MODERN CONCEPTS OF AGRICULTURE

Conservation Tillage

Dr. A.R. Sharma
Principal Scientist
Division of Agronomy
Indian Agricultural Research Institute
New Delhi-110012

Dr. U.K. Behera
Senior Scientist
Division of Agronomy
Indian Agricultural Research Institute
New Delhi-110012

(7-01- 2008)

CONTENTS

Historical Aspects of Tillage

Tillage is the oldest art associated with development of agriculture. Primitive man used to disturb the soil for placing seeds. Jethro Tull (1674-1741), an Englishman, is considered as father of tillage. He introduced ‘horse-hoeing husbandry’ in which crops are planted in rows and ‘horse-hoeing’ is done in between. He emphasized the need of tillage to improve the productivity of the soil as it causes breaking of large-sized soil particles into finer ones. He held the philosophy that deeper the tillage, better is the crop growth. He believed that the soil should be finely pulverized to provide proper pabulum for the growing plants. According to him, the soil particles are actually ingested through openings in the plant roots. Tull considered tillage as a substitute for manure, and proposed a theory that plants absorb minute particles of soils. Though his theory is not correct, tillage operations are carried out to prepare a fine seed-bed for sowing crops.

Tillage operations in various forms have been practiced from the very inception of growing crop plants. To prepare a virgin or fallow land and use it for growing crops, tillage in any form is an indispensable practice even today. Tillage is one of the forms of management practices of soil, water, nutrient, crop and pests. Tillage helps to replace natural vegetation with useful crops and is necessary to provide a favourable edaphic environment for the establishment, growth and yield of crop plants.

After harvest of the crop, soil becomes hard and compact. Beating action of rain drops, irrigation and subsequent drying, movement of inter-cultivation implements and labour cause soil compaction. Further, there are weeds and stubbles after the harvest of the crop. Seeds need loose, friable soil with sufficient air and water for good germination. The field should be free from weeds to avoid competition with the crop that follows. It should also be free from stubbles to facilitate easy and smooth movement of sowing implements.

Tillage involves transference of force from one body or system to another. Force requires some energy or power. Therefore, tillage operations require power that may come from manual, animal, mechanical and other sources as well as tools, implements and equipment as aids to disturb and disrupt the normal state of the soil to a desirable extent. Tilling the soil is the most difficult and time consuming operation in field crop production. Tillage is hard work and energy-expensive. About 30% of the total cost of cultivation is for tillage operations.

Tillage was considered as an 'art' but in the recent years, research evidences have focused tillage as a ‘science’. Since people began to cultivate crops, they did only what tillage was necessary to plant and to control weeds. From time immemorial, various methods of ploughing have been tried by trial and error, based on the labour availability and economic status of the farmer. As cultivation became more sophisticated, tillage operations and equipments were altered and specialized. Powered machinery and cheap fossil fuel brought in the age of maximum tillage, loose fine seed-bed, weedless trashless fields and extensive mixing of soils with lime, plant residues and sometimes fertilizers. The cultural practices have also undergone quite a lot of changes due to the shortage and increased cost of labour and availability of machinery. A lot of cultural operations are needed to prepare the virgin soil into a good seed-bed. Tillage operations and methods of land preparation vary from place to place and even in the same place, depending upon the climate and crops cultivated.

Tilth

Tilth is defined as the physical condition of the soil brought out by tillage that influences crop emergence, establishment, growth and development. It is the loose, friable, airy, powdery, granular and crumbly structure of the soil with optimum moisture content suitable for working and germination of sprouting seeds and propagules. It indicates two properties of soil *viz.* the size distribution of aggregates and mellowness or friability of soil. The relative proportion of different sized soil aggregates is known as size distribution of soil aggregates. Higher percent of larger aggregates (>5 mm in diameter) is necessary for irrigated agriculture, while higher percent of smaller aggregates (1-2 mm in diameter) is desirable for dryland agriculture. The size distribution of aggregates depends on soil type, soil moisture content (at which ploughing is done) and subsequent cultivation. Mellowness or friability is that property of soil by which the clods when dry become more crumbly. A soil with good tilth is quite porous and has free drainage up to water table. The capillary and non-capillary pores should be in equal proportion so that sufficient amount of water is retained in the soil as well as free air.

Tilth depends not only on granulation and its stability but also on other factors such as, moisture content, degree of aeration, rate of water infiltration, drainage and capillary water capacity. Soil tilth is not static but changes rapidly and markedly. For instance, a slight change in the moisture content may alter the workability of the soil. Mechanical forces may alter the structure, total porosity and bulk density of the tilled layer. Administering tillage in improper soil conditions may seriously impair tilth directly or set the stage for later deterioration. However, soils with a mellow tilth can be cultivated at both higher and lower moisture contents than soils with a raw tilth.

In spite of its dynamic nature, measurements of tilth can be made by aggregate analysis, determination of porosity, density, water-holding capacity, saturated hydraulic conductivity and force of penetration to study the suitability of soil management practices and crop cultivation. From the field point of view, the following properties of a good tilth are of importance:

- There should be a continuous system of wide pores from the soil surface down to the water table or the land drains through which surplus water can move rapidly and which will allow rapid diffusion of CO_2 from the sub-soil to the atmosphere.
- These pores should be sufficiently stable to last several years before being filled-up.
- There should be volumes in between these pores that hold as much water as possible against drainage, but which are readily accessible to the plant roots.
- The surface soil should be crumbly, and the crumbs should be large enough not to blow away, but small enough to allow good germination of the seed, and sufficiently unsticky when moist to keep their individuality when tractors or implements move over them.

