeter). The added value fulfils standards of European Good Agricultural Practice, and Hazard Analysis and Critical Control Point. The project has recently received the Fair Trade Label award for some of its commodities.

Another network (not presented at Londrina) on organic matter management is the interdisciplinary group on the Management of Organic Inputs in Soils of the Tropics (MOIST), coordinated by Cornell University International Institute for Food, Agriculture and Development, The United States of America. The MOIST was set up to investigate and exchange information on cover crops, green manures, managed fallows and mulches in tropical farming systems. The aim is to optimize the management of organic inputs for harnessing the biological potential of legumes, manures, residues, and soil fauna in order to improve and sustain evolving agricultural systems in Asia, Africa and Latin America. It has developed searchable databases and encourages interregional exchange through seminars, electronic networking and extension materials

SOCIAL AND CULTURAL DEVELOPMENT

In 1984, Dr Ibrahim Aboulish, who established SEKEM, founded the Egyptian Society for Cultural Development (SCD), a private non-profit organization registered as an NGO with the Ministry of Social Affairs. SCD's programme of activities is supported by a variety of organizations and donors, private, governmental and non-governmental, local and international. SEKEM's companies also dedicate part of their net profits to finance the aims of SCD.

Over the last two decades SCD has expanded its program activities from initial basic educational initiatives and now implements a variety of project and program activities in the fields of economic development, health care and education. This holistic approach to development emphasizes participation, integration and the need to foster long-term interdependence and self-determination of community members.

- Education: The SCD school was established in 1989 and includes a kindergarten, a primary and a secondary school for 300 pupils. Based on the Egyptian State curriculum, the SCD School emphasizes programs that cultivate the inner integrity and moral fiber of the individual. The conventional education is supplemented with courses in eurhythmy, crafts, drama, dance or music.
- The Illiterate Children's Program provides literacy classes for children between the ages of 10 and 14. Specially trained teachers offer curricula designed to increase awareness, raise consciousness and introduce new experiences; helping students see themselves as part of the wider community and facilitating their positive contribution.
- The Handicapped Children's Program encompasses children with all types of disabilities, both physical and mental. The program aims to allow the children to exercise their full rights as human beings and to achieve independence. The program aims not only to improve the quality of the children's life, but also to ensure that they become integrated members of society to the fullest extent possible.
- The Adult Education Center offers general consciousness-raising programs for the local community's adult residents in various areas of education, with the aim of enabling individuals to make a positive contribution to their communities and country. The Center's program includes the provision of literacy training (reading and writing), English language classes (incorporating computer literacy), computer training, hygiene in the work place, arts, music and sports.
- **Health**: SCD administers a Primary Health Care Program through its medical center located in the vicinity of the rural community of Bilbeis. Besides providing comprehensive basic health care services the Center is also involved in education and consciousness raising concerning all aspects of public health, including environmental health awareness, women's health issues and family planning. The prevention of infection and disease through better hygiene and sanitary practices is the primary goal of the medical Center's sustainable development efforts.

- ☐ In addition to the services provided by its clinic, the Center also runs an outreach program through its mobile clinic. In this way a population of 15 000 people are given access to modern health care in outlying areas.
- ☐ Employment: The Vocational Training Center established by SCD seeks to provide young people with specific skills for self-employment because of the lack of opportunities that currently exist in the labor market. Fifty trainees each year participate in a 2-3 year program that guides them in every aspect of their chosen profession. When they graduate they are sufficiently skilled to either start their own business or find employment. Through intensive course work, the students are immediately involved in production where practical skills are preferred over theory. Training by both foreign and local professional teachers includes: biodynamic agriculture, carpentry, metalwork, electrical installation, textiles, appropriate technology and office administration.

The SEKEM Initiative is considered a very sound example of integrated development within Egypt. It has spread biodynamic agriculture throughout Egypt and has given farmers easy access to education and encouragement to participate in cultural activities. The system of re-channeling part of the revenue received from the commercial section of the initiative to the social section has proved to be very successful.

Biodiversity FOR organic agriculture

Organic agriculture manages locally available resources to optimize competition for food and space between different plant and animal species. The manipulation of the temporal and spatial distribution of biodiversity is the main productive "input" of organic farmers. Instead of using mineral fertilisers, synthetic pesticides, pharmaceuticals and genetically modified seeds and breeds, adapted biodiversity is relied upon to maintain soil fertility and prevent pests and diseases.

Biodiversity FROM organic agriculture

Organic farmers are both custodians and users of biodiversity at all levels:

- **Gene level**: locally adapted seeds and breeds are preferred for their greater resistance to diseases and resilience to climatic stress;

- **Species level**: diverse combinations of plants and animals optimize nutrient and energy cycling for agricultural production;
- **Ecosystem level**: the maintenance of natural areas within and around organic fields and absence of chemical inputs create suitable habitats for wildlife. Reliance on natural control methods maintains species diversity and avoids the selection of pest species resistant to chemical control methods.

Organic agriculture and soil ecosystems

Natural soil fertility must be relied upon in organic systems. Practices such as crop rotations, symbiotic association, cover crops, organic fertilizers and minimum tillage create suitable conditions for soil fauna and flora. Twenty years of scientific research have demonstrated that organic agriculture significantly increases the density and species richness of indigenous invertebrates, specialized endangered soil species, beneficial arthropods, earthworms, symbionts and microbes (FiBL, 2000).

A living soil generates ecological services

- Soil forming and conditioning: invertebrates (e.g., earthworms and termites) decompose plant litter and create conditions that allow nutrients, oxygen and water to circulate;
- Waste disposal: micro-organisms (e.g., bacteria and fungi) reduce organic detritus to elemental nutrients and recycle nutrients and detoxify ecosystems;
- Soil stabilization: invertebrates and micro-organisms influence the physical, chemical and biological characteristics of soils and thereby play a key role against erosion and floods;
- Carbon sequestration: the higher biomass and diversity of microbial population in organic systems contributes to the carbon retention potential of soils.

