Securing soils through people-centric watershed management for sustainable agricultural development

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The sustainability of agricultural production systems is the plausible outcome of carefully managed natural resources to produce more per-unit input, which will also help to achieve the goals of 'no poverty' and 'zero hunger'. Soils from croplands and uncultivated wastelands are degraded due to erosion and nutrient depletion, requiring urgent attention to maintain the sustainability of the production system. By adopting a holistic, integrated watershed management approach, soil security measures backed by scientific knowledge have demonstrated a positive impact on agricultural productivity and profitability, with reduced soil loss and increased water availability.

"Upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel, our shelter and surround us with beauty. Abuse it and the soil will collapse and die, taking humanity with it." – Rigvedas (1500 BC).

The importance of — and need for — soil security measures was recognized by ancient intellectuals, and is also highlighted in the framework of the Sustainable Development Goals (SDGs)[1]. However, with pressure to achieve food security and other economic priorities, soil security has received less attention than required for sustainable development. Technological innovation in crop husbandry, the use of chemical fertilizers, an increase in crop coverage and cropping intensity, and access to water for irrigation have increased the production rates of agriculture commodities[2, 3]. But this has also resulted in land degradation in the form of soil erosion, depletion of soil nutrients, hardpan development, and soil salinization because of inappropriate use of the technologies. Another important factor in the increase of production rates is irrigation, although rainfed agriculture systems are suffering from both low crop yields and high land degradation[4].

Soil erosion and the depletion of soil nutrients are major causes of land degradation. Globally, 75 billion tonnes of soil are lost from arable land each year along with an estimated US$ 400 billion in agricultural production costs[5], although a recent study on global soil erosion has challenged this estimate and suggested 35.9 billion tonnes of soil loss per annum[6]. In either case, soil erosion remains the main cause of land degradation upstream as well as increasing sediment loads in downstream water bodies[7]. In India, river basins are losing 0.5 to 1.0 per cent of storage capacity every year[8].

The rate of soil erosion changes with soil type[9], rainfall intensity[10], land use, and land management practices[6]. Data from long term observations (1976–2010) of soil loss from croplands with alfisols and vertisols, at the International Crops Research Institute for the Semi-Arid Tropics, Patancheru, showed a large difference in both the mean annual soil loss and sediment concentration between these two soils[9]. Alfisols

The community role in biodiversity conservation and management

95 ha of community pasture land in Gokulpura and Goverdhanpura villages was facing land degradation due to overgrazing and failure to produce sufficient fodder to support an increasing population of livestock. People from the villages came together to devise a plan to rehabilitate the community pasture land as a part of an integrated watershed management activity. Half of the pasture was kept for the rehabilitation process, with the other half kept available for open grazing. The stakeholders — grazers, herder, and farmers —through the Gram Panchyat (village level governing institution) agreed to erect a stone wall around the 45 ha pasture area, and banned cattle from grazing within it. Thus, the area was physically and socially fenced.

An improvement was observed in the density of vegetation in the protected area, in contrast to the unprotected area. Moreover, the treated area attracted many birds and animals, prominent among which were blue bulls. The community efforts over six years brought about remarkable changes in the flora and fauna of this piece of land and, most importantly, it has begun to produce a good quantity of quality livestock fodder. These activities have generated a good income for the community, particularly for marginal and small farmers.

Farmer witnessing the transformation of grazing land, Gokulpura, Rajasthan

Various soil and water conservation structures at the Gokulpura-Goverdhanpura watershed. The soil and water conservation structures including 13 gabion structures (top left), 1,500 gully plugs, 34 loose boulder structures (top right), and 20 check dams (bottom left) were constructed in a watershed of 1,355 ha, which reduced the annual soil loss from 5.5 t/ha to 1.5 t/ha

are more susceptible to soil erosion than vertisols — the mean annual soil loss in alfisols was about 3.0 times higher in comparison. Also, soil erosion rates from croplands are several times higher than soil erosion rates from forests[6].

