Conservation of Soil Productivity through Adoption of Soil Bio-Technological Approaches in Indian Arid Zone

A.V. Rao

Central Arid Zone Research Institute, Jodhpur-342 003, India

During the past few decades significant achievements have been made to increase the food production by manifolds to meet the ever increasing needs of human population. But in the process of achieving undefined targets in food production, practised intensive agricultural practices including high yielding varieties, excessive use of chemical fertilisers and pesticides, irrigation practices without proper drainage etc. besides over exploitation of natural resources that has disturbed the natural balance of every ecosystem including arid environment. This had led to soil erosion, build up of soil salinity, nutrient deficiency, loss of organic matter and development of insect resistance to pesticides resulting in a static or declining trend in agricultural productivity and degradation of the environment. So the soil productivity needs to be conserved by efficient utilisation of available natural resources as well as by adoption of soil bio-technological approaches involving biofertilizers for better sustainability of agricultural production.

1 Arid soils and crop production

Camborthids and Solorthids are the major groups among arid soils. These are extremely light, sandy, loamy sand or sandy loam. Calcium carbonate occurs at various depths influencing the effective depth of the soils. Soil depth varies from 70cm—120 cm. Crusting is a problem in these soils resulting in a significant reduction in per cent germination. Soil erosion by wind is even more serious leading to loss of surface fertile soil. These soils hold very low amount of moisture and nutrients because of sandy nature of the soils. These soils are poor in organic matter and very low in nitrogen. Soil salinity is a common problem because of the extreme aridity and poor quality under ground waters. In view of the above cropping intensity is very low as only one crop is taken during the rainy season. Pearl millet is the main staple food crop of this area. Besides pearl millet, arid legumes such as clusterbean, moth bean, green gram and cowpea are also cultivated. Animal husbandry is the mainstay. To sustain the animal population, grasses like *Cenchrus ciliaris*, *C. setigerus* and *Lasiurus sindicus* are grown extensively.

Production levels of pearl millet and arid legumes vary from 0.93 q ha^{-1} to 14.3 q ha^{-1} depending on the intensity and distribution of rainfall. In some years it is not uncommon to harvest the straw only because of the terminal drought. The soils do respond to nitrogen if the moisture availability is normal as per the crop requirements. Response of pearl millet to 40 kg N ha^{-1} in terms of grain yield varied from 12 to 49% depending on the pattern of rainfall distribution.

2 Soil bio-technological approaches

Sustainable agriculture encompasses soil and crop productivity and integration of agricultural management technology to produce quality at the same time maintaining and enhancing the farm profitability and environmental quality. Woomer and Swift (1994) indicated that monitoring the status of biological activity and functioning of the soil ecology may provide useful information in assessing the sustainability of an agricultural system. In this direction soil biological productivity plays an important role. Soil biological productivity is the fertility/productivity of the soil developed/maintained by enhancing the natural soil processes through biological means. It provides balanced nutrition for sustainable plant production through steady turnover and to release the nutrients in harmony with the need of the plants. At the same time the nutrients will not be available in excessive amounts. Visser and Parkinson (1992) stressed that various cropping systems should be evaluated for their effects on soil biological activity. Soil biological productivity can be conserved by adoption of various soil biotechnological approaches as indicated below.

- Use of bio-inoculants

- Use of organic manures
- Crop rotation
- Adoption of various cropping systems that improve the soil biological productivity
  ① Agro-forestry
  ② Silvi-pasture
  ③ Agro-horticulture
  ④ Ley farming
  ⑤ Inter/mixed cropping

The systems using animal crop residues, crop rotations involving legumes, agro-forestry, silvi-pasture, ley-faming, alley cropping etc. regulate soil microbiological activities, organic matter turnover and nutrient cycling besides improving the soil physical properties. The recycling of nutrients particularly nitrogen and the proper balance between organic matter and biological activities have been shown to be necessary components of a productive soil in various cropping systems.

(1) Response to bio-inoculants:

Bio-inoculants are synonym to biofertilizers. Use of beneficial micro-organisms such as nitrogen fixing bacteria and phosphate solubilizing bacteria, is an integral component of cultivation practices for various crops because of their eco-friendly and cost effective technology. But in arid zone the response of different crops to bio-inoculants varies from year to year depending on the amount and distribution of rainfall. The response of cluster bean, moth bean and green gram to inoculation with efficient strains of *Rhizobium* varied from 10%—18% in normal year (Rao and Venkateswarlu,1983) while an amount of 13—18 kg N ha^{-1} can be saved by employing *Azospirillum brasilense* as seed inoculant in pearl millet (Joshi and Rao, 1989). Because of the uncertainty of the beneficial effects of bio-inoculants in arid zone, its adaptation is low. However, it is always better to use bio-incoulants as they provide enhanced yields in good rainfall years and they are cheap and eco-friendly besides the microbial build-up which is always important for various microbial transformations. Further arbuscular mycorrhizal fungi were found to help in the better establishment of seedlings in out-plantations and improve the growth and dry matter production.