Objectives of Tillage

There are several objectives of tillage, of which, the most important ones are: suitable seed-bed preparation, weed control, and soil and water conservation. The other objectives include improvement of soil structure, soil permeability, soil aeration, root penetration, destruction of pests, soil inversion etc. Good seed-bed is necessary for early seed germination and initial good stand of the crop. The seed-bed should be fine for small-seeded crops and moderate for bold-seeded crops. Intimate contact between the soil particles is necessary to facilitate movement of water for quicker germination.

Weed control is an important object of tillage. Tillage reduces or eliminates weed competition for moisture, nutrients, light, and CO2 in the micro-environment, and thereby improves crop growth. Tillage may induce the germination of weed seeds which can then be destroyed by subsequent tillage or chemical treatment to impoverish the population of weed seeds in the soil. Tillage may also prevent weed seed germination by the burial effects on seeds. Tillage physically alters the weed relationship with the soil. It may destroy weed seedlings by uprooting, smothering, desiccating, decomposing or merely weakening weed plants through dislodging, damaging, disorienting, depleting food reserves, root pruning or other injury. Tillage may bring out roots, stolons and other such fleshy and regenerative organs of weeds to the surface where they dry out. Until herbicides came on the scene, hand pulling and tillage were the only means to destroy weeds, which consumed the major share of the labour spent for producing the crop. The availability of herbicides has changed the whole gamut of tillage practices.

Proper tillage results in soil and moisture conservation through higher infiltration, reduced runoff and increased depth of soil for moisture storage. When the compact soil is ploughed, it becomes fluffy and can hold more amount of water. Removal of hard pans increases the soil depth for water absorption. Surface roughness and furrow dikes slow down the velocity of runoff and provide more opportune time for infiltration of water.

Summer deep ploughing improves soil structure due to alternate drying and cooling. Frequent harrowings result in destruction of soil structure. Tillage at improper moisture also damages soil structure and leads to development of hard pans. Soil permeability is increased by breaking the compacted layers. Tillage improves soil aeration which helps in multiplication of micro-organisms. Organic matter decomposition is hastened resulting in higher nutrient availability. Increased aeration also helps in degradation of herbicide and pesticide residues and harmful allelopathic chemicals exuded by roots of previous crop or weeds.

Roots occupy only about a tenth of the soil mass. Breaking of hard pans and compacted layers increase depth of root penetration. In addition, root growth is unhindered when the soil mechanical resistance or soil strength is less. Roots proliferate profusely in loose soil. Increase in soil mechanical resistance decreases root growth of barley, wheat, pea, rapeseed, linseed, safflower, sunflower etc. The seminal and lateral root growth of these crops is reduced due to high soil mechanical resistance of unploughed compact soil. Thus, loosening the soil is necessary for better growth.

Roots grow into soil pores or root channels of the decomposed roots of the previous crop(s). Where such pores or channels do not exist, the growing root makes its own path by displacing the soil particles. Therefore, the purpose of tillage is to create pores larger in size than the root tip or to facilitate the displacement of soil particles by the growing root. Dense layers in the sub-soil, which develop high soil strength on drying, restrict root growth. Loosening of such layers by sub-soiling or chiseling is reported to enhance root extension into deeper soil layers. Apart from mechanical impedance, root growth is also sensitive to soil wetness status, aeration, and variations in soil temperature.

Tillage favours break-up of clods, incorporates the organic matter into the soil and kills the weeds to create more favourable seed-bed conditions. Physical condition of the soil significantly influences its moisture retention, root spread and penetration. It also influences the supply and uptake *of* nutrients by the crop plants. Soil aggregation depends on the clay and the humus contents in the soil. Soil porosity considerably influences root penetration.

Exchange of CO_2 from the soil and oxygen from the atmosphere is essential for normal root development and microbial activity. Tillage ensures good soil aeration on heavy clay soils. The critical level of oxygen for better root growth is about 1-2%. Due to restricted oxygen supply, the root hair growth is much restricted. High concentration of CO_2 in the soil is toxic to the roots. The critical limit of CO_2 for most species is between 10 to 20%.

Tillage exposes the lower soil to weather and places the surface soil underneath; thus soil inhabiting organisms, predatory animals and birds, pathogenic and parasitical organisms are destroyed by heat, desiccation or by direct injury and the burial effect. Many of the insect-pests remain dormant as pupae in the top layers of the soil. They are exposed to sun's heat or to birds during tillage. It is a common sight during preparatory cultivation that the root grubs are exposed and eaten away by crows and others birds. The stubbles of previous crop which harbour insects are removed following tillage resulting in reduced pest attack in the succeeding crop. Clean cultivation is generally advocated as one of the methods of controlling insects and diseases. Tillage helps to destroy some of the fungi causing plant diseases e.g. scab disease causing organism of Gibbrella.

Crop residues and farmyard manure are incorporated into the soil by soil inversion action of tillage. Decomposition of these materials is quicker when incorporated into the soil. Herbicides and fertilisers are also mixed and incorporated into the soil to reduce volatilization losses.

Disadvantages of Tillage

Though tillage is an indispensable operation in crop production, it has some drawbacks. As field soil is a habitat for several organisms including crop plants, it is exposed to weather. Therefore, soil environment is greatly modified by the ever-dynamic atmospheric environment. In general, a very short time is available to prepare all the fields at their optimum conditions for seasonal cropping. If the fields are not prepared within the required period, the soil may either lose or gain moisture, and become unworkable or the sowing season is delayed considerably. This condition is particularly true for rainfed farming or areas under a monsoon climate with poor soil conditions.

