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Management of stressed soils of dryland agriculture in semi-arid tropics - A review

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ABSTRACT

United Nations has brought the global attention by commemorating the International Year of Deserts and Desertification (IYDD) during 2006 with catchy slogan *"Don't Desert Drylands"*. In India, 'dryland' feeds nearly half of country's population and contributes more than 40% of total food grain production. This region generally experiences low and uncertain returns, land degradation, frequent mid-season dry spells and water scarcity. Rainfed areas (90 m ha) are characterized by hotspots of poverty, malnutrition and child mortality. Soils of these regions are thirsty and hungry, especially in secondary and macronutrients (NPK). Studies in these areas reveal that except manganese (Mn), availability of other micronutrients (Fe, Zn and Cu) is quite low in agricultural fields (marginal land) and Gullied (ravine) land. Appropriate land management practices that conserve soil and water coupled with integrated nutrient management and legumes in crop rotations would restore these stressed dryland soils. This paper lucidly revolves around the soils of drylands and their management in semi-arid tropics of India.

1. INTRODUCTION

Despite industrial revolution, agriculture plays a pivot role in economic development and poverty reduction, especially in third world country like India (World Bank, 2007). In 21st century, agriculture is facing multiple challenges; it has to produce more food and fibre to feed a growing population with a smaller rural labour force, more feedstock for a potentially huge bioenergy market, contribute to overall development in many agriculture-dependent developing countries, adopt more efficient and sustainable production methods and adapt to climate change (FAO, 2009; Lal, 2011). Growth in the agricultural sector is indispensable and there is need to doubling the food production over the coming 2030 years to feed the 2.3 billion people (Rockstrom *et al*., 2010). There are signs of an increasing number of countries (developed) reaching 'saturation' levels, *i.e.* agricultural production hardly grows anymore and arable land is taken out of production (Bruinsma, 2009). So, world's ever growing population is looking towards developing countries for their food. Out of total world's land area (13.4 billion hectares), drylands occupy 6.15 Bha or 47.2% (Lal, 2003). Of this, nearly 72% (4.42 Bha) occurs within developing countries (93 countries) and only 28% (1.72 Bha) within developed countries (53 countries) (Bruinsma, 2009). This indicates that to feed the world, there is need to harness the potential of dryland.

Furthermore, proportion of drylands occupied by developing countries increases with aridity, reaching almost 100% for hyper-arid region (Fig. 1). Majority of dryland peoples live in developing countries *i.e.* 87 to 93% and only 7-15% reside in industrial countries.

India's population of 1.1 billion in 2007 is expected to reach 1.59 billion by 2050. With need to increase food grain production from 206 Mt in 2001 to 301 Mt with low food demand, 338 Mt with medium food demand and

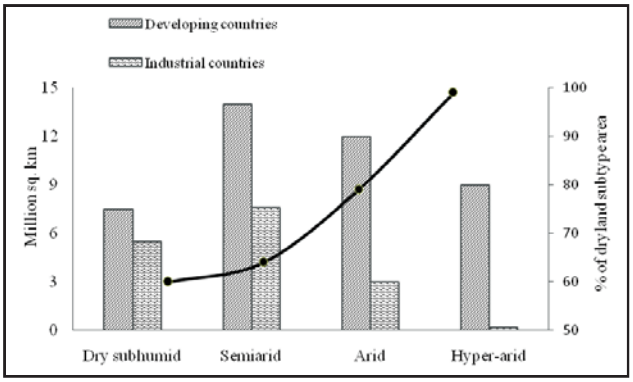

Fig. 1. Dryland subtypes and socio-economic-political status (Adapted and modified from Safriel and Adeel, 2005)

423 Mt with high food demand by (Sekhon, 1997; Lal, 2008a). Recently, India has achieved all time high food grain production of 257 Mt during 2012-13 (http://www.pib.nic.in) and it was attributed to record production of wheat, maize and pulses, which is about 7 Mt higher than previous year's (2011-12) production. Notwithstanding to this jubilant figure, world is facing crisis for staple food grains especially in rice and wheat due to a paradigm shift from food crops to energy and/or biofuel plants (John Vidal, 2008).

Furthermore, some developed countries have also begun rationing of rice with 4 kg per person so as to prevent supplies from running short and also to avoid illegal hoardings of food grains (Clark *et al*., 2008). Globally, increase in inflation has resulted in escalation of prices of food grains which forced the country to redesign its farming system and strategies to produce more food grains per unit land. Total cropped area in India is around 142 m ha, out of which about 90 m ha are rainfed. To meet the requirement of growing demand of food grains it is imperative to increase the production potential especially in rainfed region besides irrigated areas. Country's first green revolution had greater benefits on irrigated lands where wheat and rice were grown, while the drylands growing coarse cereals were unattended. Yields of the latter remained very low (<1.0 t ha^{-1}) and this requires the immediate attention. Depletion of soil carbon and nutrients from these fields are some of the major threats to soil productivity and land degradation. Several scientists have also reported on the connection between climate change, soil and water resources, and population growth, and have noted that these issues will pose severe challenges that can potentially impact food security (Montgomery, 2007; Lal, 2002; Verdin *et al.,* 2005; Bryan *et al.,* 2009; Morton, 2007).

