SOIL ENGINEERING AND TECHNOLOGY

Surinder S. Kukal
Department of Soils, Punjab Agricultural University, Ludhiana, India

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Contents

Summary

The use of soil for agricultural purposes with various engineering techniques, conservation irrigation techniques, techniques enhancing the aggregate size and stability, better soil husbandry in regions of potential soil erosion and other forms of land degradation may help in sustaining better life for a longer period of time. The structural, chemical, and physical degradation of soils may lead to the deterioration of soil health resulting in the inefficient use of applied inputs, including water and fertilizers. In addition, the optimum and need-based use of inputs in agricultural production is now the need of the hour to sustain natural resources and hence agricultural productivity.

This document describes the resource conservation technologies in relation to tillage, irrigation water, crop residue management, land degradation etc. Technologies developed in recent years have been referred to for the use by farmers and policy makers. Soil and crop residue management with different tillage practices in different scenarios is discussed. Optimum and need-based irrigation scheduling in crops is highlighted; irrigation methods in dry regions are discussed. An overview of various forms of land degradation and their management through engineering, agronomic and soil practices is given.

1. Introduction

Soil is the upper layer of earth crust regulating natural habitats and life sustaining resources. Soils hold water and nutrients, releasing them for plant use over a longer period of time. Soil biota decompose organic materials, recycle nutrients and regulate gas flux to and from the atmosphere. Soils filter toxic and non-hazardous compounds through surface adsorption and largely determine the quality of underground and terrestrial waters.

The soil is a combination of primary particles (sand, silt and clay) bound together in secondary particles (aggregates), the size and strength of which determine the soils' capability and use for crop production, water storage, road building and other infrastructures. Soil productivity is a direct function of sustenance of its structure. The degradation of soil structure due to tillage, soil erosion, salinity, or surface sealing is a growing phenomenon globally, and an understanding of the process of soil deterioration in relation to different anthropogenic activities is essential for proper soil management.

The use of soil for agricultural purposes with various engineering techniques, conservation irrigation techniques, techniques enhancing the aggregate size and stability, better soil husbandry in regions of present and potential soil erosion hazards, etc. may help in sustaining better life for a longer period of time. This document highlights such techniques in relation to soil degradation due to various anthropogenic activities.

2. Soil Tillage

Tillage encompasses a broad range of techniques of physical manipulation of the soil specifically designed to prepare a seedbed that optimizes edaphological conditions of seed germination, seedling establishment and crop growth. There are two types of tillage. Primary, tillage that loosens the soil and mixes in fertilizer and/or plant material, resulting in soil with a rough texture. Secondary, tillage which is due to produce finer soil and sometimes shapes the rows. Tillage can be done by using various combinations of equipment viz. plow, disk plow, harrow, dibble, hoe, shovel, rotary tillers, subsoilers, ridge or bed forming tillers, rollers, etc.

Tilling was first performed by labor force, sometimes involving slaves. Hoofed animals were used to till soil through trampling. The (wooden) plow was then invented, which could be pulled by mules, oxen, elephants, water buffaloes, or similar sturdy animals. The steel plow allowed farming in more difficult soils like in the American Midwest, where tough prairie grasses and rocks caused trouble. Soon after 1900, the farm tractor was introduced, which eventually made modern large-scale agriculture possible.

Weed plants (seeds, tubers, etc.) may be exhausted by repeated tilling of the soil. The weeds expend energy to reach the surface, and then get turned into the soil by tilling. Plowing loosens and aerates the soil which in turn facilitates deeper penetration of roots. It helps in the growth of microorganisms and worms present in the soil, and thus maintains the fertility. It helps in the mixing of organic matter (humus) and nutrients evenly throughout the soil. However, repeated and excessive tillage leads to physical degradation of the soil thereby altering soil’s physical environment.

2.1. Intensive Tillage

Intensive or conventional tillage is a major component of soil management influencing the performance of a crop production system. In fact, the mindset of farmers is based on the thought that intensive tillage leads to better seedbed for sowing purposes and, hence, for higher crop yields. They go for 2-6 plowings and “plankings” to create a fine layer of soil, which they believe acts as a mulch, thereby preventing further evaporation from the sown fields. The Romans considered that grain land had to be rich and well tilled for 50-60 cm down. The mould board plow was introduced in England during 5th to 10th centuries. It was believed that the objective of plowing was to pulverize the soil grains into small particles so that they could be ingested by plant roots.

The objectives of intensive tillage are somewhat different for temperate and tropical climates. In temperate regions, fall plowing with the mould board plow leaves the soil surface rough with large clods and numerous ridges and furrows, which undergo mellowing or crumbling to become friable due to wet/dry and freeze/thaw cycles. During spring, the mellowed soil is refined into friable tilth by the use of cultivators and harrows, which also eradicate weeds. In the tropics, however, the soil at the onset of heavy seasonal rains (monsoons) following a long dry season is parched and extremely hot. Therefore, the objective of seedbed preparation in the tropics is to conserve water in the root zone, to lower soil temperature and to suppress weeds.