In non-plastic or less plastic soils (which when moist cannot be rolled into a long cylinder and even if they can be rolled, they will break on bending e.g. light soils), more than adequate tillage operations cause the soil more droughty. In plastic soils if a tillage operation is scheduled at beyond the optimum moisture conditions, negative results occur. If such soils are ploughed when too wet, the soils get puddled and become practically impervious to air and water and also structureless. On drying, the soils become hard, dense and unworkable until remoistened. On the other hand, if heavy soils are ploughed when too dry, great clods are turned up which are difficult to work into a good seed-bed.

Repeated tillage operations or tillage over longer periods have detrimental effects on surface soil. Tillage hastens the oxidation of organic matter from the soil. Tillage operations with heavy equipment tend to break down the stable soil aggregates and form a hard pan immediately below the tilled layer. All this reduces infiltration and induces runoff, soil erosion and other negative effects.

Frequent tillage pulverizes the soil into dust, breaks down the soil aggregates, and enhances wind and water erosion. Repeated cultivation even under optimum soil moisture conditions impairs the tilth. The soil surface is puddled forming a reduced condition in the root zone due to the beating action of rain drops on powdery structureless conditions. On drying, it forms a layer of crust which causes mechanical resistance to the emergence of crop plants, restricts gaseous exchange and thus impairs crop stand and growth. It also creates more intimate soil-seed contact for weed seeds to germinate since most weed seeds are quite small.

Tillage operations immediately after the harvest of crop plants often incorporate weed seeds in soil. Deep ploughing increases the volume of soil containing weed seeds and other propagules and preserves a source of infestation for a longer time. Tillage helps to spread colonies of different soil-borne pests, pathogens and parasites. Weeds that propagate vegetatively, particularly rhizomatous and stoloniferous perennials, multiply and spread profusely from the fragments of stem and root stocks by the severing, shearing and tearing action of tillage implements. Tillage operations may cause shifting of the weed flora of difficult-to-control species. Tillage has limited effectiveness against weeds within crop rows.

Development of herbicides has made it possible to study the effects of tillage as an agricultural practice independent of weed control. In general, it has been found that tillage is of little benefit, other than for weed control under most soil conditions.

Tractors and heavy equipments are used for land preparation. Hence, there is a possibility of wind and water erosion as the land is left barren after the conventional tillage. There is also soil compaction due to repeated usage of heavy equipments and possibility of development of a dense zone (plough pan) below the plough layer.

Negative effects stemming from badly-chosen tillage practices are presented in Figure 1.

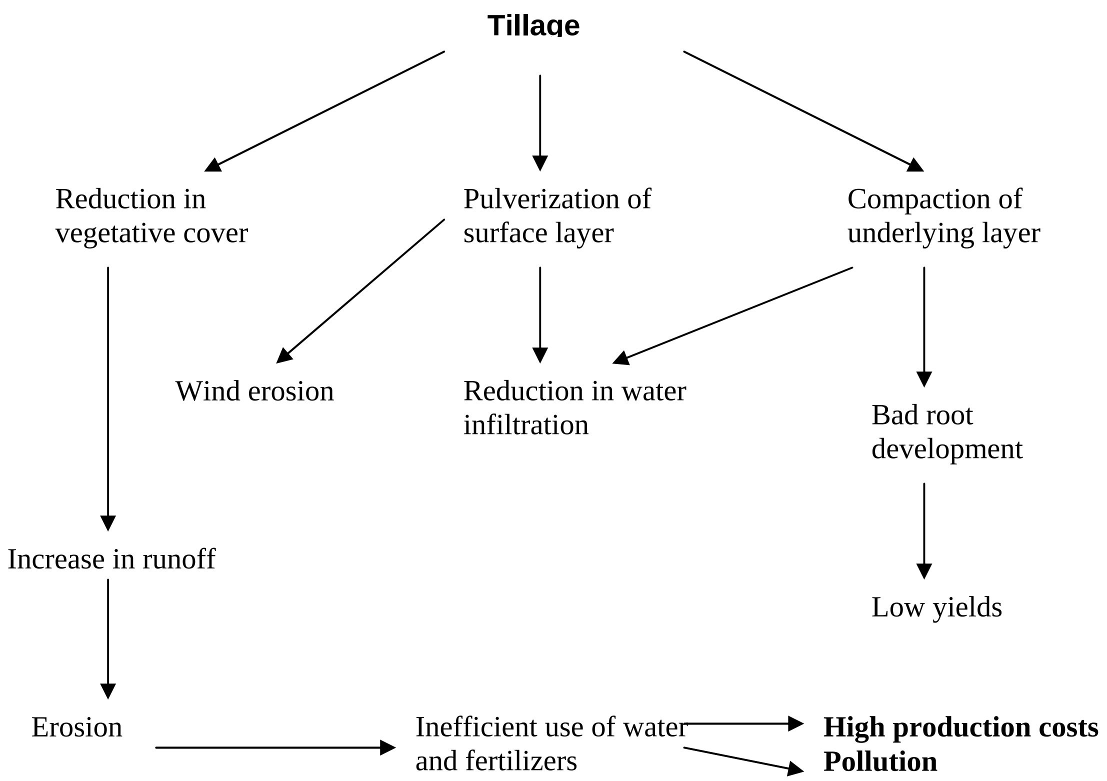

Figure 1: The effects of badly chosen tillage practices
(Source: Proceedings of an International Workshop on Increasing Wheat Yield Potential ,2006)

Tillage Effects on Edaphic Environment

Tillage has considerable influence on soil physical properties like bulk density, roughness, soil water content and hydraulic conductivity (Table 1). Further, it also affects pore space, structure, and soil colour. These effects of tillage last for about a month. Tillage practices have, therefore, greatest effect on seed germination, seedling emergence and stand establishment.