2. THE INDIAN SCENARIO

India has about 47 m ha of drylands out of 108 m ha of total rainfed area. 'Dryland' agriculture feeds half of country's population and contributes more than 42% of total food grain production. These areas produce 75% of pulses and more than 90% of sorghum, millets, groundnut and pulses (Patnaik, 2010). Thus, dryland and rainfed farming will continue to play a dominant role in agricultural production. Rainfed area is not only characterized by low and uncertain returns, land degradation, frequent mid-season dry spells and water scarcity but (William Dar, 2007; Lal, 2008b; Sharma *et al*., 2009) also with hotspots of poverty, malnutrition and child mortality. Largely, soils in these regions are not only thirsty but also hungry, particularly in micronutrients such as Fe, Zn, B and secondary nutrients along with macronutrients (Table 1). Moreover, resource- poor farmers in dryland regions apply meager quantity of nutrients and thus crops suffer from multi nutrient deficiencies (Srinivasarao *et al*., 2003).

Century old traditional soil husbandry coupled with modern management of farmlands through decade of research on soil and water conservation has yielded significant increase in productivity in drylands in late 90's. Though, the food grain production has increased from 50 Mt in 1950 to 257 Mt in 2012; however, food insecurity is growing concern of scientists, planners and policy makers. Among more than 850 million food-insecure people around the world (Borlaug, 2007), India is home to more than 200 million or about 20% of the total population of the country (Lal, 2008).

Table: 1
Nutrient status of semi-arid regions of India

	pH	Organic C (%)	Olsen-P (mg kg^{-1})	Exchangeable K (mg kg^{-1})	Extractable nutrient elements (mg kg^{-1})		
					S	B	Zn
Andhra Pradesh	7.70	0.36	7.54	133	5.65	0.30	0.71
Karnataka	7.25	0.45	9.70	105	9.20	0.42	0.68
Rajasthan	7.40	1.02	8.60	108	13.40	0.68	1.68
Madhya Pradesh	8.10	0.62	2.41	179	5.63	0.22	0.33
Gujarat	7.50	0.77	6.90	105	16.20	0.22	0.45
Tamil Nadu	7.60	0.51	9.20	122	11.30	0.34	0.78

Source: Sahrawat *et al.* (2007)

In recent past, decline in factor productivity (Chaudhary, 2012) and soil health (NAAS, 2012) have been reported from several parts of the country. This was attributed to poor soil health and forcing soils for higher returns with minimal input, which further decline productivity in dryland agriculture. Hence, there is an urgent need to protect rainfed region for better and sustainable production.

Drylands, besides being water deficient, are characterized by high evaporation rates, exceptionally high day temperature during summer, low humidity and high run off and soil erosion during monsoon season. Very often these soils are having problems of salinity/alkalinity in addition to poor fertility. Since water is the most important factor of crop production, low and erratic distribution of rainfall often results in partial or complete failure of crops and leads to food scarcities and famines. Thus, life of both human being and cattle in these areas becomes difficult and insecure.

3. CROPS AND CROPPING SYSTEMS

Traditional crops/varieties which are inefficient utilizers of soil moisture, less responsive to production input and low producers should be substituted by more efficient ones. Enhancement in cropping intensity would depend on length of growing season which is also dependent on the rainfall pattern and water holding capacity of soils (Table 2). Thus choice of appropriate cropping system, with high WUE and ability to recycle nutrients, can improve and sustain crop productivity in these areas. Only those crops can be grown under dryland conditions which require less water to complete their life cycle or which can withstand or yield under drought conditions. This includes both drought resistant and drought tolerant plant species. In addition, plants can be grown only where some water is available to sustain the growth. Similarly, low input farming systems have a niche in these areas, which can potentially increase and stabilize crop productivity for resource poor stakeholders.

One of the recommended farming systems for rainfed areas is growing of two or more crops simultaneously in the same piece of land which are complementary to each other. This system of intercropping is an age old practice. Cultivation of short duration and long duration crops together for higher productivity and economic returns is most prevalent in dryland areas. However, in this high input farming and industrial crops era, this practice has minimum role to play. Pigeonpea is an ideal intercrop under different soil situations in rainfed region. As an intercrop along with sorghum at 1:1 ratio, it is more productive and profitable. Apart from biological insurance against crop failure, roots of pigeonpea are able to break the hardpan in sub-surface layer of black (clayey) soils. Intercropping also gives fairly good protection to mild sloping land against erosion and helps in runoff conservation by 11-15% (Sharda and Ojasvi, 2005). It is also observed that approximately 1200-1300 kg of leaf litters ha^{-1} from pigeonpea alone is added into soil every season. This in turn helps in enriching nutrient content and adds soil carbon during its decomposition (Singh *et al*., 2004). Increased soil carbon increases plant nutrient supply and turnover capacity of soils and also improves soil physical, biological and fertility status (Franzluebbers, 2002). As a result, there is an increase in water holding capacity of soils and ability to withstand longer dry spells during crop growing period. Alternate cropping sequence is also one of the options that is important for maintaining soil fertility in the rainfed region (Kar *et al*., 2003). Soil nourishing crops *i.e.,* green gram, black gram, pigeonpea and soybean followed by nutrient depleting crops *i.e.,* sorghum, maize, safflower and wheat offer an opportunity to manage the dryland soils efficiently.