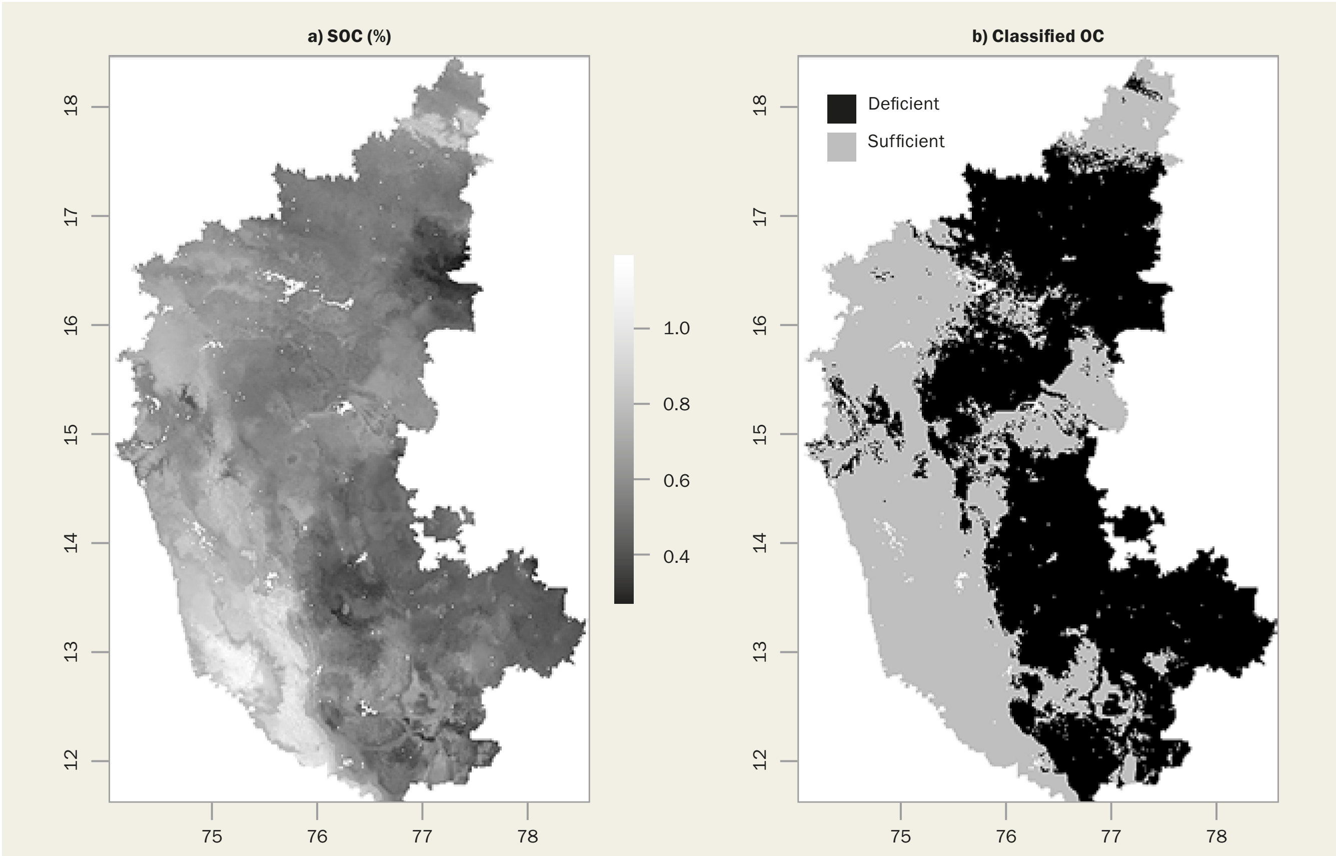
Another mechanism of land degradation is soil nutrient depletion which may result directly from sediment transport or through crop uptake and imbalanced nutrient applications. During soil erosion, sediments also carry useful soil nutrients and harmful agricultural chemicals to downstream waterbodies, thus causing nutrient deficiencies in croplands, and water contamination downstream.

The nutrients depleted from croplands are not being replenished appropriately. For example, since the era of the green revolution in India, attention has been given to only three macronutrients: nitrogen, phosphorous, and potassium, but the application of micro- and secondary nutrients such as boron, zinc, iron and sulphur has been ignored, leading to widespread deficiencies of those micronutrients[11]. Although the quantity required of secondary and micro-nutrients is very small compared to macro-nutrients, their role is critical for maximizing crop yield.

ICRISAT and its partners have been working together with farming communities to alleviate land degradation, overcome water scarcity, and harness the potential of rain-fed agriculture by adopting integrated watershed management programmes. The important interventions adopted are low-cost soil and water conservation and rainwater harvesting structures, soil test-based balanced nutrient management, and the reuse of treated wastewater.