Table 1: Soil characteristics before and after Tillage

Soil characteristics	Clay loam		Sandy soils	
	Before	After	Before	After
Hydraulic conductivity (cm/hour)	17.64	22.23	1.91	6.08
Random roughness (cm)	1.15	1.75	1.72	2.77
Soil water at saturation (%)	32.00	38.00	40.00	61.00
Bulk density (g/cm^3)	1.42	1.11	1.24	0.80

Bulk Density, Porosity and Mechanical Impedance: Tillage is often referred to as a physical modification of soil properties. It either loosens or compacts the soil, thus changing particle-to-particle contact and porosity of soil. One property that is always changed by tillage is the bulk density. A decrease in bulk density affects an increase in total porosity and large pores. Compaction has a reverse effect. A change in porosity and particle-to-particle contact affects all the (physical) state variables of soil that in turn modify the edaphic parameters (Gajri and Majumdar, 2002).

Mechanical strength of soil is a function of bulk density and water content; therefore, tillage affects soil strength as well. Root growth and seedling emergence are better related to soil strength - the resultant of bulk density and soil water content rather than soil bulk density *per se*. When the soil is loosened, the soil volume increases without any effect on weight. Therefore, bulk density of tilled soil is less than the untilled soil.

Change in porosity directly affects water and heat transmission characteristics of soil. It also has a bearing on the creation of the water-free porosity that affects soil aeration. Thus, all physical parameters affecting seedling emergence and root growth, that is, soil wetness, aeration, temperature, and penetration resistance, are affected by tillage.

Soils are made up of particles of different sizes. Air-filled spaces between these particles constitute pore space. When a field is ploughed, the soil particles are loosely stacked in a random manner and pore space is increased. When the soil is in good tilth, the capillary and non-capillary pores would be roughly equal. This facilitates free movement of air and moisture in the soil. The pore system in unploughed plots is often more continuous because of earthworm activity, old root channels, and vertical cracks between pads, especially in clayey soils. The number and geometry of water-conducting pores determine the tillage and traffic effects on soil infiltrability.

Soils with crumbly and granular clods are considered as soils with good structure. When the soil is subjected to tillage at optimum moisture, crumb structure is developed so that loss of soil by erosion is greatly reduced. Rain water is held in the large pores, between the aggregates and also in the micro-pores of the aggregates. It is considered that soil aggregates of 1 to 5 mm in size are favourable for growth of plants. Smaller aggregates may clog the soil pores and larger ones may have large pore space between them and affect the development of rootlets of the young seedlings.

Tillage operations are done to loosen the soil and facilitate root penetration for better anchorage and exploitation of soil nutrients and water by the plant. In a study at Karnal, it was found that bulk density was the highest when no tillage operation was performed to prepare the soil and direct seeding was done using no-till drill, followed by conventional tillage, rotary tillage and bed planting (Table 2). The changes in bulk density were mainly confined to top 10-15 cm layer. The soil strength measured at 70% field capacity for the top 10 cm depth using probing ring cone penetrometer and presented as cone index increased with bulk density, and the minimum value was recorded for bed planting and maximum for zero tillage.

Table 2: Soil bulk density and cone index under various Tillage Options

Tillage options	Soil depth, cm				Mean bulk density (kg/m^3)	Cone index (kg/cm^2)
	0-5	5-10	10-15	15-20		
Zero tillage	1.62	1.62	1.71	1.80	1.69	10.81
Rotary tillage	1.45	1.56	1.69	1.75	1.61	7.40
Bed planting	1.39	1.45	1.69	1.78	1.58	3.79
Conventional tillage	1.51	1.56	1.65	1.78	1.63	8.49

(Source: Bulletin - Directorate of Wheat Research, Karnal , 2002)

Soil wetness: Tillage affects the soil water status and also the capacity of the crop to utilize water. It alters surface and sub-surface soil conditions that govern infiltration, runoff, and evaporation of water, weed growth, crop establishment, and root growth of the crop. The rough soil surface and depressions caused by tillage determine the amount of water on sloping lands before the runoff begins. However, the effectiveness of tillage-induced roughness depends on the stability of surface aggregates, and the intensity and amount of precipitation. Adverse effects of roughness include rapid loss of small rain showers through evaporation from a cloddy surface.

Soil stirring by tillage accelerates the initial evaporation loss from the tilled soil and, thus, the formation of a dry surface layer. The loose dry layer created by tillage reduces unsaturated water flow to the surface because of decreased hydraulic conductivity of soil, thus decreasing the loss of deeply stored soil water. Tillage suppresses evaporation loss of water by insulating and cooling the soil surface, reflecting solar energy, decreasing wind speed at or near the soil surface, and providing a barrier against water vapour movement. Tillage also influences the advance of the wetting front of specified water content into the soil.

Soil Aeration: Loosening of soil through tillage increases the relative proportion of larger pores in the tilled layer, which will drain out rapidly and restore adequate water-free porosity soon after heavy rain and/or irrigation. In fact, the effect of tillage on aeration of soil is directly linked with its effect on infiltration rates. The faster the rate, the shorter the time the surface remains sealed to air exchange. Sometimes, tillage may prolong wet conditions by breaking pore continuity and by creating a firm layer below the loosened layer. Puddling of soil surface clearly reduces gas diffusion. Usually, soil aeration is not a serious problem in the seed zone because in addition to drainage, air porosity is also restored due to surface drying by evaporation.