4. WATER MANAGEMENT *VIS-A-VIS* SOIL AND WATER CONSERVATION

Many developing countries located in arid or semi-arid regions experience significant problems in securing adequate amounts of water for rainfed crop production. Water scarcity problems in arid regions result simply from

Table: 2
Guidelines for potential cropping systems in India

Rainfall (mm)	Broad soil group	Growing season (week)	Cropping system
350-650	Alfisols and shallow Vertisols; Aridisols and Entisols	<20	Single rainy crop
350-650	Deep Aridisols and Inceptisols	20	Either rainy or post-rainy crop
350-650	Deep Vertisols	20	Sole post-rainy crop
650-800	Alfisols, Vertisols, Inceptisols, Mollisols	20-30	Intercropping
800 and above	Deep Vertislos, deep Alfisols, Entisols	>30	Double cropping

Source: Venkateswarlu (1987)

the lack of sufficient rainfall. Semi-arid regions, however, may receive enough annual rainfall to support crops but it is distributed so unevenly in time or space that rainfed agriculture is not viable (Reij *et al*., 1988). Rockström and Falkenmark (2000) note that due to high rainfall variation in semi-arid regions, a decrease of one standard deviation from the mean annual rainfall often leads to the complete loss of the crop. Water loss through evaporation and runoff exacerbates water scarcity problems in these areas. Areas that receive low rainfall, between 300-600 mm annually, may be able to combat these problems partially through use of supplemental irrigations, but regions receiving less than 300 mm of annual rainfall must resort to other options to secure enough water to support crop production (Oweis *et al*., 1999).

According to characteristics of dry farming, either there may be no rain at all or there may be torrential rain having very high intensity. Thus, in the former case the crops will have to suffer under severe drought and in the latter case they suffer either flood or water logging conditions and ultimately farmers suffer due to weather vagaries. Also, land degradation is bound to occur under these situations due to runoff and soil losses occurring due to very heavy downpour resulting in decline in the productive capacity of these soils overtime. The watershed concept has emerged as silver bullet approach to tackle all water related issues in dryland region. World famous Sukhomajri watershed model is the best epitome for the above mentioned statement. Growth and development from communities are stressing water resources. Community based watershed management helps reduce flood damage, decreases the loss of green space, reduces soil erosion and also improves water quality. At the same time, watershed management planning works to protect water resources by empowering local people to provide for the environmental, social, and economic health of the community. Thus, efficient rainwater management can increase agricultural production from dryland areas. Additionally, soil health management through use of compost and farmyard manure, raising legumes and addition of organic matter in soil is helpful in increasing nutrient and water availability to crops. Excess runoff water diverted to farm pond or ditches can be successfully utilized for lifesaving irrigations during dry spells.

In-situ moisture conservation practices are to be adopted for conservation of top fertile soil and increased soil water availability in soil profile in these regions. Contour cultivation, tillage practices and mulching are to be adopted for resource conservation and increased productivity. Through watershed approach, it is possible to optimize the land use, water and vegetation in an area and mitigate drought, moderate floods, prevent soil erosion, improve water availability and increase fuel, fodder and agricultural production on a sustained basis. Water harvesting structures like contour bunding, graded bunding, conservation bench terrace (CBT), contour trenches conservation ditches and broad bed and furrow (BBF) for very gentle to gentle sloping (3-6% slope) fields and also for undulated fields reduce runoff and conserve it *in situ* for higher crop productivity. In addition, check dam, tanks and reservoirs constructed also store runoff water in lower catchment area. Based on past experiences, a range of soil and water conservation measures have been found promising for diverse agro-ecological regions in India (Table 3) which are effective in reducing soil and nutrient losses as well as enhance the moisture conservation (Sharda and Ojasvi, 2005). Infiltration or percolation loss of water

Table: 3
Recommended soil and water conservation measures for various rainfall zones in India

Seasonal rainfall (mm)			
<500	500-700	750-1000	>1000
Contour cultivation with	Contour cultivation with	BBF (Vertisols)	BBF (Vertisols)
conservation furrows	conservation furrows	Conservation furrows	Field bunds
Ridging	Ridging	Sowing across slopes	Vegetative bunds
Sowing across slopes	Sowing across slopes	Tillage	Graded bunds
Mulching	Scoops	Lock and spill drains	Chos
Scoops	Tide ridges	Small basins	Level terraces
Tied ridges	Mulching	Field bunds	
Off-season tillage	Zingg terrace	Vegetative bunds	
Inter row water	Off-season tillage	Graded bunds	
harvesting system	BBF	Nadi	
Small basins	Inter row water	Zingg terrace	
Contour bunds	harvesting system		
Field bunds	Small basins		
Khadin	Modified contour bunds		
	Field bunds		
	Khadin		

Source: Vittal *et al*. (2003)

need to be reduced by spraying of asphalt compounds or by covering bottom of tanks or ponds through thin plastic sheets. Seepage loss can also be reduced by providing a plastic lining and evaporation loss of water is controlled through surface spread of burnt crude oil.

Nearly 1% of water absorbed by plant roots is used for growth and development of plants and rest 99% is lost through transpiration to atmosphere. Hence, use of any chemical substance that reduces rate of transpiration *i.e.* anti-transpirant, may be effectively used for reducing transpirational water loss. Any substance that reduces vapour pressure gradient in stomatal cavity or increases stomatal resistance to water vapour diffusion, will act as anti-transpirant. The substances that reduce water loss from plant body include phenylmercuric acetate (PMA), hydroxy sulphonates (HS), alkenyl succinic acid (ASA), Adol-52 (a formulation of alcohol), and S-600 (a plastic transplanting spray). Some chemicals like alkenyl succinic acid (ASA) and decenyl succinic acid (DSA), when applied, penetrate into root and increase its water absorption power by nearly eight times. Therefore, these chemicals may also be applied in root zone for increased water absorption along with the chemicals that retard transpiration from foliage.