The participatory Integrated Watershed Management approach is a holistic rural development intervention targeting the soil, water, ecosystem and community. This approach was taken a step forward through a comprehensive public–private partnership (corporate social responsibility programme). Through one such partnership in the drought-prone semi-arid Bellary area of south India, where water scarcity is a major issue, 7,680 people across four villages have been positively impacted. The holistic approach has increased the groundwater level by 1.5–2 metres in less than five years. Check dams and water conservation structures built as part of the programme have conserved a gross amount of 45,000m^3 due to refilling in the rainy season. An additional 25,000m^3 of rainwater was harvested, providing water security to the community. This helped sustain crop yields during long dry spells and the overall yield of groundnut and maize increased by 19 and 27 per cent respectively from 2013 to 2018.

With the help of a loan from the Asian Development Bank, the Government of China piloted 100 watersheds in preselected provinces. Today, this model has reached 12 million farmers in five countries across Asia and Africa. In addition, through spillover and dissemination, holistic watershed intervention has reached at least one billion people.



Prediction maps of surface layer soil organic carbon (SOC) derived using digital soil mapping techniques. The environmental covariates used for creating these maps were elevation, slope, aspect, annual mean temperature, mean diurnal range of temperature, temperature seasonality, maximum temperature of warmest month, minimum temperature of coldest month, temperature annual range, annual precipitation, precipitation of wettest month, and precipitation seasonality

Soil security measures adopted in watershed programmes
Understanding that soil erosion is one of the most serious threats to the soil in India, the Indian government initiated a watershed development programme in the early 1970s with the aim to reduce soil erosion in agricultural lands and to control gully formation. The investment in soil and water management has resulted in reduced sedimentation which has a positive impact on the water quality downstream, but also on the water harvesting interventions which are strengthening the resilience to drought. These interventions have reduced the soil loss by a factor of five to ten and is expected to make a positive impact on in-stream river ecology and runoff generation for other downstream water uses[10]. Moreover, a higher groundwater recharge from 9 to 20 per cent of total rainfall, together with a 10 to 30 per cent higher soil moisture availability in the fields resulting from the watershed interventions, have enabled the farmers to provide supplementary irrigation to crops during dry spells, enhancing greenwater use efficiency.

Resource conservation technologies were also adopted for practicing resilient and climate-smart agriculture. Two of these conservation technologies are zero or minimum tillage and retention of crop residues on the soil surface, which are also basic principles of conservation agriculture. Minimizing tillage reduces the volume and velocity of surface runoff, leading to a reduction in soil erosion and nutrient loss[12–14]; the incorporation of crop residues; enhanced soil water availability; reduced evaporation loss; improved infiltration by restricting surface runoff; and reduced surface sealing from raindrop impact[13]. A study to assess the global impact of land use on soil erosion[6] has suggested that conservation tillage practices have reduced the soil erosion from croplands by 64 per cent.

Nutrient cycling and rectifying nutrient deficiencies
Bhoochetana (rejuvenation of soil) was a mission project from the semi-arid tropic region of Karnataka state in southern India. The project addressed soil nutrient deficiencies on a large scale through policy interventions aimed at characterizing the fertility status of soils and adopting integrated nutrient management holistically to increase productivity and profitability for the farmers. The statistically proven random stratified sampling method[15] was adopted to collect 95,000 soil samples representing farming fields of 30 districts covering approximately 5.3 million ha in Karnataka. In 2009, the samples were analysed and soil fertility maps and soil health cards were prepared. The collected samples represented a huge variability in terms of rainfall, topography, cropping system, farm size, and management.

The soil fertility maps[16] and descriptive statistics indicated that almost 50 per cent of the area was deficient in organic carbon, sulphur, boron, and zinc, thus requiring a soil fertility management programme, especially within the croplands. Soil organic carbon (SOC), values ranged from 0.3 to 1.5 per cent. The soils in the Western Ghats had higher SOC values compared to the South Deccan Plateau. Moreover, the southern part of Western Ghats gave the highest values of SOC, a trend that could be due to a combination of high vegetation and precipitation. The SOC map also indicated that almost 50 per cent of the area in Karnataka state showed less than 0.5 per cent SOC.

The soil fertility maps prepared during this project have changed the perception of policymakers that fertilizer requirements are same at every location. The crop wise balanced nutrient recommendations prepared during the project were incentivized by state government through subsidizing the cost of the required inputs by 50 per cent.