Tillage implements include the plow to invert soil, and cultivators and harrows to pulverize, mix and stir soil clods. In addition, rollers are sometimes used to consolidate lose tilth, and hoes and broad shares to create soil mulch. It must be noted that tillage when repeated every season to a depth of 15-20 cm, renders the soil in a state of unstable equilibrium. Some people have called this drastic perturbation as “rape of the earth”. Tillage leads to exposure of the soil to the impact of raindrops and blowing wind exacerbating the risks of accelerated soil erosion by water and wind. Also, the humus is mineralized due to increased ease of microbial decomposition of organic matter. It leads to accelerated soil erosion and desertification. The process of soil degradation is set in motion by crusting and by compaction of loosened soil that results from raindrop impact and from human, animal and vehicular traffic.

2.2. Conservation Tillage

Conservation tillage is a method of seedbed preparation that leaves at least 30% of the soil surface covered by crop residues. A major breakthrough during the 1950s and 1960s in weed control chemicals completely replaced the tillage for seedbed preparation. Advantages of conservation tillage include erosion control, water conservation, improvements in water quality, saving of time, fuel, labor and money for seedbed preparation, and increase in soil organic carbon (Karlen *et al.*, 1994). Conservation tillage systems are essentially the mulch farming techniques. Plant residues left on the soil surface are effective in reducing evaporation and conserving soil moisture (see also: *Conservation Agriculture).*

A conservation tillage practice widely used in semiarid and humid regions is stubble mulching where wheat stubbles or corn stalks from previous crops are uniformly spread over the soil surface. The land is then tilled with special implements, which leave most of the residues on the soil surface. The next crop is planted through the stubble, which results in a healthy environment (temperature, water and air) for seed germination.

Conservation agriculture also has significant benefits at the global level, including carbon sequestration in the organic matter accumulated in the soil from the crop residues and cover crops (Hobbs and Gupta, 2003), less leaching of soil nutrients or chemicals into the groundwater, less pollution of the water, practically no soil erosion (erosion is less than soil build-up), recharge of aquifers through better infiltration and less fuel use in agriculture.

2.2.1. Minimum Tillage

This is a method of conservation tillage for which pre-planting tillage is limited. The approach can involve a number of techniques including direct drilling, broadcasting into existing stubbles or adopting a strategy of reduced tillage viz. sowing after disking, or following strip tillage (Figure 1), where the line of actual sowing is tilled normally instead of tilling the whole soil surface to create a uniform fine seedbed whereas the inter-row space is left untilled with crop residues on the surface. There have been significant developments in minimum tillage and drilling equipment over the last ten years. Strip tillage offers a high residue alternative to full-width tillage systems.

Figure 1. Strip-till drill (left) and the clean strips tilled and sown (right) with corn residues in between

2.2.2. Zero Tillage

Zero tillage or no-tillage is another conservation tillage system that leaves residues on the soil surface, while a new crop is planted directly through the residue of the previous crop with no plowing or disking (Lal, 2003). No-tillage is called 'sod-seeding' when crops are sown into a sod produced by application of herbicides on a cover crop. Sowing through the residue of previous crop is referred to as 'direct-seeding' (Figure 2). Surface seeding or direct seeding on flats lands requires no machinery and minimal labor. Surface seeding has been promoted for timely sowing of wheat following rice on clay soils that were normally left fallow after rice because of the difficulty of preparing a seedbed for wheat. The studies on no-till in tropical countries have shown considerable benefits in terms of soil and water conservation, lower soil temperature and better soil structure and crop yields (Koller, 2003).

Figure 2. Wheat growing in zero-tilled field with standing stubbles (left) and a zero-till drill (right)

2.3. Deep Tillage

Coarse textured soils, characterized by low water retention and high permeability, exhibit a sharp increase in soil strength on drying at 15-20 cm depth due to repeated intensive tillage, particularly during puddling for rice cultivation. Because of the low available water storage of the root zone and the high potential for leaching of mobile nutrients, crops on these soils are subject to yield reducing nutrient and water stresses. The problem is further exacerbated by the slow growth of roots due to high soil strength. Deep tillage of such soils helps alleviate these stresses by enlarging the root system, thus enhancing the water and nutrient uptake capacity of the crop, which results in increased yields.

In several investigations from north-west India, 40 cm deep chiseling (deep plowing), 35-40 cm apart of sandy, loamy sand and sandy loam soils increased the yields of corn, wheat, mustard and sunflower compared to conventional tillage (10-12 cm deep disking). Deep tillage enhances the production base of the crop to respond to higher level of nutrients (Table 1).