Organic agriculture and agro-ecosystems

Natural disease resistance and pest predation must be strengthened in organic systems. Crop rotation is considered the cornerstone of organic management, functioning as a tool for pest management and soil fertility. This, together with inter-cropping, integrated crop-tree-animal systems, the use of traditional and under-utilized food and fodder species and the creation of habitats attracts pest enemies and pollinators and spreads the risk of crop failure across the agro-ecosystem. Agro-biodiversity is conserved and developed through the use of locally adapted landraces and the improvement of genotypes of many plant varieties and animal races near extinction (IFOAM, 2000).

Diversified organic farms enhance ecological services

- Nitrogen cycling: atmospheric nitrogen is fixed by legumes and other nitrogen-fixing plants (e.g., Azolla) which are used during rotations;
- Symbiosis and parasitism: symbionts (e.g., rhizobia and mycorrhiza) play a most important role in absorbing nutrients and reducing pathogen invasions. Parasitism is used in the biological control of insects;
- Predation: inter-specific competition between predator and prey populations keeps pest in check;
- Pollination: enhanced habitats and absence of chemical use on organic farms reverse the trend of pollinator population decline. One third of agricultural crops and the majority of flowering plants are pollinated by insects (e.g., bees, butterflies, beetles) and other animals (e.g., bats).

Organic agriculture and nature conservation

The maintenance of natural areas of vegetation adjacent to crops and plant corridors is common in organic systems, providing alternative food and refuge for many insect predators, wild flora, birds and other wildlife. The absence of pesticide drifts and herbicides and on-farm integration of natural habitats (e.g., productive perennial plants, hedgerows) and other structures (e.g., stepping stones and corridors for migrating species) attract new or re-colonizing species to the area. Ultimately, the diversity of landscape and wildlife brings people in the form of eco-tourism, providing an important source of off-farm income (Mc Neely and Scherr, 2001).

Organic habitats conserve wildlife

- Studies have shown that organic field margins conserve weed species at risk of extinction. On-farm diversity and biomass of arable flora was found to be higher in organic fields (e.g., vineyards and olive groves in Greece);
- The abundance of food sources and habitats attracts micro and macro fauna to organic farms. Surveys have found that the quantity of organic land is very important for migratory birds. The abundance of birds in organic shade coffee is 90% more than in sun-grown coffee plantations. Organic agriculture has been found to have positive effects on declining ground-breeding bird species (e.g., skylark, whinchat and yellow wagtail).
- Where agriculture is a dominant land-use in buffer zones, the use of organic farming is encouraged for wildlife conservation. For example, the Meso American Biological Corridor stretches over seven countries and envisages organic agriculture within the buffer zones and linking areas.

THE CHALLENGE OF SUSTAINING FOOD PRODUCTION WHILE ENHANCING BIODIVERSITY

SOIL BIODIVERSITY

Living soils for agriculture

Soils contain enormous numbers of diverse living organisms assembled in complex and varied communities. Soil biodiversity reflects the variability among living organisms in the soil - ranging from the myriad of invisible microbes, bacteria and fungi to the more familiar macro-fauna such as earthworms and termites. Plant roots can also be considered as soil organisms in view of their symbiotic relationships and interactions with other soil components. These diverse organisms interact with one another and with the various plants and animals in the ecosystem, forming a complex web of biological activity. Soil biological communities and their functions are affected by environmental factors, such as temperature, moisture and acidity, as well as anthropogenic actions, in particular, agricultural and forestry management practices.

Soil organisms contribute a wide range of essential services to the sustainable functioning of all ecosystems. They act as the primary driving agents of: nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emissions; modifying soil physical structure and water regimes; enhancing the amount and efficiency of nutrient acquisition by the vegetation; and enhancing plant health. These services are not only critical to the functioning of natural ecosystems but constitute an important resource for sustainable agricultural systems.

Healthy soils from agriculture

Capturing the benefits of soil biological activity for agricultural production requires adhering to the following ecological principles:

* **Supply of organic matter.** Each type of soil organism occupies a different niche in the web of life and favours a different substrate and nutrient source. Most soil organisms rely on organic matter for food; thus a rich supply and varied source of organic matter will generally support a wider variety of organisms.

* **Increase of plant varieties**. Crops should be mixed and their spatial-temporal distribution varied, to create a greater diversity of niches and resources that stimulate soil biodiversity. For example, diverse habitats support complex mixes of soil organisms, and through crop rotation or intercropping, it is possible to encourage the presence of a wider variety of organisms, improve nutrient cycling and natural processes of pest and disease control.

* **Protection of soil organisms' habitats**. The activity of soil biodiversity can be stimulated by improving soil living conditions, such as aeration, temperature, moisture,

and nutrient quantity and quality. In this regard, reduced soil tillage and minimized compaction - and refraining from chemical use - are of particular note.

Improvement in agricultural sustainability requires, alongside effective water and crop management, the optimal use and management of soil fertility and soil physical properties. Both rely on soil biological processes and soil biodiversity. This calls for the widespread adoption of management practices that enhance soil biological activity and thereby build up long-term soil productivity and health.