5. SOIL MANAGEMENT

Soils of dryland in the semi-arid tropics are marginal and distinctly different compared to irrigated soils which undergo various stresses namely physical, chemical and biological. This review moreover concentrated on soil physical and chemical aspects since the improvement in physical and chemical conditions of soils eventually results in improved biological activities (Schoenholtz *et al*., 2000).

Dryland region is characterized by uncertain returns, the deficiencies of major nutrients, especially nitrogen (N) and phosphorus (P) (El-Swafy *et al*., 1985; Motsara, 2002). of late, extensive research efforts have also been carried out to diagnose the extent of deficiencies of micronutrients and secondary nutrients such as S in various crop production systems (Singh, 2004). It is evident that the productivity of dryland soils is low due to water shortage. Besides this, low fertility is also an issue because it constraints crop productivity in the SAT regions of India; but in practice the deficiencies of major nutrients (N and P) are considered important. Even the inputs of major nutrients to dryland crops are meagre. Moreover, due to low productivity in the drylands, it is assumed that the mining of micronutrient reserves in soils is much less than in irrigated production systems (Rego *et al*., 2003). Pal *et al.* (2010) found that in undulating rainfed areas, the soil nutrient depicted spatial variability and hence site specific nutrient management is recommended to optimize crop production.

In general, the rainfed soils are very low in organic carbon (OC) and other nutrients. In majority of the rainfed lands, OC is in the range 0.3-0.6% on weight basis (Srinivasarao *et al.,* 2009; IARI, 2012). Levels of organic carbon in soil are dropping across the country, making soils more vulnerable to erosion and results in deterioration of soil health. This eventually disrupts many soil ecosystem functions and results in poor soil fertility of rainfed regions. Carbon sequestration through conservation agriculture (CA) not only improves fertility and productivity of soils, but also mitigates climate change effects. Next to the forests, agriculture lands with better management have great potential for sequestering carbon. It is evident that retention/incorporation of crop residues through CA on the soil surface has several positive influences on physical, chemical and biological properties of soil.

Growing of two or more crops a year coupled with imbalanced fertilization has exacerbated nutrient shortages and changing soils' chemical composition. Crop management systems solely based upon chemical fertilizers may not be sustainable in the long run, thus, holistic approach should be followed to restore soil organic carbon. This single determinant controls total nutrient scenario in the region. Sharawat *et al.* (2007) also reported that crops grown under rainfed agriculture in the semi-arid tropical regions of India not only face water shortages and deficiencies of major plant nutrients (nitrogen and phosphorus), but they also suffer from multi-nutrient deficiencies of S, B and Zn. In addition to this soils under dry land agriculture showed that almost all farmers' fields sampled were low in organic carbon and low-to-moderate in extractable phosphorus, but generally adequate in extractable potassium. Tree based land use systems are a better option for carbon builds up in soil. Even the variation in tree species can have a wide variation in carbon budget of soil and vegetation (Devi *et al*., 2013). Similarly, Panwar *et al*. (2013) observed significant variation in organic carbon contents in soils under different agroforestry systems.

There is a vast untapped yield reservoir is available in rainfed areas. It is reported that the productivity of *kharif* sorghum can be increased by 3 to 4 times, *rabi* sorghum by 1.4 to 2.3 times and bajra around 1.8 to 2.3 times from their current level of productivity by appropriate crop management options. Similarly, pulses and oilseed production can also be increased from 2.3 to 2.5 times through use of superior seeds and soil and pest management practices coupled with lifesaving irrigation (Swaminathan, 2005, 2008).

Carbon and Major Nutrient (NPK) Management

The terrestrial C pool has been a source of atmospheric carbon dioxide (CO_2) ever since the beginning of settled agriculture (Ruddiman 2003). Conversion of natural systems to agricultural ecosystems (e.g., croplands, grazing lands) often leads to depletion of the terrestrial C pool because of deforestation, biomass burning, drainage and soil cultivation. In general, relatively less biomass C is returned to the soil in agricultural ecosystems than in natural ecosystems, although there may be exceptions to this generality (Lal, 2010).

In general, the rate of decomposition of soil organic matter (SOM) is greater in managed than natural ecosystems because of changes in soil temperature, moisture regimes, and soil disturbance, and water and wind erosion could also contribute to the transportation of SOM off-site. For the top surface layer (the top 15 cm), most agricultural soils lose about 50% of their antecedent soil organic carbon (SOC) pool in about 25 to 50 years after conversion from natural ecosystems in temperate climates and in about 5 to 10 years in tropical regions (Lal, 2004). Because most agricultural soils have a lower SOC pool than their natural counterparts under undisturbed conditions, these soils can be managed to enhance their SOC pool by humification of a part of the net primary production (biomass-C) returned to the soil. The SOC sink capacity of agricultural soils, created by the historic depletion of the SOC pool, can be regenerated through conversion to a restorative land use and adoption of those soil and crop management practices which create a positive C budget. Tree based land use systems are a better option for soil carbon build up. Different tree species have wide variability in potential carbon sink (Devi *et al.,* 2013).

Soils of dryland regions of India mostly belong to Alfisols, Vertisols, Aridisols, Entisols depending upon rainfall received in these regions and have uneven physiography. There is loss of soil organic matter either by prevailing high temperature or by erosion that results in multiple nutrient deficiencies in soil and ultimately reduces the nutrient availability to plants. Maintenance of soil organic carbon (SOC) is vital in rainfed agricultural productivity. This is the main source of energy to fuel biological activities in soil, that in turn controls the availability of water and nutrients for plant growth water (Campbell, 2008; Lal, 2004).