Soil Temperature: Tillage creates soil temperature optimum for seed germination and seedling establishment. Tillage loosens the soil surface, resulting in decrease of thermal conductivity and heat capacity. Changes in surface roughness and plant residue cover affected by tillage influence the thermal regime of soil. Change in bulk density alters the specific heat capacity of the soil, primarily by changing the relative amounts of mineral matter and water per unit volume of soil. Reduced particle-to-particle contact and volume water content of soil accompanying decreased bulk density lowers the thermal conductivity of the soil. Also, tillage systems that leave most of the residue on the soil surface result in lower soil temperatures.

Biological and chemical properties: Tillage-induced changes in physical environment of soil influence its biological and chemical properties too. Stirring of soil and redistribution of residue at or into the soil influence soil environment by modifying temperature, moisture, and aeration status of soil, which in turn affect the soil chemical and biological properties. Tillage effects on biological and chemical properties of soil depend on climate, soil type, quantity of residue produced, previous management history, time of year, and time since the tillage system was initiated.

Ploughing and secondary tillage stimulates microbiological activity and degradation of organic matter. However, conservation tillage systems (zero tillage with residue retention on surface) not only reduce soil disturbance and mineralization but also allow more intensive cropping by increasing water availability and storage of carbon. Continuous conservation tillage increases total organic carbon and the N pool in surface soil. The reasons for this phenomenon are immobilization of N and less intensive mineralization of plant residues.

The soil N cycle is directly affected by microbial activity. Ploughing of soil often stimulates N mineralization. Higher water contents in unploughed soils result in lower nitrifiers and higher denitrifiers than in ploughed fields. Nitrogen fertilizer is immobilized more rapidly in conservation tillage systems than in conventional tillage systems. However, in semi-arid sub-tropical climates in summer, lowering of surface temperature and improved moisture regime under paddy straw mulch resulted in 3 to 7 ppm more $N0_3$-N in the surface 15 cm layer compared to no mulch treatment on a sandy loam soil (Prihar et al., 2000). Tillage system also influences leaching of N, depending on soil type, climate, rate, and time of N mineralization and rate of applied N.

Tillage-induced changes in organic matter and clay content caused by mixing and inversion of soil are likely to influence the soil's cation exchange capacity. Cation exchange capacity of surface soil layers is generally lower with conventional than with conservation tillage systems. Organic matter is mainly responsible for the dark brown to dark grey colour of the soil. Tillage increases oxidation and decomposition, resulting in fading of colour.

Tillage Operations

Seed germination and seedling growth are greatly affected by the fineness of the soil clods. The degree of soil pulverization differs with the type of machine used, tilling method and operating condition of machine. Pulverization also differs with soil conditions such as water content or particle distribution and ground cover like straw or grass. Some soils are compact and do not allow the entry of plant roots into the soil. Soil furnishes anchorage for plant roots. Soil must be sufficiently open so that roots can penetrate easily. The soil is being constantly and uniformly moved in a forward and upward direction as the plough advances and hence pulverization takes place.

Time of Ploughing: Early ploughing has a distinct advantage over late ploughing because it gives more opportunity to kill weeds. Early ploughing may help in getting the soil granulated at the time of sowing. In intensive cultivation, the field is to be prepared without any time lapse for raising the next crop. Ploughing is to be done immediately after the harvest of the crops like sugarcane and crops that leave heavy stubbles or sod. Ploughing is also needed after the harvest of crops which have a thick stand.

Ploughing operations should be carried out at appropriate soil moisture conditions to improve the physical condition of the soil. Ploughing dry soils with a hard consistency may lead to form numerous clods. There is an optimum moisture range for each soil for the most effective ploughing. This moisture range is called as 'friable consistence'. It is important to plough the field within the moisture range of friable consistence. This will help in achieving maximum granulation with minimum energy input.

The correct time for ploughing depends on soil moisture. When the soil is dry, it is difficult to open the soil, more energy is used and large-sized clods are formed. When the soil is ploughed under wet conditions, the soil sticks to the plough, the soil below the plough sole becomes compacted and on drying becomes a hard pan, soil structure is destroyed and the clods on drying become very hard. The optimum range of soil moisture for effective ploughing is 25-50% depletion of available soil moisture. Light soils can be ploughed in a wide range of soil moisture conditions, while the range is narrow for heavy soils.

Depth and intensity of Ploughing: The purpose of cultivation is to control weeds and conserve soil moisture. Deep ploughing gives better response in fields infested with weeds. This is also practised to incorporate the residues, particularly in sandy soils. Incorporation of residues in the deep layer having fine texture may improve the chemical properties of the soil. Under dryland conditions, deep ploughing improves soil moisture content. However, yield advantages due to deep ploughing depend on rainfall and type of crop. Normally, yield advantage is reported during normal and above normal rainfall years.

Depth of ploughing mainly depends on the effective root zone depth of the crops. Generally, crops with tap root system require greater depth of ploughing, while fibrous, shallow-rooted crops require shallow ploughing. It is important to practice deep ploughing for long duration, deep-rooted crops. Root crops generally respond better to deep tillage than shallow-rooted crops like cereals. Potato generally responds better to deep tillage, particularly in clayey and loamy soils. Sugarbeet also shows positive response to deep ploughing. In black cotton soil, deep ploughing gives higher yield in flue-cured cigarette tobacco. Deep tillage is also practised for crops like sugarcane. Small grain crops such as millets, sesame and flax do as well with shallow as with deep ploughing.

Deep cultivation is important to break the compact layers. Compaction occurs due to use of tractors in wet soil condition. Chiseling up to 75 cm helps to break the sub-soil compaction. Deep ploughing helps to break the soil compaction and increase water absorption and root penetration, resulting in improved plant growth.

The number of ploughings necessary to obtain a good tilth depends on soil type, weed problem and crop residues on the soil surface. In heavy soils, more number of ploughings is necessary, the range being 3 to 5 ploughings. Light soils require 1 to 3 ploughings to obtain proper tilth of the soil. When weed growth and plant residues are higher, more number of ploughings is necessary.