(2) Response to organic manures:

Application of farm yard manure for improving the availability of nutrients and physical properties is an age old practice in Indian agriculture. But with the introduction of chemical fertilisers and slow response of organic manures, its use is reduced. Earlier studies conducted on various crops at different locations indicated that the application of FYM in many crops enhanced the grain yields through the improvement in the availability of nutrients caused by enhanced soil biological productivity (Table 1). However, with the non-availability of organic manures and to meet the ever increasing demand for food grains, it is suggested that the application of chemical fertilisers may be regulated in conjunction with the use of organic manures and biofertilizers. Pearl millet production was sustainable over the years with the application of FYM (sheep/goat manure) @ 10 t ha^{-1} once in two years compared to 40 kg N ha^{-1} as urea. This is not only due to balanced nutrition but also to the improvement in physico-chemical and microbiological properties of soil.

Table 1 Populations of different microorgnisms under various trees (Rao *et al.*, 1989)

Species	Bacteria ($\times 10^5$)	Fungi ($\times 10^3$)	Actinomycetes ($\times 10^5$)	N_2 fixing bacteria ($\times 10^2$)	*Nitrosomonas* ($\times 10^2$)
Acacia tortilis	43.8	12.8	8.3	3.9	9.2
Albizia amara	38.2	14.6	6.3	3.9	7.2
Eucalyptus tereticornis	28.0	9.3	4.3	2.2	3.5
Prosopis cineraria	73.0	15.2	9.0	4.3	24.0
Tecomella undulata	82.6	13.9	8.7	4.6	28.0
Bare site	16.5	5.9	3.8	1.1	1.3

LSD (*P* = 0.05)	15.2	4.6	3.9	0.9	3.5

(3) Crop rotation:

It is common to adopt different crop rotations over mono cropping year after year to avoid the risk involved in arid agriculture. A significant reduction in the yields of pearl millet was observed when it is grown year after year (Mann and Singh, 1977). However grain and straw yields of pearl millet was maximum after 3 years of continuous legume followed by 2 year, 1 year and continuous pearl millet. This was due to the improvement in the soil biological productivity as reflected in the enhancement in the activities of various soil enzymes, levels of beneficial micro-organisms, organic matter and, the levels of available forms of N, P and K (Table 2). Presence of legumes in rotation promoted a strong rhizosphere effect through the changes in the root exudation and increase in below ground inputs of C and N which often enhance the microbial populations and their activities.

Table 2 Soil biological productivity as influenced by different leys (Rao *et al*., 1997)

Grass ley	DHA	Alk. Phosphatase	N_2-ase activity	AMF spores (no.100 g^{-1})	*Nitrosomonas*
		n· kat· 100g^{-1}	(n moles $C_2H_4\,h^{-1}$)		($10^4 g^{-1}$)
Cultivated field	4.4	5.7	58	130	4.2
4 year with stubble	6.1	8.5	162	264	6.4
4 year without stubble	4.8	6.4	128	208	5.2
6 year with stubble	7.2	11.7	175	390	7.9
6 without stubble	5.2	10.1	227	256	5.6
8 year with stubble	7.2	13.2	198	276	7.6
8 year without stubble	5.8	11.8	162	226	6.3
LSD (*P* = 0.05)	0.3	1.2	12	26	0.7

(4) Cropping systems:

In arid areas it is suggested to grow more than one plant species in different combinations viz. inter/mixed cropping, agro-forestry, silvi-pasture, ley farming, alley cropping etc. for assured supply of either grains, fodder or fuel wood even in bad rainfall years. The benefits of growing more than one species are numerous including more efficient capture and use of sunlight, and more efficient utilisation of soil resources from different depths. Invariably one of the components is a legume. The legume component helps in improving soil biological productivity. Legume provides nitrogen to the non-legume either directly by transfer of fixed N or indirectly by non-competing for soil N which is referred as a facilitative production principle. The enhanced availability of various nutrients through higher microbiological activities of the soil under the canopy of *khejri* (*Prosopis cineraria*) trees resulted in the significantly higher grain yields of pearl millet (Aggarwal and Praveen-kumar, 1990). Similarly it was observed that the biomass production and N-accumulation of *dhaman* (*Cenchrus ciliaris*) growing along with *subabool* (*Leucaena diversifolia*) were enhanced compared to that of mono-cultured grass and was due to the transfer of about 20% of the fixed nitrogen from subabool to dhaman (Rao and Giller, 1993).