From the soil analysis under various research projects and model watersheds, it is inferred that more than 70-80% of soil samples fall under low status (below 0.5%) in soil organic carbon (Motsara, 2002). Hence, '*look down at the soil to make the agricultural productivity look up*' is the new motto of agricultural scientists and land managers (William Dar, 2007). However, it always remains a challenging task in tropics since summer temperature oscillates between 45-49ºC that enhances oxidation process resulting in loss of soil organic carbon. To overcome direct beating of solar radiation on soil surface, it is advised to incorporate crop residues into the soils. In this process, it reduces direct exposure to the sun radiation and addition of organic material to the soils increases microbial activity that in turn helps in nutrient transformation in soil for higher plant productivity. Minimum tillage practices play important role in synthesis of water stable aggregates and helps in binding of soil particles. A sharp fall in organic matter occurs with climate scenario changing from humid to arid. Similarly, compared to 2 to 4% of organic carbon of temperate environments, semi-arid tropical soils contain less than one per cent organic carbon and available nutrients (Tandon and Kanwar, 1984) and it results soils in these regions supporting primarily rainfed crops like sorghum (Table 4).

It has been observed that the soils of about 57% districts were low, 36% medium and 7% were high in available N. Similarly, soils of about 51% districts were low, 40% were medium and 9% were high in available P. Available K status showed that the soils of about 9% districts were low, 42% were medium and 49% were high in available K status. There is no much change in the soil fertility status as compared to earlier reports of 1967 and 2002 (Table 5). These results showed that the status of P was increased in some areas due to continuous application of phosphatic fertilizers. Similarly, per cent soils high in available K increased from 27% in 1976 to 49% in 2011. The per cent soils low in available N increased from 52% in 1976 to 57% in 2011 which may be due to various losses of nitrogen. Analysis of more than 0.25 million soil samples revealed the deficiencies of Zn in 49% soils followed by S in 41% soils, Fe in 12% soils, Cu and Mn in 3-4% soils.

To counter the declining soil fertility and to maintain soil quality and productivity, promoting integrated nutrient management (INM), balanced and judicious use of chemical fertilizers, bio-fertilizers and locally available organic manures like farmyard manure, compost, vermicompost and green manure based on soil testing are the ways out in addition to focusing on site-specific individual deficient nutrient in soil. Efforts have already

Table: 4
Extent (%) of N, P and K deficiency in sorghum growing districts

Status	N	P	K
Low	77	47	11
Medium	23	51	57
High	0	2	52

Table: 5
Change in available N, P and K status of Indian soils with time

Year	% soils in different categories		
	Low	Medium	High
	Available N Status		
1976	52 (117)	43 (97)	4 (10)
2002	63	26	11
2011	57 (283)	36 (182)	7(33)
	Available P Status		
1969	47 (106)	49 (110)	4 (10)
1979	46 (170)	50 (184)	5 (17)
1996	49 (179)	49 (177)	2 (7)
2002	42	38	20
2011	51 (257)	40 (200)	9 (40)
	Available K Status		
1976	20 (36)	53 (98)	27 (50)
1980	22	44	34
2002	21	51	28
2002	13	37	50
2011	9 (47)	42 (212)	49 (231)

Figures in parenthesis are number of districts
Sources: Motsara (2002), IISS Annual Report (2011-12)

been made to develop integrated nutrient management technologies for crops and cropping systems in different agro-ecological settings for adoption at the farmers' fields under rainfed situations. Balanced nutrition of the cropping system including secondary and micronutrients through organic alone or in combination with inorganic has been found to augment the yield and net profit to a greater extent. Among INM strategies, 75% NPK+2.5 t FYM ha^{-1} + soil moisture conservation measure proved to be the best at Bhopal and Raisen districts of M.P in terms of yield and B:C ratio. Similarly, best remunerative manurial treatment for sorghum-chickpea and urd-chickpea was combined application of 100% NPK + FYM to each crop. Similarly, Subba Rao *et al*. (2009) reported that integrated use of 75% NPK and FYM @ 5 t ha^{-1} or poultry manure @ 1.5 t ha^{-1} or phospho compost @ 5 t ha^{-1} to rainy season crops and 75% NPK to wheat recorded higher yields and sustainable yield index in comparison to 100% NPK which leads to saving of 25% NPK both in rainy and winter seasons. Oilseed productivity is low due to inherent poor soil fertility and uncertainty of rainfall and its distribution. Field trials on INM revealed yield improvements from 1.5 q ha^{-1} at Palem in castor to 4.7 q ha^{-1} in groundnut at Ranchi. Table 6 shows the INM modules for different cropping systems.

6. MICRONUTRIENT MANAGEMENT

Apart from macronutrients, widespread deficiency of micronutrients is another concern in these areas owing to intensive cropping and unbalanced fertilization (Kanwar and Randhawa, 1974; Katyal and Vlek, 1985). Crops grown in most soils in India suffer from deficiencies of one or more micronutrients even though the soils often contain apparently adequate total amounts of the respective elements. The nature and extent of deficiencies vary with soil types, crop genotype and management and agro-ecological situations. Micronutrient deficiencies are now frequently observed in intensively grown cereals, oilseeds, pulses and vegetables. Analysis of soil and plant samples indicated extensive deficiency of Zn, Fe, Cu and Mn to the tune of 49, 12, 3, and 4%, respectively (Singh, 2004). Deficiencies of boron and molybdenum are found in 33 and 13% samples, respectively (Behera *et al*., 2009). Of late, stagnation in crop productivity in rainfed areas has also been attributed to deficiencies of micronutrients as these play an important role in physiological process in crop plants, and are directly linked with yield parameters. As it was evident by the published literature that soils of semi-arid region showed low to medium status of availability (DTPA extractable), micronutrients (Fe, Zn and Cu) barring Mn in agricultural fields (Marginal land) and ravine lands of semi-arid region of Rajasthan (Table 7) (Somasundaram *et al*., 2009). Results of earlier study suggested the occurrence of Fe chlorosis or Zn deficiency symptoms in many crops indicate the need for corrective measures like soil application or foliar spray of micronutrients to overcome these deficiencies.