Soil health indicators could be simply assessed as illustrated in figure 6, which presents the suite of soil health assessments in the form of a pyramid, with three sides corresponding to biological, chemical and physical indicators (**World Soil Resources Reports 101).**

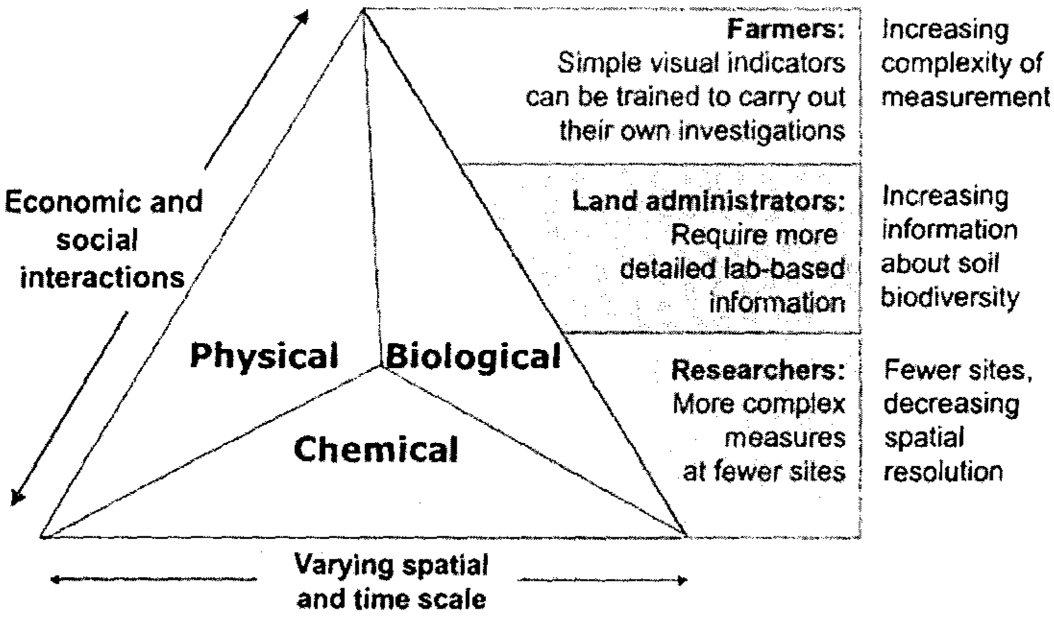

Figure 6. Pyramid of soil health indicators

Adaptation and further development of soil biodiversity management into sustainable land management practices requires solutions that pay adequate consideration to the synergies between the soil ecosystem and its productive capacity and agro-ecosystem health. One practical example of holistic agricultural management systems that promote and enhance agro-ecosystem health, including biodiversity, biological cycles and soil biological activity is organic agriculture.

Building of soil fertility is the cornerstone of organic agriculture. Organic practices create suitable conditions for soil biotic and abiotic resources through: manipulation of crop rotations and strip-cropping; green manuring and organic fertilization (animal manure, compost, crop residues); minimum tillage; and avoidance of pesticides and herbicides use. Scientific research in Europe has demonstrated that organically-managed soils significantly increase biological activity and total density and diversity of soil micro-organisms. Such biodiversity enhances nutrients recycling and soil structure. The impact of organic management on soil biological activity and related benefits is summarized below (FiBL, 2000)

- **Abundant earthworms and arthropods.** Organic management increases the abundance and species richness of earthworms and beneficial arthropods living above ground, and thus improves the growth conditions of crops. The biomass of earthworms in organic systems is 30-40 percent higher than in conventional systems, their density even 50-80 percent higher. Compared to the mineral fertilizer system, this difference is even more pronounced. More abundant predators help to control harmful organisms (i.e. pests). In organic systems, the density and abundance of arthropods, as compared to conventional systems, has up to 100 percent more carabids, 60-70 percent more staphylinids and 70-120 percent more spiders. This difference is explained by prey deficiency due to pesticide influence as well as by a richer weed flora in the standing crop that is less dense than in conventional plots. In the presence of field margins and hedges, beneficial arthropods are further enhanced, as these habitats are essential for over-wintering and hibernation.
- **High occurrence of symbionts.** Organic crops profit from root symbioses and are better able to exploit the soil. On average, mycorrhizal colonization of roots is highest in crops of unfertilized systems, followed by organic systems. Conventional crops have colonization levels that are 30 percent lower. The most intense mycorrhizal root colonization is found in grass-clover, followed by the vetch rye intercrop. Roots of winter wheat are scarcely colonized. Even when all soils are inoculated with active micorrhizae, colonization is enhanced in organic soil. This

indicates that, even at an inoculum in surplus, soil nutrients at elevated levels and plant protection suppress symbiosis. This underlines the importance of appropriate living conditions for specific organisms.

- **High occurrence of micro-organisms.** Earthworms work hand-in-hand with fungi, bacteria, and numerous other micro-organisms in soil. In organically managed soils, the activity of these organisms is higher. Micro-organisms in organic soils not only mineralize more actively, but also contribute to the build up of stable soil organic matter. The amount of microbial biomass and decomposition is connected: at high microbial biomass levels, little light fraction material remains under composed and vice versa. Thus, nutrients are recycled faster and soil structure is improved.
- **Microbial carbon**. The total mass of micro-organisms in organic systems is 20-40 percent higher than in the conventional system with manure and 60-85 percent higher than in the conventional system without manure. The ratio of microbial carbon to total soil organic carbon is higher in organic systems as compared to conventional systems. The difference is significant at 60 cm depth but not at 80 cm depth. Organic management promotes microbial carbon and thus, soil carbon sequestration potential.
- **Enzymes**. Microbes have activities with important functions in the soil system: soil enzymes indicate these functions. The total activity of micro-organisms can be estimated by measuring the activity of a living cell-associated enzyme such as dehydrogenase. This enzyme plays a major role in the respiratory pathway. Proteases in soil, where most organic N is protein, cleave protein compounds. Phosphatases cleave organic phosphorus compounds and thus provide a link between the plant and the stock of organic phosphorus in the soil. Enzyme activity in organic soils is markedly higher than in conventional soils. Microbial biomass and enzyme activities are closely related to soil acidity and soil organic matter content.
- **Wild flora.** Large organic fields (over 15 ha) feature flora as six times more abundant than conventional fields, including endangered varieties. In organic grassland, the average number of herb species was found to be 25 percent more than in conventional grassland, including some species in decline. Vegetation structure and plant communities in organic grassland are more even and more typical for a specific site than in conventionally managed systems. In particular, field margin strips of organic farms and semi-natural habitats conserve weed species listed as endangered or at risk of extinction. Animal grazing behaviour or routing activity (e.g. pigs) was