Types of Tillage

Tillage operations are grouped into two types based on the time (with reference to crop) at which they are carried out. They are: preparatory cultivation which is carried out before sowing the crop, and after cultivation that is practiced after sowing the crop.

1. Preparatory Cultivation: Tillage operations that are carried out from the time of harvest of a crop to the sowing of the next crop are known as preparatory cultivation or off-season tillage. These operations are carried out in any cultivable land to prepare seed-bed for sowing of crops. Preparatory tillage or off-season tillage operations include post-harvest tillage and summer ploughing. Soil is tilled immediately after the harvest of the crop under adequate soil moisture. This is mostly practiced after the harvest of the long-duration crops like sugarcane ratoon, sod or turf crop. This operation helps in controlling weeds and the soils are receptive to rain water. Tillage operations done during the summer using the rainfall is known as summer ploughing. This helps in preparing the main field well in advance.

Preparatory tillage is divided into primary and secondary tillage operations.

(i)Primary Tillage*:* In preparatory tillage, the first cutting and inverting of the soil that is done after the harvest of the crop (turn around period) or untilled fallow or to bring virgin or new land under cultivation (as it is in shifting cultivation) is known as primary tillage. The primary tillage may be done once or twice a year in normal and settled agriculture or once in four to five years in dryland agriculture.

Ploughing is initially done to open the compact or hard soil. During the primary tillage, the soil is inverted, weeds are uprooted and stubbles incorporated into the soil. The depth of the tillage varies from 10 to 30 cm. During this operation, soil is cut, lifted, shattered, twisted, inverted and sheared for further ploughing. The implements used for this purpose are called primary tillage implements. These implements may be bullock or tractor drawn. Bullock-drawn implements may be indigenous plough and mould board plough. The tractor-drawn implements include mould board plough, disc plough, sub-soil plough and chisel plough.

Primary tillage may be post-harvest tillage, summer tillage, deep tillage, winter tillage and fallow tillage.

(a)Post-harvest Tillage*:* Immediately after the harvest of the crop from the field, the soil is tilled if it is in a favourable condition for such an operation. Ploughing becomes indispensable after a wetland crop (rice), long-duration crop (sugarcane), sod or turf crop, green mulch crop or green manure crop. If the preceding crop is grown in aerobic soil conditions, harrowing serves the purpose.

Removing stiff stubble, turning under trashes and weeds, improving the physical condition of the soil, mixing the stratified layers of soil constituents, breaking up clay pans and other soil barriers and making the soil receptive to rain water are the major objectives of such tillage operations. Post-harvest tillage prevents seed setting of late maturing annuals and eliminates the seedlings of annuals and biennials that come up at the later stage of crop growth. Shallow post-harvest tillage which causes minimum disturbance of crop plant residues, may place newly-matured weed seeds in a more favourable environment for over-ripening that has variable effects on survival. It also provides a better environment for the germination of volunteer crop plants from shattered crop seeds and thus exhausts the population of such seeds which may cause an admixture in the forthcoming crop seasons.

(b) Summer Tillage*:* In tropical zones, the warm humid period is preceded by hot summers. There may be intermittent rains with variable intensity which induce weed seed germination even though conditions are not favourable for raising any crop. Tillage operations done during this period are known as summer tillage. This is done mostly as pre-preparatory tillage for main season crops. It is generally of the soil stirring type to destroy weeds and other soil-borne pests, pathogens and parasites by baking under the sun, receiving and retaining rainwater and checking water erosion. Summer tillage affects soil aggregates and soil organic matter and induces wind erosion.

(c) Deep Tillage*:* One cm of surface soil over one ha of land weighs about 50 tonnes. Therefore, to plough deeper, enormous amount of energy is required. Deep ploughing turns out large-sized clods, which are baked by the hot sun when it is done in summer. These clods crumble due to alternate heating and cooling and due to occasional summer showers. This process of gradual disintegration of clods improves soil structure. The rhizomes and tubers of perennial weeds viz. *Cyhodon dactylon* and *Cyperus rotundus* die due to exposure to hot sun. Summer deep ploughing kills pests due to exposure of pupae to hot sun.

Deep tillage also improves soil moisture content. However, the advantage of deep tillage in dry farming condition depends on rainfall pattern and crop. In a normal rainfall year, the yield advantage can be obtained for both short-duration and long-duration crops, while the advantage in above normal rainfall years is restricted to long-duration crops only. There is no yield advantage if the rainfall is below normal. The residual effect of deep tillage is marginal. Therefore, it is advisable to go for deep ploughing only for long-duration, deep-rooted crops.

(d)Winter Tillage: In temperate zones or in areas with severe winters that are unfit for raising crops or in fields where cropping is not possible during winter months for various reasons, (e.g. lacking irrigation facilities) but the soil is in good condition for tillage, ploughing and harrowing are practised. In lowland areas or in areas where the water table is high and drainage is impeded during the post-monsoon period but the soil moisture is in the optimum condition for tillage during the cool dry period, winter tillage is practiced. This is mostly as pre-preparatory tillage for raising spring-planted crops. It is practiced mainly to destroy weeds, improve the physical condition of the soil and incorporate crop residues. In some areas autumn ploughing is practiced after harvesting short duration *kharif* rice.