Similarly, Sahrawat *et al.* (2007) characterized fertility status of soils collected (3622 Nos.) from farmers' fields under dryland agriculture in the semi-arid regions of India

Table: 6
Most efficient INM for different cropping systems

Cropping System	INM module
Soybean- chickpea	100% RDF+FYM @ 2 t ha^{-1} to soybean and 50% RDF to Chickpea
Green gram- safflower	Incorporation of green gram stalk before sowing of safflower along with 75% RDF of safflower + soil moisture conservation measure (summer ploughing and interculture with blade hoe)
Fallow-sunflower (Latur and Ranchi)	100% RDF+FYM @ 2 t ha^{-1} + soil moisture conservation measure (opening furrow after every 6 rows)
Castor monocropping	Cowpea incorporation after first picking and 75% RDF of castor
Fallow-mustard system	Green manuring with sesbania and FYM @ t ha^{-1} + 75% RDF
Maize-raya system	100% RDF+ S @ 20 kg ha^{-1} + soil moisture conservation measure (sumer ploughing+maize residue application on surface)

Table: 7
Mean value range of micronutrient content in soils (mg kg^{-1})

Particulars	Depth	Mn	Fe	Zn	Cu
Agricultural (marginal) Land	Surface (0-15cm)	12.03-23.85	2.14-11.59	0.74-1.41	0.23-2.44
	Sub surface (15-30cm)	12.82-23.03	1.49-10.24	0.66-1.04	0.12-2.58
Gullied (ravine) land	Surface (0-15cm)	6.98-8.07	2.83-2.88	0.44-1.15	1.93-2.61
	Sub surface (15-30cm)	5.01-9.90	2.93-3.09	0.44-1.29	1.44-2.38

spread in several districts of Andhra Pradesh (5 districts), Karnataka (5 districts), Tamil Nadu (5 districts), Rajasthan (3 districts), Madhya Pradesh (2 districts) and Junagadh District, Gujarat. Results of soil analysis indicated that soil samples collected from Rajasthan watersheds showed the lowest extent of occurrence of S (66%), B (38%) and Zn (15%) deficiencies (Table 3). On the other hand, occurrence of deficiencies of these nutrients was highest in MP watersheds: 100% of the farmers' fields were deficient in S and B and 98% of fields was deficient in Zn. The occurrence of S, B and Zn deficiencies in Andhra Pradesh and Karnataka watersheds was also widespread (Table 1).

Micronutrient fertility maps showed that almost all soils of Punjab, Haryana and Himachal Pradesh in North Zone are high in available Zn whereas majority of Uttar Pradesh soils are medium in available Zn (www.iiss.nic.in). Majority of soils of this zone are high in available Fe, Cu and Mn with minor exceptions. Manganese deficiency is wide spread in 4 districts of Punjab (15-56%). Fe deficiency was observed over an area of 25-61% in Fatehabad and Hisar districts. In West Zone, Zn and Fe deficiency is wide spread in Maharashtra. Otherwise, majority of soils are sufficient in available Zn, Fe, Cu and Mn. In East Zone, majority of soils are high in available micro nutrients. Zn deficiency was observed only in West Bengal. In South Zone, Majority of soils of Andhra Pradesh, Karnataka and Kerala are sufficient in available micro nutrients. In Tamil Nadu, about 50-60% of the area is low in available Zn and 20-30% deficient in Cu. All soils of Wayanad district in Kerala are deficient in Mn.

Balanced fertilization is a must which is possible through proper assessment of multiple nutrient deficiencies in soils and plants. Development of blended formulations for replenishment of deficient nutrient in soil more judiciously with minimum cost involved (Behera *et al*., 2009). In order to ensure correction of hidden deficiencies of micronutrients, Government of India (GOI) has approved zincated urea and boronated super phosphate under Fertilizer Control Order (FCO) besides straight fertilizer of zinc sulphate, iron sulphate, manganese sulphate, copper sulphate, borax, and sodium molybdenum. *Fertilizer micro-dosing* is one another technique developed by International Crop Research Institute for Semi-Arid Tropics (ICRISAT) where it enables farmers to measure right amount of fertilizer in caps of soft drink bottles and placing these along with the seed. *Micro-dosing* is a practice of application of micronutrient and cultivation of crop with appropriate quantity at right time. This method helps thousands of farmers in western and southern Africa to get their crops to mature faster and overcome the drought effects.

7. CONCLUSIONS

Dryland and rainfed farming will continue to play a dominant role in country's food grain production. However, soils in these regions are not only thirsty but also hungry particularly plant nutrients (nitrogen and phosphous). Moreover, resource-poor farmers in these regions apply meager quantity of organic manures, residues, and nutrients and thus crops suffer from multi nutrient deficiencies. It is evident that, stagnation in crop productivity in rainfed/dry lands areas has been attributed to very low organic carbon, deficiencies of macro and micro-nutrients. As these play an important role in physiological process in crop plants, and are directly linked with yield parameters.