Alternate farming systems are sought for higher sustainable crop production at low input levels and to protect the soil from further degradation. Soil physical and biological properties often change when different cropping, tillage or management systems other than conventional cultivation practices are imposed (Follett and Schimel,1989). Soil biological productivity and soil physical properties were significantly improved with different leys resulting in enhanced dry matter production and grain yield of pearl millet compared to that of the conventionally cultivated field (Table 3). This was mainly due to significant improvement in the soil biological productivity. Weil *et al.* (1993) stressed the role of continuous growth of grass roots in improving the total fertility of the soil for sustainable agricultural production and soil conservation.

It is concluded that given the socio-economic conditions of the farmers, and the low and erratic distribution of rainfall, the extensive use of chemical fertilisers to augment crop production is a risky proposition. So sustainable crop production can be accomplished through the adoption of such soil biotechnological approaches that enhance the biological productivity of the soils. Further integrated nutrient management practices employing organic manures and biofertilizers with the minimum input of chemical fertilisers can help in conserving the soil productivity for sustainable crop production in Indian arid zone.

Table 3 Soil biological productivity parameters as influenced by crop rotation (Rao *et al.*, 1995)

Crop rotation	DHA	Phosphatase *		N_2-ase activity (n moles $C_2H_4h^{-1}$)	Nitrifying bacteria (10^5 g^{-1})
		Acid	Alkaline		
F-PM-F	9.31	2.42	6.75	52.8	0.44
PM-PM-PM	10.16	3.20	8.99	62.9	0.65
MB-PM-MB	10.63	3.18	9.02	73.0	0.93
CB-PM-CB	10.26	3.63	9.71	76.7	0.77
F-MB-MB	11.72	3.80	9.41	127.1	0.98
F-CB-CB	11.10	3.97	9.54	115.5	0.71
MB-MB-MB	13.17	3.85	9.63	180.7	1.17
CB-CB-CB	12.60	4.25	11.64	181.6	0.87
LSD (*P*=0.05)	0.45	0.16	0.36	25.9	0.18

*- n kat100g^{-1}, F- Fallow, PM- Pearl millet, MB- Mung bean, CB - Clusterbean

References

Aggarwal, R.K. & Praveen Kumar 1990. Nitrogen response to pearl millet (*Pennisetum typhoides* S & H) grown on soil beneath *P. cineraria* and adjacent open site in an a rid environment. Annals of Arid Zone, 29: 289-293.

Follett, B.F. and Schimel, D.S. 1989. Effect of tillage practices on microbial biomass dynamics. Soil Science Society of American Journal, 53: 1091-1096.

Joshi N.L. and Rao A.V. 1989 Response of pearl millet to *Azospirillum* as influenced by N-fertilizer under field conditions. Ann. Arid Zone, 28: 291-297.

Mann, H.S. and Singh, R.P. 1977. Crop production in Indian arid zone. In: *Desertification and its control*, pp. 215-224. ICAR publication, New Delhi.

Rao, A.V. and Giller, K.E. 1993. Nitrogen fixation and its transfer from *Leucaena* to grass using ^{15}N. Forest Ecology and Management, 44: 221-227.

Rao, A.V., Kiran Bala & Lahiri, A.N. 1989. Influence of trees on micro-organisms of aridisol and its fertility. The Indian Forester, 115:680-683.

Rao, A.V., Tarafdar, J.C., Sharma, S.K., Praveen Kumar and Aggarwal, R.K. (1995). Influence of cropping systems on soil biochemical properties in an arid rainfed environment. *Journal of Arid Environments*, 31: 237-244.

Rao, A.V., Singh, K.C. and Gupta, J.P. 1997. Ley farming-an alternate farming system for sustainability in Indian arid zone. *Arid Soil Research and Rehabilitation*, 11: 201-210.

Sanginga, N., Mulongoy, N. & Ayanaba, A. 1989. Nitrogen fixation of field inoculated *Leucaena leucocephala* (Kam) de Wit. Estimated by the ^{15}N and the difference methods. Plant and soil, 117: 269-274.

Visser, S. and Parkinson, D. 1992. Soil biological criteria as indicators of soil quality: Sol microorganisms. American Journal of Alternative Agriculture, 8: 5-14.

Woomer, P.L. & Swift, M.J. 1994. *The biological Management of Tropical Soil Fertility*. John Wiley and Sons, Chicnester, U.K. pp. 243.