(e)Fallow Tillage: Fallow refers to the leaving of arable land uncropped for a season or seasons for various reasons which may be intentional or need-based or due to unfavourable weather and/or soil conditions. Tilled fallow represents an extreme condition of soil disturbance in that the soil is tilled frequently to eliminate all vegetation. Intentionally leaving the land fallow is done mostly for the eradication of pernicious, problematic, poisonous, perennial weeds, for exhausting the population reserve of weed and volunteer crop plant seeds, the destruction of soil-borne ubiquitous pests, pathogens and parasites of monophagous in particular and polyphagous in general or for the improvement of edaphic conditions of the field by changing the agro-ecological situation.

Regarding the control of perennial weeds, repeatedly tilled fallow continues to exhaust food reserves in the roots or underground parts particularly when they are not in a dormant state. Any serious lapse in the tillage sequence permits storage of food reserves and prolong the time required for eradication. The beginning of fallow tillage should be when food reserves in the underground portions of the weed plants are at the lowest level.

If the soil moisture is inadequate during the season, the survival of annual weed seeds or disease spores in a dormant condition is enhanced under tilled fallow system, and tillage intended to promote their germination and destruction during fallow tillage is futile and wasteful of soil moisture. Soils dry rapidly as the depth of tillage increases; the shallow and stirring type of tillage is less wasteful of rainfall than deeper tillage. Fallow tilled soil is prone to be eroded both by wind and water, degraded and depleted.

(ii)Secondary Tillage: Tillage operations that are carried out after the primary tillage are called secondary tillage operations. These operations are done to bring a good soil tilth. In this, soil is not inverted but instead is stirred and conditioned by breaking clods and crusts, uprooting and moving weeds, stubble, and root stocks, incorporating manures and fertilizers, closing cracks and crevices that form on drying; and accelerate drying of deeper soil layers, leveling, preparing ridges, furrows, and irrigation and drainage channels in the fields, conserving moisture, increasing infiltration, and aeration and checking erosion. Post-ploughing but pre-seeding tillage operations with their stirring effect on the soil destroy weed seedlings and prevent weed-seed germination.

Secondary tillage includes cultivating, harrowing, pulverizing, grazing, raking, hoeing, leveling and ridging. Harrowing is done to a shallow depth to crush the clods and to uproot the remaining weeds and stubbles. Planking is done to crush the hard clods to smoothen the soil surface and to compact the soil lightly. The field is made ready for sowing after ploughing by harrowing and planking. Generally, sowing operations are also included in secondary tillage. Various types of implements are used for this operation e.g. cultivators, harrows, clod crushers and leveling implements.

(iii). Seed-bed preparation, layout and Sowing: A good seed-bed preparation enables the seed to come in close contact with moist soil and to begin its growth under favourable conditions. Weeds are removed, which otherwise compete with the crop and limit its growth. Seed-bed preparation needs adequate care so as to provide early seed germination and better crop stand. It varies with the crops to be grown, soil type, prevailing climate and type of farming. The fineness of the seed-bed is determined by the seed size. Small-seeded crops need a finer seed-bed than the large-seeded crops. It is also important to make the fine seed-bed fairly firm. Small-seeded crops like finger millet, sesame and lucerne require a fine seed-bed. However, crops like sorghum do well in moderately compact, coarse seed-bed. Maize, chickpea and cotton require a coarsely prepared soil.

Coarse textured soils like sandy soils and red soils can be easily brought to powdery condition, with the receipt of rainfall, However, heavy clay soils i.e. black cotton soils are to be ploughed and left in cloddy condition to facilitate the rains being retained on the surface. If such soils are repeatedly ploughed and kept in powdery condition for a long period before sowing, they get caked when dried after a rain. Then the soil is unable to absorb more water and there is loss of rain water due to runoff.

After the seed-bed preparation, the field is laid out properly for irrigation and sowing or planting seedlings. These operations are crop-specific. For most of the crops like wheat, soybean, pearl millet, groundnut, castor etc., flat leveled seed-bed is prepared. That is, after the secondary tillage, these crops are sown without any land treatments. However, growing crops during rainy season in deep black soils is a problem due to ill-drained conditions and as tillage is not possible during the rainy season, broad-bed and furrows are, therefore, formed before the onset of monsoon and dry sowing is resorted to. For some crops like maize and vegetables, the field has to be laid out into ridges and furrows. Sugarcane is also planted in the furrows or trenches. Crops like tobacco, tomato, chillies are planted with equal inter- and intra-row spacing so as to facilitate two-way inter-cultivation.

After seed-bed preparation, sowing is done with seed drills. These seeds are covered by running blade harrow to a shallow depth followed by planking so as to level and impart necessary compaction. Sowing is also done by dropping seeds behind the country plough.

2. After Cultivation: Tillage operations that are carried out in the standing crop are called after cultivation. This is also known as inter-cultivation, inter-tillage, on-season tillage or post-seeding/planting cultivation. It includes cultivating, harrowing, hoeing, weeding, drilling or side dressing of fertilizers, earthing-up, ridging and furrowing. The objective is to control weeds and to have dust mulch on the soil surface to reduce evaporation losses. Large area can be easily weeded with the use of intercultural implements. The intercultural operations decrease the bulk density of the soil and increase the total porosity. Loosening the surface soil due to inter-cultivation enables to maintain high porosity at the soil surface. There is rapid increase in the initial rate of infiltration. The runoff loss is reduced and there is rapid intake of water in the beginning of the rainy season. This operation provides aeration in the root zone. Depth of intercultural operation depends on the condition and the type of crop. Shallow or deep cultivation may be advantageous for certain specific cases. Intercultural operations using cultivators are normally followed for wide-spaced crops like cotton, particularly under dry land conditions.

Earthing-up is an operation carried out with country plough or ridge plough so as to form ridges at the base of the crop. It is done either to provide extra support against lodging as in sugarcane or to provide more soil volume for better growth of tubers as in potato or to facilitate irrigation as in vegetables. Inter-cultivation is working blade harrows, rotary hoes etc. in between the crop rows so as to control weeds. Inter-cultivation may also serve as moisture conservation measure by closing deep cracks in black soils.