On-farm yield under dryland agriculture can be increased from present level to nearly 2-3 times higher through proper selection of crop/varieties and judicious soil and water management practices. Furthermore, appropriate land management to conserve top fertile soil and rain water coupled with integrated nutrient management along with legume based cropping systems would be more useful in restoring stressed dryland soils and stabilizing crop productivity in these regions.

REFERENCES

Annual report, 2011-2012. Indian Institute of Soil Science, Nabibagh, Bhopal.

Behera, S.K., Singh, M.V. and Lakaria, B.L. 2009. Micronutrient deficiencies in Indian soils and their amelioration through fertilization. *Ind. Farm.,* 59(2):28-31.

Borlaug, N.E. 2007. Feeding a hungry world. *Science,* 318: 359.

Bruinsma, J. 2009. The resource outlook to 2050. By how much do land, water use and crop yields need to increase by 2050? In Session 2: The resource base to 2050: Will there be enough land, water and genetic potential to meet future food and biofuel demands?

Bryan, E., Deressa, T.T., Gbetibouo, G.A. and Ringler. C. 2009. Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environ. Sci. Policy,* 2: 413-426.

Campbell, A. 2008. Food, energy, water conflicting insecurities (and the rare win-wins offered by soil stewardship). *J. Soil Water Conserv.,* 63: 149-151.

Chaudhary, S. 2012. Trends in total factor productivity in Indian agriculture: state-level evidence using non-parametric sequential malmquist index. Working Paper No. 215, Centre for Development Economics, Department of Economics, Delhi School of Economics.

Clark, A., Carroll, R. and Borger, J. 2008. Panic as global food crisis reaches America. The Hindu (National Daily) 25th April, 2008.

Devi, B., Bhardwaj, D.R., Panwar, P., Gupta, N.K. and Thakur, C.L. 2013. Carbon allocation, sequestration and carbon dioxide mitigation under planatation forests of North Western Himalayas, India. *Ann. For. Res.,* 56(1): 123-135.

El-Swaify, S.A., Pathak, P., Rego, T.J. and Singh, S. 1985. Soil management for optimized productivity under rainfed conditions in the semi-arid tropics. *Adv. Soil Sci*., 1: 164.

FAO. 2009. The state of food and agriculture. ISBN 978-92-5-106215-9.

Franzluebbers, A.J. 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. *Soil Till. Res.,* 66(2): 197-205.

IARI, 2012. Crop residues management with conservation agriculture: Potential, constraints and policy needs. Indian Agricultural Research Institute, New Delhi, vii+32 p.

John Vidal. 2008. Food Shortage likely in Global rush for biofuel: UN, The Hindu (National Daily) 1st May, 2008.

Kanwar, J.S. and Randhawa, N.S. 1974. Micronutrient research in soils and plants in India: A review. *ICAR Tech. Bull*. (Agric.), 50: 160.

Kar, G., Singh, R. and Verma H.N. 2003. Crop diversification technology in rainfed upland rice area of eastern India for increased productivity and rainwater use efficiency. Research Bulletin 13/2003. Water Technology Centre for Eastern Region, Bhubaneswar-751023, Orissa, India.

Katyal, J.C. and Vlek, P.G.L. 1985. Micronutrient problems in tropical Asia. *Fert. Res*., 7: 69-74.

Lal, R. 2002. Carbon sequestration in dryland ecosystems of West Asia and North Africa. *Land Deg. Dev.,* 13: 45-59.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. *Geoderma,* 123, 122.

Lal, R. 2008a. Soils and India's Food Security. *J. Ind. Soc. Soil Sci*., 56(2): 129-138.

Lal, R. 2008b. Managing soil water to improve Rainfed agriculture in India. *J. Sustainable Agri.,* 32: 51-75.

Lal, R. 2010. Carbon sequestration potential in rainfed agriculture. *Ind. J. Dryland Agric. Dev.,* 25(1), 1-16.

Lal, R., Delgado, J.A., Groffman, P.M., Millar, N., Dell, C. and Rotz, A. 2011. Management to mitigate and adapt to climate change. *J. Soil Water Cons*., 66(4): 276-285.

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. *Proc. Natl. Acad. Sci*., 104: 13268-13272.

Morton, J.F. 2007. The impact of climate change on smallholder and subsistence agriculture. *Proc. Natl. Acad. Sci*., 104: 19680-19685.

Motsara, M.R. 2002. Available nitrogen, phosphorous and potassium status of Indian soils as depicted by soil fertility maps. *Fert. News*, 47: 15-21.

NAAS, 2012. Sustaining Agricultural Productivity through Integrated Soil Management. Policy Paper No. 56, National Academy of Agricultural Sciences, New Delhi. 24 p.

Oweis, T., Hachum, A. and Kijne, J. 1999. Water harvesting and supplementary irrigation for improved water use efficiency in dry areas. SWIM Paper 7. Colombo, Sri Lanka: International Water Management Institute.

Pal, S., Panwar, P. and Bhatt, V.K. 2010. Evaluation of spatial variability of soil properties based on geostatistical analysis A case study in lower Shivaliks. *Ind. J. Soil Cons.,* 38(3): 178-183.

Panwar, Pankaj, Pal, S., Chakravarty, S. and Alam, N. 2013. Soil quality and production of lowland paddy under agrisilvipature systems in acid soils of West Bengal, India. *Range Mgmt, & Agroforestry,* 34(1): 51-57.