Crop	Soil type	Crop yield, Mg/ha	
		Conventional tillage	Deep tillage
Winter corn	Sandy	3.9	4.9
	Loamy sand	4.8	5.0
Summer corn	Sandy	0.9	2.2
	Loamy sand	1.1	2.2
	Sandy loam	4.0	4.8
Wheat	Sandy	3.4	4.6
	Loamy sand	4.9	5.3
	Sandy loam	5.2	5.4
Sunflower	Loam sand	1.3	1.7
	Sandy loam	1.6	2.0

Table 1. Response of different crops to deep tillage in comparison to conventional tillage in the Indo-Gangetic Plains of India (Gajri *et al.*, 2002)

2.4. Puddling

Puddling refers to the physical manipulation of a wet soil to slake and disrupt structural aggregates, and to decrease total- and macro-porosity (Figure 3). Puddling implies reduction in apparent specific volume (inverse of bulk density) and void ratio (volume of pores to volume of soil solids) of soil by mechanical work done on it. The puddlability – susceptibility of soil for puddling - increases with clay content, presence of expanding clay minerals, proportion of Na^+ on the exchange complex, and low concentration of sesquioxides. Puddling changes the soil from a three-phase (solid, liquid and gases) to a two-phase (solid and liquid) system. Aggregates are weakened upon saturation, and the electric double layer of the clay particles is fully expanded. The work done during puddling involves two kinds of deformation stresses viz. normal stress causing compression and tangential stress causing shear.

Figure 3. Puddling with a mechanized puddler (left) and a puddled transplanted rice field (right)

2.4.1. Significance of Puddling

Puddling creates soft conditions in the soil for easy transplanting of rice seedlings, and improves weed control particularly during wet conditions. Its primary aim is to reduce water percolation losses and to ensure saturated conditions in the surface area for a longer period of time, conserving water from rainfall and irrigation.

Farmers of the Indo-Gangetic Plain in India, Vietnam, Indonesia and many other places in South-East Asia have been cultivating rice under puddled conditions over long periods of time. Being a semi-aquatic plant, rice is grown under saturated soil conditions with surface ponding. The differential settling of soil particles immediately after puddling results in sealing the soil surface with clay particles and in reducing infiltration. Stress applied on wet soil aggregates during puddling leads to a reorientation of clay particles causing reduced air porosity.

2.4.2. Puddling and Soil Physical Properties

Destruction of aggregates during puddling triggers a series of changes in soil physical properties affecting plant growth. Puddling of a well-aggregated porous soil results in the development of a massive structure and high bulk density. The change in bulk density depends not only on the intensity of puddling but also on the cropping systems and crop residue management. A dried puddled soil is very compact and develops broad and deep cracks, depending on the nature and amount of clays. Puddling of a compact soil brings the soil particles back in suspension and lowers the bulk density. Re-flocculation of dispersed clay particles depends on soil texture, clay type and ionic concentration of soil solution. Settling is faster in sandy soils with 1:1 clay mineralogy.

Urea top dressings might cause soil particles to settle by lowering the zeta potential of a soil. Lower bulk density and soil strength in puddled soils facilitates transplanting and favors plant growth (though critical values for rice are not known). Soil strength in the puddled layer may be near zero because of higher moisture content and loosely arranged soil particles, particularly in the surface layers.

Soil porosity may increase or decrease with puddling depending upon the changes in soil bulk density. The non-capillary pores are reduced with a corresponding increase in capillary pores. The changes in pore-size distribution with puddling strongly influence other soil physical processes, such as gaseous exchange, water retention and transmission and evaporation losses from soils. Water retention in puddled soils at lower water potentials (more negative) always exceeds that in non-puddled soils depending on soil texture and initial aggregation. Consequently, the available water capacity of puddled soils is usually higher than of non-puddled soils.

Puddling affects the thermal properties of the soil by changing the bulk density, moisture content and percolation rates. The thermal conductivity and volumetric heat capacity of a soil increase with bulk density and moisture content, because these properties are much higher for soil particles and water than those of air. Thermal properties are influenced more by moisture than by bulk density. Higher percolation rates may increase or decrease soil temperature depending on irrigation water temperature and solar radiation received. In general, puddling of tropical soils decreases soil temperature at least in 0-15 cm soil layer, where more than 80% of the rice roots are concentrated.

The long-term physical effect of puddling is the formation of 5-10 cm thick subsurface (10-40 cm) hardpans below the puddled layer. It may form within as little as 3 years, or as many as 200 years in polder lands of Japan, depending on soil type, climate, hydrology and frequency of puddling. These layers often form as a side effect of the use of heavy machinery and from human and animal pressure during tillage, transplanting, weeding, etc. Traffic pans are common in fine loamy soils. Very sandy and clayey soils often perform similarly.

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Biographical Sketch

Surinder S Kukal, a Ph D in Soils is Professor of Soil Conservation at Punjab Agricultural University, Ludhiana, teaching at undergraduate and post-graduate levels in the field of Soil Physics, Soil Conservation and Water Management. He has been guiding post-graduate research students in the field of Soil Conservation and Soil Physics. Prof Kukal has been involved in research on water management in rice and wheat in the Indo-Gangetic Plains and behaviour and patterns of gully erosion in the Lower Himalayas. A visiting scientist to CSIRO, Land and Water, Australia, he has authored more than 160 research publications. He has served as Editor-in-Chief of Indian Journal of Ecology and is currently Editor of World Association of Soil and Water Conservation.