found important in enhancing plant species composition. Weeds (often sown in strips in organic orchards to reduce the incidence of aphids) influence the diversity and abundance of arthropods and flowering weeds are particularly beneficial to pollinators and parasitoids.

- **High-energy efficiency.** Organic agriculture follows the ecosystem theory of a closed (or semi-closed) nutrient cycle on the farm. Organic land management allows the development of a relatively rich weed-flora as compared to conventional systems. Some "accompanying plants" of a crop are considered useful in organic management. The presence of versatile flora attracts beneficial herbivores and other organisms that improve the nourishment of predatory arthropods. When comparing diversity and the demand of energy for microbial maintenance, it becomes evident that diverse populations need less energy per unit biomass. A diverse microbial population, as present in the organic field plots, diverts a greater part of the available carbon to microbial growth. This increases the turnover of organic matter, with a faster mineralization and delivery of plant nutrients. Finally, more organic matter is diverted to build up stable soil humus.
- **Erosion control:** Organic soil management improves soil structure by increasing soil activity and thus, reduces erosion risk. Organic matter has a positive effect on the development and stability of soil structure. Silty and loamy soils profit from organic matter by an enhanced aggregate structure. Organic matter is adsorbed to the charged surfaces of clay minerals. The negative charge decreases with increasing particle size. Silt is very susceptible to erosion since it is not charged, but organic-matter layers on the silt surface also favour aggregates with silt.

ORGANIC AGRICULTURE AND SUSTAINABLE AGRICULTURE AND RURAL DEVELOPMENT

ORGANIC AGRICULTURE AND NATURAL RESOURCE MANAGEMENT

Soil conservation. Careful planning of animal husbandry and crop associations, and the building of organic matter in the soil through the addition of green and farmyard manure, compost and mulches encourages an enriched soil fauna and flora that enhances soil fertility, recycles nutrients, stabilises soils against erosion and floods, detoxifies ecosystems and contributes to carbon sequestration. Under European conditions, soils managed under organic systems show 30-40% higher biomass and 30-100% higher microbial activity than those managed conventionally. In Malleco, Chile, 4 years of organic management has reduced soil erosion from 60 tonnes/ha to about 12 tonnes/ha.

Water conservation. Higher levels of organic matter and practices of minimum tillage in organic systems increase the water percolation and retention ability of the soil, reducing irrigation needs and associated problems, such as nutrient leaching and salination. In some locations where water pollution from agriculture is a real problem, organic production is actively encouraged around water sources as a restorative measure. In Germany, waterworks subsidise conversion to organic agriculture to reduce costs for cleaning-up drinking water.

In this respect, an excellent recent document published by FAO (Shaxson and Barber, 2003) reviewed the effect of residues cover on increasing infiltration and reduce runoff. A residue cover absorbs most of the energy of the raindrops that fall on it and by the time this rainwater reaches the soil below, its ability to disintegrate soil aggregates and detach fine particles is greatly reduced. Consequently, there is little or no clogging of surface soil pores by detached particles, and little deposition of soil particles that would form a crust on the surface.

The benefits of a residue cover are most apparent on soils initially in reasonable physical condition, but even under these conditions runoff can sometimes occur despite a good soil cover. For example, runoff will occur when rainfall intensity is greater than the soil's infiltration rate, or when the soil's pore spaces are already filled with water because the soil is shallow, its water holding capacity is low, or its subsoil is only slowly permeable.

When a residue cover is applied to a soil with a very degraded surface of low porosity, the beneficial effect of the cover on infiltration may be initially limited. In such situations, it is advisable to accelerate the recuperation of surface porosity before applying residue covers by tilling the soil once to break-up the crust and any subsurface pans, followed by a fallow period under a cover crop to enhance the formation and stabilization of soil porosity. Annex 9 provides a list of publications about cover crops.

The choice of a cover material depends on what is locally available. Residue covers may consist of:

- Crop residues left in the field after harvesting the previous crop.
- Cover crops sown the previous season and left on the soil surface after slashing or applying a herbicide.
- Leaves and branches lopped from trees growing within the cropping area.
- Mulches of grasses, shrubs, weeds, litter, husks and other organic waste materials.

The last option (mulches) requires residues to be collected from elsewhere, transported to the cropping area and then applied in the field, whereas in the other options, the residues are produced within the cropping area.