Patnaik, I, 2010. Distress Situation in Dryland Areas Impacts on Livelihood Pattern and the Coping Strategies: A Review. Working Paper No. 91.

Rego, T.J., Rao, V.N., Seeling, B., Pardhasaradhi, G. and Kumar Rao, J.V.D.K. 2003. Nutrient balances A guide to improving sorghum and groundnut-based dryland cropping systems in semi-arid tropical India. *Field Crops Res*., 81: 5368.

Reij, C., Mulder, P. and Begemann, L. 1988. Water harvesting for Plant Production. World Bank Technical Paper, 91, World Bank, Washington, D.C.

Rockstrom, J. 2010. Planetary boundaries. New Perspect. Q. 27, 7274. http://dx.doi.org/ 10.1111/j.1540-5842.2010.01142.x.

Rockström, J. and Falkenmark, M. 2000. Semiarid crop production from a hydrological perspective: gap between potential and actual yields. *Critical Rev. in Plant Sci*. 19(4): 319-346.

Ruddiman, W.F. 2003. The anthropogenic greenhouse era began thousands of years ago. *Climatic Change,* 61:261-293.

Safriel, U. and Adeel, Z. 2005. Dryland Systems in Hassan, R., R. Scholes and N. Ash, (2005) Ecosystems and Human Well-being: Current State and Trends, Volume 1, Island Press, Washington DC, USA.

Sahrawat, K.L., Wani, S.P., Rego, T.J., Pardhasaradhi, G. and Murthy, K.V.S. 2007. Widespread deficiencies of sulphur, boron and zinc in dryland soils of the Indian semi-arid tropics. *Curr. Sci.,* 93(10): 1428-1432.

Schoenholtza, S.H., Van Miegroet, H. and Burger, J.A. 2000. A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities. *Forest Ecol. Manage.*, 138, 335-356.

Sekhon, G.S. 1997. Nutrient needs of irrigated food cropsin India and related issues. In: Plant Nutrient Needs, Supply, Efficiency and Policy Issues 2000-2025 (J.S. Kanwar and J.C. Katyal, Eds), National Academy of Agricultural Sciences, New Delhi, India.

Sharda V.N. and Ojasvi P.R. 2005. Water harvesting through watershed management in different agro-ecological regions of India. *Ind. J. Agric. Sci.,* 75: 771-780.

Sharma, K.L., Ramakrishna, Y.S., Samra, J.S., Sharma, K.D., Mandal, U. K., Venkateswarlu, B., Korwar, G.R. and Srinivas. K. 2009. Strategies for Improving the Productivity of Rainfed Farms in India with Special Emphasis on Soil Quality Improvement, *J. Crop Improvement*, 23:430-450.

Singh, M.V. 2004. Micronutrient deficiencies in Indian soils and field usable practices for their correction. Paper presented at the International Fertilizer Association International Conference on Micronutrients held in New Delhi, India, February 23-24, 2004, 18 p.

Singh, R. 2004. Simulations on direct and cyclic use of saline waters for sustaining cotton-wheat in a semi-arid area of north-west India. *Agric. Water Manage.*, 66: 153-162.

Somasundaram, J., Singh, R.K., Parandiyal, A.K. and Prasad. S.N. 2009. Micronutrient Status of Soils under Different Land Use Systems in Chambal Ravines, *J. Ind. Soc. Soil Sci*., 57:307-312.

Srinivasarao, Ch., Ganeshamurthy, A.N. and Ali, M., 2003. Nutritional constraints in pulse production. Bulletin, Indian Institute of Pulses Research, Kanpur, 134 p.

Srinivasarao, Ch., Vittal, K.P.R., Venkateswarlu, B., Wani, S.P., Sahrawat, K.L., Marimuthu, S. and Kundu, S. 2009. Carbon stocks in different soil types under diverse rainfed production systems in tropical India. *Comm. Soil Sci. Plant Anal.,* 40(15): 2338-2356.

Subba Rao, A., Biswas, A.K., Sammi Reddy, K., Hati, K.M. and Ramana, S. (Eds) (2009). IISS: Two Decades of Soil Research, Indian Institute of Soil Science, Bhopal, 1-132.

Swaminathan, M.S. 2005. Science and India's Agricultural Future, *The Hindu* (National Daily) 17th October, 2005.

Swaminathan, M.S. 2008. Saving Rural Livelihoods and strengthening food security. *The Hindu* (National Daily) 15th April, 2008.

Tandon, H.L.S. and Kanwar, J.S. 1984. Research Bulletin 8. International Crops Research Institute for the Semi-arid Tropics, Patencheru, A.P.

Venkateswarlu, J. 1987. Efficient Resource Management Systems for Drylands of India. *Adv. Soil Sci.,* 7: 165-221.

Verdin, J., Funk, C., Senay, G. and Choularton, R. 2005. Climate science and famine early warning. *Philo. Trans. Royal Soc.,* 360: 2155-2168.

Vittal, K.P.R., Singh, H.P., Rao, K.V., Sharma, K.L., Victor, U.S., Chary, G.R., Sankar, G.R.M., Samra, J.S. and Singh, G. (Eds.), 2003. Guidelines on Drought Coping Plans for Rainfed Production Systems. All India Coordinated Research Project for Dryland Agriculture, Central Research Institute for Dryland Agriculture, Indian Council of Agricultural Research, Hyderabad, 39 p.

William Dar. 2007. Carbon sequestration for better dryland productivity. The Hindu (National Daily), 24th October 2007.

World Bank. 2007. Agriculture for development. World Development Report 2008. The World Bank, Washington, DC.