Another major hurdle in any scaling-up project, is reaching out to large farming communities through a limited and poor extension system. This issue was addressed by introducing an innovative system of farm facilitators — progressive farmers who have practiced agriculture and have a minimum of academic qualifications. The farm facilitators were trained by State Agriculture Universities to spread good agricultural practices. The project covered 4.75 million farmers with US$ 353 million net benefits to the state between 2009 and 2013. Overall the project recorded a significant yield increase from 25 to 47 per cent in cereals, 28 to 37 per cent in pulses and 22 to 48 per cent in oilseed crops[17].

Rehabilitation of the wastelands through agro-forestry

The wastelands often have undulating topography and severely degraded soil with a very shallow depth, supporting no more than a scattering of short, and stunted bushes exposed to the increased pressure of grazing, and facing severe land degradation. Open grazing practices, typical in villages, have over-exploited common pasture and forest land adjoining the village. Deforestation and mining activities have reduced the fodder source, increasing pressure on common grazing lands. The most appropriate solution to reduce the degradation of wastelands and to achieve fodder security in a village is to develop the wastelands as fodder banks. A silvopasture system comprising suitable species of fodder grasses and trees on wasteland treated with soil and water conservation structures can provide a sustainable source of fodder for livestock. Here, the village committee is responsible for the development of wastelands and the protection of the silvopasture system.

Another option for rehabilitating the wastelands is to grow biofuel plants such as Jatropha (*Jatropha curcas* L.). These plants are drought tolerant and suitable for degraded soils with a low nutrient content. This option is also considered as a means of addressing concerns about climate change and improving energy security while at the same time providing an additional source of income for the community. There is also the benefit that nutrients are recycled through leaf fall, for example a three-year-old Jatropha plant recycles 21 kg/ha nitrogen back into the soil.

In collaboration with the National Oilseeds and Vegetable Oils Development Board, the Indian government, ICRISAT and village community have initiated a project to rehabilitate the 160 ha common property land in Velchal village, India

Plantation in the wastelands of Velchal village in which Jatropha seedlings approximately 30–60 cm high were planted in 2m x 2m spacing by planting the Jatropha as biofuel plants. Firstly, the soil and water conservation structures were established in the wasteland for reducing soil erosion and rainwater harvesting. Then the plants were grown as rainfed crop, but fertilizers were applied as per requirements for achieving optimum yield. The beneficial effects of wasteland rehabilitation included the effective use of rainfall for producing biomass, an increase in groundwater recharge, a reduction in runoff and soil loss, and an improvement in downstream water-bodies[18]. The annual average soil erosion in the villages was high, ranging from 10 to 15t/ha as the soils in the village are shallow with a low water holding capacity. The Jatropha plantation reduced the intensity of runoff and thus reduced total soil loss by almost 50 per cent[18]. Moreover, Jatropha as a biofuel crop also creates a complementary source of income for the village community.

The way forward

The Indian government's goal of doubling farmers' incomes was successfully demonstrated through corporate social responsibility projects in the states of Telangana, Andhra Pradesh, Karnataka, Maharashtra and Odisha. More than 500,000 most-at-need people benefited with increased productivity and incomes. With improved management of watershed pilot sites, farmers' incomes doubled with an increased cropping intensity of 70–100 per cent over the baseline[19]. The initiative to double farmers' incomes was piloted in 27 districts of Maharashtra and Uttar Pradesh.

Because of the impact of these pilots, the initiative was scaled up across regions, into national level policies and shared with countries across the world.

The strategy to arrest land degradation depends on its cause. Soil and water conservation interventions reduce soil erosion; balanced nutrient management in crops checks excessive nutrient mining from the soil; appropriate tillage practices reduce soil and nutrient erosion from croplands; and the development of wastelands provides a sustainable solution to fodder production as well as additional income. These interventions are being implemented as a part of integrated watershed management programme and provide beneficial effects in terms of crop production and environmental security. Scaling-up of these initiatives is urgently needed to achieve food, nutrition and water security for the growing population; which is always a challenging task as it requires coordinated and collective efforts from both the scientific and farming communities, and from policymakers.

The Bhoochetana project may be a guiding example for such scaling-up activities. Another critical limiting factor for the sustainable land management programme is the availability of correct and actionable information to end users. Such information may often be available in a complex form that very few could understand and use for planning process. The digitization of this information, and the building of a spatial data infrastructure for natural resource management would be the first step towards developing agro-ecoregion-based planning and implementation processes.

The *Jatropha* is a shrub with the potential for use in rehabilitating degraded lands