Examples of materials that may be used as mulches are grasses and sedges, banana leaves and pseudostems (Plate 2), shrubs such as *Lantana* and wild sunflower (*Tithonia*), forest litter and tree loppings (Plate 3). Other materials occasionally used are weeds, rotten thatch and coffee husks. Where soils have a cover of stones, these may be left on the surface as a protective cover provided they do not interfere with planting or weeding operations. Mulching is most commonly practised on horticultural crops that produce negligible residues (foliage), or are completely harvested for their foliage, or are completely harvested (e.g. tuber + foliage)

Plate 2. Mulching of bananas with their own leaves and pseudostems and with grasses in western Uganda

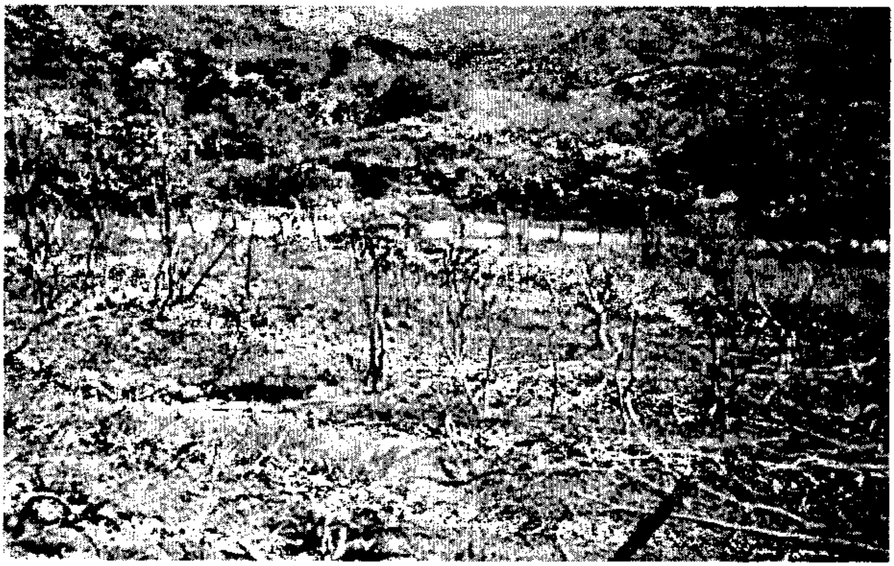

Plate 3. Example of tree loppings used as a mulch in the Quesungual system (Honduras) to reduce the loss of rainwater through runoff and evaporation

Advantages of surface residue covers

The advantages of mulches are the same as for crop residue, i.e. increased infiltration, decreased runoff, and greater soil water availability. They both provide additional benefits, notably less soil water losses by evaporation, less weed incidence and water losses by transpiration, softer and more workable soils, increased earthworm activity, the incorporation of additional nutrients and frequently increased yields.

Constraints to using surface residue covers

The main disadvantage of applying mulch is the cost or labour of collecting, transporting and applying the mulch. This is not the case with crop residues, which are produced on-site. Often, there will be no suitable mulching materials in the vicinity of the farm, or there is insufficient labour available. Transporting large quantities of mulch for large-scale cropping is seldom economic and mulches cannot be applied after emergence to closely spaced crops.

When a cover crop is used as mulch, there is the cost of slashing the cover crop or applying a herbicide. Similarly, lopping trees and distributing the branches and leaves over the cropping area requires considerable labour. On steep slopes, the application of residue covers is not easy and requires much labour as well. Moreover, these materials are easily washed downhill on steep slopes.

Mulching materials and crop residues are often grazed by cattle belonging to the farmer, the community or the landowner (in the case of tenant farmers), fed to livestock, or sold as fodder. Sometimes these materials are in demand for thatching or fuel; in many semiarid areas they are rapidly consumed by termites, and in hot humid climates, they decompose rapidly. Another disadvantage of mulches is a progressive decrease in soil fertility where the mulching materials are produced, unless manures or fertilizers are applied. In parts of Uganda, the residues of cereals grown on hillsides are used to mulch bananas on the lower slopes or valley bottoms, which become enriched in nutrients at the expense of the cereal areas. Soil erosion may also degrade the source areas when the cover provided by the vegetation is removed for use as mulch.

Sustainable use of biodiversity. Successful organic systems increase and encourage biodiversity through multiple cropping and rotations, integrated crop-tree-animal systems, the use of traditional and adapted food and fodder species and the creation of wildlife habitats to attract pest enemies and pollinators. The potential of organic agriculture to sustainably use biodiversity while producing food is recognised by IUCN and organic agriculture is encouraged in several national and regional protected areas and their buffer zones (e.g. the "Terra Capital Investors" 10-year project in Latin America).

ORGANIC AGRICULTURE AND FOOD SECURITY

Access to food. Organic agriculture encourages farmers to manage locally available resources, reducing dependence on external inputs or food distribution systems over which they have little or no control. Further research has great potential to improve organic production to or above conventional yield levels, especially in areas with limited access to conventional inputs. Organic systems in Cheha, Southwest Ethiopia, have allowed people to increase their yields by 60%, producing enough food to feed themselves and even have a surplus to sell at local markets.

Food security. When international markets can be accessed, organic agriculture improves food security by increasing income opportunities. Through polycultures, raised fields and agro-forestry systems, organic farmers sustain year-round yields, reducing chances of crop failures. Organic agriculture is important to the food security of poor farmers and peasants located in environmentally fragile or market-marginalized areas. Cuba reached self-sufficiency in fruit and vegetables through organic agriculture: about 7000 organic urban gardens produce almost 20kg of food per square meter. In Tanzania, one hectare of Chagga home garden could easily support an average household of 9 members.

Food safety. Good agricultural management is vital to the success of organic operations as farmers cannot resort to synthetic inputs, if problems emerge. Practices of biological pest and disease control minimise incidence of food contamination (by pesticide residues, hormones, and antibiotics) and health hazards to farmers. Organic livestock systems, which are extensive and based on organic feeds, reduce the possibilities of epidemics within livestock and associated food scares (e.g. BSE and dioxins).

ORGANIC AGRICULTURE AND RURAL DEVELOPMENT

Price premiums. Certified organic farmers can tap premiums available on organic products sold on the international markets. The organic food market is the most rapidly growing food sector (average growth of 20-25% per year over the last decade) and is projected to grow at the same rate over the medium term. Although price premiums (at present within the range of 20-40%) are expected to decrease, they will continue to exist while consumers are willing to pay higher prices than for conventional products, where production costs are greater and whenever demand exceeds supply, which is likely to be the case for most products.

Alternative sources of income. The encouragement of biodiversity both on- and off-farm means farmers can utilise wild plants and animals such as medicinal plants, fungi, bees and other non-wood forest products, supplementing both diet and income. Diversified landscapes also attract people in the form of eco-tourism, and can provide an important source of off-farm income. In Poland, the European Centre for Ecological Agriculture and Tourism-Poland encourages the conversion to organic agriculture using agri-tourism as a tool.

Fair trade. Growing markets in developed countries demand both environmentally friendly and socially just products. Organic certification bodies are beginning to consider social standards (e.g. fair wages), tightening their links to the fair trade system, where an increasing share of food products sold is already produced organically. For example, 27% of fair trade coffee and 47% of fair trade tea sold in 1999 in Germany was also certified as organic.

Rural community development: Due to changes in the production methods, labour demands are usually increased on organic farms, providing employment and higher returns on labour, therefore improving the viability of rural areas and reducing migration to cities. In Egypt, organically grown fruit, vegetables, herbs and cotton in former desert sites allowed expansion of the SEKEM community into value-added activities: the production of phytoceuticals and essential oils; the establishment of a fruit and vegetable packing facility; and the manufacture of garments. SEKEM is viewed as an important force for social change within Egypt, based on biodynamic agriculture.

Why organic agriculture for food security?

Modern agricultural methods have brought spectacular increases in productivity - more cereals and animals per hectare, more meat and milk per animal, more food output per person employed. Given access to sufficient inputs, knowledge and skills, large amounts of food can be produced. But most farmers in developing countries are poor and marginalized from input and product markets, and some 790 million people still face hunger. Thus it is still very important to evaluate the extent to which farmers can improve domestic food production with cheap, low-cost, locally available technologies and inputs as well as improving the environment (Pretty *et al.,* 2000, 2001; Uphoff, 2002).

In contrast to modern systems, organic agriculture represents a deliberate attempt to make the best use of local natural resources. The aim of organic agriculture, also known as ecological or biological agriculture, is to create integrated, humane, environmentally- and economically-viable agriculture systems in which maximum reliance is placed on locally or farm-derived renewable resources, and the management of ecological and biological processes. The use of external inputs, whether inorganic or organic, is reduced as far as possible.

Recent evidence from certified and non-certified organic systems in developing countries

The University of Essex, in the United Kingdom, recently completed an audit of progress towards agricultural sustainability in 208 projects in 52 developing countries (Pretty *et al.,* 2002). These projects included both integrated and near-organic systems (179 cases), and certified and non-certified organic systems (29 cases). These organic cases comprised a mix of food, fibre and beverage based systems of agriculture, with 154 742 households farming 106 197 hectares (Table 13). The average area per household is small (0.7 ha), as many of the projects involve small-scale organic vegetable production.

This audit indicated that promising improvements in food production are occurring through one or more of four mechanisms:

- Intensification of a single component of the farm system - such as home-garden intensification with vegetables and trees.
- Addition of a new productive element to a farm system - such as fish in paddy rice - that boosts the farm's total food production, income, or both but that does not necessarily affect cereal productivity.
- Better use of natural capital to increase total farm production, especially water (by water harvesting and irrigation scheduling) and land (by reclamation of degraded land), enabling growth of additional new dryland crops, increased supply of water for irrigated crops, or both.

- Improvements in per-hectare yields of staples through introduction of new regenerative elements into farm systems (for example, integrated pest management) or locally appropriate crop varieties and animal breeds.

Food outcomes are not the only measures of success. A selection of the positive side effects reported in these projects and initiatives include:

- Improvements to natural capital, including increased water retention in soils; improvements in water table (with more drinking water in the dry season); reduced soil erosion combined with improved organic matter in soils, leading to better carbon sequestration; and increased agro-biodiversity.
- Improvements to social capital, including more and stronger social organizations at local level; new rules and norms for managing collective natural resources; and better connectedness to external policy institutions.
- Improvements to human capital, including more local capacity to experiment and solve problems; reduced incidence of malaria in rice-fish zones; increased self-esteem in formerly marginalized groups; improved status of women; better child health and nutrition, especially from more food in dry seasons; and reversed migration and more local employment.

Table 13: Summary of scale and impacts of certified and non-certified organic projects and initiatives

Country	Project	Number of farm households	Area under organic agriculture (ha)	Changes in productivity
1. Bolivia	PRODINPO integrated development programme	2 000	1 000	Potato yields from 4 to 10-15 t/ha
2. Brazil	AS-PTA alternative agriculture	15 000	60 000	Bean yields up 50-100%
3. Brazil	Agroecology in Zona da Mata	215	50	Coffee – nd
4. Cameroon	Macefcoop organic coffee	600	300	Coffee – nd
5. Chile	CET organic vegetable gardens	10	5	Vegetables, 20-30 kg per month
6. Cuba	Organic urban gardens4 000 to 700 000 t/yr	26 000	8 000	Total production up from
7 Dominican Republic	Plan Sierra soil conservation	2 000	1 000	Maize – nd
8. Egypt	SEKEM biodynamic cotton	150	2 000	Cotton from 2.25 to 3.0 t/ha
9. Ethiopia	FAO Freedom from Hunger	2 300	2 150	Sweet potato yields up from 6 to 30 t/ha
10. Ethiopia	Cheha integrated rural development	12 500	5 000	Cereal yields up 60%
11. Guatemala	San Jose Poacil ADECCA	1 450	1 260	Mixed crops - nd
12. India	SPEECH, Tamil Nadu	500	409	New rice crop in dry season
13. Kenya	Manor House Agriculture Centre	70 000	7 000	Maize yields from 2.25 to 9 t/ha; new vegetable crops
14. Kenya	C-MAD programme	500	1 000	Maize from 2 t/ha to 4 t/ha
15. Kenya	Mumias Education for Empowerment project	2 069	217	Beans/groundnut yields from 300 to 600 kg/ha

Country	Project	Number of farm households	Area under organic agriculture (ha)	Changes in productivity
16. Kenya	Push-pull pest management	300	150	Maize yields up 60%
17. Lesotho	Machobane farming systems	2 000	1 000	Whole system productivity improved
18. Malawi	Small-scale aquaculture	200	10	New fish crops
19. Mexico	ISMAM organic coffee	1 200	1 200	Coffee – nd
20. Mexico	UCIRI fair trade and organic coffee	4 800	5 000	Coffee yields from 300-600 kg/ha to 600-1 200 kg/ha
21. Nepal	Community welfare and development	600	250	Maize and rice yields up (nd), new vegetable crops
22. Nepal	Jajarkot permaculture Programme	580	350	Rice yields from 1.8 to 2.4 t/ha; maize from 1.2 to 1.6 t/ha
23. Pakistan	Sindh Rural Women's Uplift Group	5 000	2 500	Mango yields from 7.5 to 22.5 t/ha; citrus up from 12 to 30 t/ha
24. Senegal	Rodale Regenerative Agriculture Research Centre	2 000	2 000	Millet/sorghum yields from 0.34 to 0.6-1.0 t/ha
25. Senegal	ENDA organic cotton	523	233	Cotton yields - no change at 300 kg/ha
26. Tanzania	GTZ organic cotton	134	778	Cotton yields - no change at 660 kg/ha
27. Zimbabwe	Chivi Food Security Project	500	600	Sorghum/millet yields doubled; new vegetable crops
28. Zimbabwe	Silveira House	1 211	735	New vegetable crops
29. Zimbabwe	Zambezi Valley organic cotton	400	2 000	Cotton – nd
	TOTAL	154 742	106 197	

(nd = no confirmed data on yields)

Prospects and future needs

Sustainable agriculture is broadly defined as agriculture that is managed towards greater resources efficiency and conservation while maintaining an environment favorable for the evolution of all species. One of the driving forces behind agricultural sustainability is the effective management of nitrogen in the environment. Successful manipulation of nitrogen inputs through the use of biological fixed nitrogen result in farming practices that are economically viable and environmentally prudent. Biological nitrogen fixation constitutes the main natural input of nitrogen in the biosphere. The agronomic use of symbiotic nitrogen fixers used as inoculants or "biofertilizers" is a good alternative to chemical fertilization. An important goal for sustainable agriculture, which will result in humanitarian and economic benefits, is to enhance the use and to improve the yield of biologically fixed nitrogen by legumes.

The important issue is how we can exploit BNF technology for developing sustainable cropping systems. Until now considerable effort in BNF research has gone in the area of selection of **efficient bacterial strains** for using as inoculants. For realizing the maximum benefits from BNF we must take a holistic approach (Wani et al. 1995). In this regard, several needs should be put into consideration:

- To understand the BNF system including host, bacteria and environment.
- Ensure that all the partners involved work in harmony to deliver maximum benefits.
- Accurately estimation of N_2-fixation.
- Identify type of legumes and also genotype, which yields more, and also derive larger part of its N requirements from fixation.
- Identify host genotypes, which can fix well under adverse conditions.
- Demonstrate the benefits from BNF technology in terms of maintenance or improvement of soil fertility through long-term experiments.

Along with the selection of appropriate host plant (plant breeding aspects, for more details, see Herridge and Danso (1995) there is a need to provide **optimum management practices** to ensure maximum contribution from the BNF. The enhancing of legume N_2 fixation through plant and soil management was excellently reviewed by Peoples *et al.* (1995 b). In addition to land management practices, efforts for selection of efficient strains of bacteria to be used as inoculum, and identification of specific host-bacteria combination must go on.

For increasing crop yields through biofertilizers, Wani *et al.* (1995) suggested the following strategy:

-The quality of the inoculants (Quality control procedure).

-Capacity building for the extension personnel and the farmers about inoculation technology (Education and Demonstration sites).

-Effective inoculant delivery system (Marketing and distribution).

-Formulation of the policy to exploit BNF successfully.

In addition to the above-mentioned constraints, the pricing of biofertilizers must be controlled, otherwise if farmers don't see the significant effects in term of economic yields, they may not be interested in using the biofertilizers.

Future targets for research on BNF technology discussed by Giller and Cadisch (1995) includes:

- The problem of soil degradation and its effects on organic matter and nutrient losses.
- Introducing more legumes into farming systems can in itself help to reduce erosion losses.
- The role of BNF in providing the future needs of an expanding population.

Approaches and timescales for increasing inputs from BNF had been summarized in the following table (14). These targets and approaches has been recently discussed on a global perspectives (Finan et al. 2002; Sylvia et al. 1998).

In addition, organic farmers have successfully dealt with organic fertilizers, composting, crop rotation design, nitrogen fixation and nitrogen supply in crop rotations (Niggli, 1999). Therefore, research in organic farming should concentrate on the following:

- holistic approach to animal health;
- technical progress in horticulture crops;
- minimum tillage and precision agriculture in arable crop rotations;
- improving consumer-oriented food quality in general;
- ecological and socio-economic implications of organic agriculture in comparison to conventional agriculture ;
- ensuring future seed and animal breed supply for organic farming

Table 14. Approaches to enhancement of the role of biological nitrogen fixation in agriculture, the potential benefits which might accrue and the time scale for improvements given our current technical understanding. *Giller and Cadisch (1995)*

Problem/Target	Research approach	Potential for enhancement of inputs from N_2-fixation	Time scale for improvement
Environmental constraints			
- Soil acidity	Liming/fertilizer use, green manure use	High	Immediate
- Water stress	Irrigation	High	Immediate
	Drought tolerance/avoidance	Medium-high	Medium-long
- Nutrient deficiencies	Fertilizer use	High	Immediate
- High soil-N status	Crop rotation	Medium	Immediate
Rhizobium			
- Absence of compatible strains	Inoculate	High	Immediate
- small/poorly effective indigenous population	Inoculate	Medium-high	Immediate
- Effective population present	Strain selection	Low-medium	Medium
	Genetic engineering	Low-medium	Medium
Host legume			
- No nodulation due to lack of compatible rhizobium	Selection for promiscuity	High	Medium
- Effectively nodulated - Legume	Breeding for increasing N_2-fixation	Low-medium	Medium
	Genetic engineering	Low-medium	Long
-Environmental constraints	Selection/breeding for adaptation	Medium-high	Medium
Non-legumes			
- Associative N_2-fixation	Strain selection	Low	Medium
	Genetic engineering	Low	Long
- Lack of N_2-fixation	Nodulation/N_2-fixation	High	Long
	Crop engineering for N_2-fixation	High	Long
Farming system			
- New crop/product/forage	Legume introduction	High	Immediate
- Poor soil fertility	Legume introduction	High	Immediate
	Crop residue management	High	Immediate

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مفهوم التسميد الحيوي والزراعة العضوية

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التسميد الحيوي مصطلح يعبر عن إستخدام الكائنات الحية الدقيقة في تحسين وإثراء خصوبة التربة من خلال العديد من الميكانيكيات والتي من أهمها عملية التثبيت الحيوي لآزوت الهواء الجوى سواء تكافليا أو لا تكافليا مع البقوليات وغير البقوليات وكذلك إفراز منشطات النمو والهرمونات التي من شأنها تنشيط النمو للنباتات المصاحبة أو تغير فى كتلة وبناء المجموع الجذري للنبات مما يزيد من مساحة الجذر وبالتالي تؤدى إلى زيادة امتصاص المغذيات الأرضية وانعكاس ذلك فى زيادة إنتاجية النباتات الملقحة مقارنة بمثيلاتها غير الملقحة.

ولقد أدى الارتفاع المطرد فى أسعار الأسمدة الكيماوية منذ السبعينات من القرن المنصرم إلى الاهتمام بفكرة إحلال الآزوت الحيوي محل الآزوت السمادى حيث كان الاتجاه إلى دعم البحث العلمي فى مجال التثبيت الحيوي لآزوت الهواء الجوى مع الأنظمة المختلفة من النباتات و الكائنات الدقيقة.

تشمل الأنظمة المختلفة من الكائنات الدقيقة البكتريا (العقدية-الريزوبيا ، الأزوسبيريللم ، الآزوتوباكتر ، مذيبات الفوسفات وغيرها) والكائنات التي تعيش حرة في التربة و السرخس المائي (الآزولا) وكذلك فطريات الميكوريزا. وتعتبر العلاقة التكافلية ما بين بكتيريا الريزوبيوم والبقوليات من اكثر المنظومات الحيوية شيوعا، حيث اتجهت الجهود العلمية خلال العقود الأخيرة من القرن الماضي إلى إنتاج تلك الكائنات فى صورة لقاحات تجارية تداولت على نطاق كبير وتحت ظروف مختلفة أرضية وبيئية وبيولوجية فى العالم وبصفة خاصة فى بلدان العالم النامي والتي يبحث فيها المزارعون – ومعظمهم يحوزون مزارع صغيرة ويعانون الفقر- عن منظومة زراعية قليلة التكلفة وفى نفس الوقت ذات عائد مادي مجزى. وكفاءة تلك المخصبات الحيوية في زيادة وتحسين إنتاجية المحاصيل وخاصة الإستراتيجية منها مثل محاصيل الحبوب، يتوقف على العديد من العوامل البيئية والأرضية المحيطة بها كما تتأثر أيضا بمدى خصوصية النبات العائل.

إن مقارنة التسميد الحيوي (المخصبات الحيوية) بالتسميد الكيماوي من الوجهة الاقتصادية- البيئية يعطى الأفضلية لاستخدام مثل تلك المخصبات حيث أنها رخيصة ولا تؤثر سلبيا على البيئة المحيطة من تربة ومياه جوفية وكذلك الهواء كما وأنها تعد من المصادر الطبيعية المتجددة. إلا أن المأمول من استخدام هذه التقانة مستقبلا يتطلب الكثير من الجهد على كافة المستويات من البحث العلمي فى هذا

المجال ورصد التمويل اللازم لإرشاد وتعليم الكوادر المدربة وكذلك المزارعين المهتمين بتطبيق تلك التقنية بمزارعهم مع وجود الحقول الإرشادية المناسبة لبيان العائد البيئي - الاقتصادي لإستخدام تقانة التسميد الحيوي. إلا أننا نرى بضرورة إدخال المخصبات الحيوية فى منظومة متكاملة مع التسميد العضوي فيما يعرف بالزراعة الحيوية (Organic Farming) والتي تشترط عدم إستخدام الأسمدة الكيماوية أو الكيماويات الزراعية بوجه عام (Agrochemical) وكذلك عدم زراعة تقاوي النباتات المهندسة وراثيا (Genetically modified plants) لضمان إنتاج غذاء آمن للإنسان وكذلك أعلاف آمنة لتغذيه حيوانات المزرعة.