Inter-tillage is shallower in nature and allows the crop to emerge, keeps the field free from weeds for a significant period of time by killing germinated but pre-emerged or emerging weeds. Post-planting tillage which provides the minimum disturbance to crop plants in rows is more advantageous to destroy weeds that come out from different depths of the soil and have different root systems. It is advantageous to the thinning of extra plants.

Inter-tillage helps to incorporate top-dressed manures and fertilizers, to earth-up and to prune roots. In wetland direct-seeded paddies, it induces puddling and bueshening of rice plants by inducing tillering.

3. Special Purpose Tillage: Tillage operations intended to serve special purposes are said to be special purpose tillage. They may be sub-soiling, leveling, blind tillage, clean tillage, mulch tillage, contour tillage, wet tillage etc.

(i) Sub-soiling: Hard pans may be present in the soil which restrict root growth of crops. These may be silt pans, iron or aluminium pans, clay pans or man-made pans. Man-made pans are tillage pans induced by repeated tillage at the same depth. These are present in most of the Indian soils. Root growth of crops is confined to top few cm of soil where deep penetration of roots is inhibited by hard pans. For example, cotton roots grow to a depth of 2 m in deep alluvial soil without any pans. When hard pans are present, they grow only up to hard pan, say 15-20 cm. Similarly, vertical root growth of sugarcane is restricted due to hard pans and it is not compensated by horizontal spread.

Sub-soiling is breaking the hard pan without inversion and with less disturbance of top soil. To break the hard pan beneath the plough layer, special tillage operations (chiselling) are performed to reduce compaction so that a greater volume of soil may be obtained for the cultivation of crops, less water may percolate downward to recharge the permanent water-table, and reduce runoff and soil erosion. Roots of crop plants can penetrate deeper to extract moisture from the parched water table. Sub-soiling is essential once in 4-5 years where heavy machinery is used for field operations such as tillage, seeding, harvesting and transporting and where there is a colossal loss of top soil due to carelessness. A narrow cut is made in the top soil while share of the sub-soiler shatters hard pans. Chisel ploughs are also used to break hard pans present even at 60-70 cm. The effect of sub-soiling does not last long.

(ii). Levelling: Arable fields require a uniform distribution of water and plant nutrients for uniform crop growth. This is achieved when the fields are kept fairly leveled. In leveled fields soil erosion is restricted and other management practices become easy and uniform. Erosion, siltation and the wrong operation of tillage implements disturb the leveled condition of fields. Some special tillage operations are needed for shaping, scraping and leveling the fields at regular intervals and as a routine measure for land improvement. This leveling is very important for large fields having many crop-beds, irrigation and drainage channels, or ridges and furrows in different directions. It necessitates the shifting of a layer of soil from one side to the other or *vice versa*. Levelers, scrapers and rollers are used for such operations.

(iii). Blind tillage: Blind tillage refers to the tillage of the soil after seeding or planting the crop, either at the pre-emergence stage of crop plants or while they are in the early stages of growth so that crop plants (e.g. cereals, tuber crops etc.) do not get damaged but broad-leaved weeds and extra plants are uprooted. The germination of weeds should have begun but emergence is not necessary before tillage starts. This tillage is mostly of the soil stirring type and the depth of it is restricted to above the seeding zone of the crop. This is practiced mainly when crop emergence is delayed because of low temperatures or the intrinsic nature of the seeds but soil conditions are favourable for profuse weed infestation. Tillage operations are done blindly assuming that there is no standing crop in the field. Tillage implements should be light, shallow and speedy, and therefore, secondary tillage implements are used for this purpose. Tillage operations may be along or across the crop rows.

(iv). Clean tillage: This refers to the working of the soil of the entire field in such a way that no living plant (weed, crop plant or crop residues) is left undisturbed. It is adopted to destroy weeds and crop plants that may regenerate or volunteer as weeds or may trap insect-pests, pathogens and parasites as direct or alternate hosts or provide feeding, breeding and hiding sites for them by maintaining a green-bridge for subsequent infestation of the succeeding crop or crops. It is practiced between two cropping periods with repeated tillage operations. Such a practice enhances the loss of soil, water and soil structure. Soil turning implements are used for this purpose.

(v). Mulch tillage: It refers to tilling the soil in such a way that the mulch materials, surface clods or crop residues are least disturbed. In areas and seasons with deficient and precarious rainfall and high speed desiccating winds, stubble-mulch tillage is beneficial for various reasons. Tillage implements are light and sub-surface soil stirring types.

(vi). Contour tillage: This refers to the tilling of the land along contours or lines of uniform elevation in order to reduce soil erosion. Tillage operations, such as ploughing, discing, harrowing, cultivating, and others can be done on the contour but it is usually more difficult because there are no permanent markings to follow. It is practised in gently to moderately sloping land (5-12% slope), subject to wind or water erosion or both. Contour tillage in such lands is helpful for prevention of runoff and erosion.

(vii). Wet tillage: This refers to tillage operations done when the soil is in a saturated (anaerobic) condition. Ploughing and harrowing the soft saturated soil are practised for preparing an impervious soil layer to reduce loss of water by percolation from wetland paddies and wet nurseries, for the incorporation of green manure and for weed control and the reclamation of salt-affected soils. In areas and seasons which have a prolonged humid period (in which total precipitation exceeds potential evapo-transpiration) or in lowlying areas with impeded drainage or widespread surface flood irrigation from canals for a prolonged period and beyond the control by the farmer locally (at the field level), wet tillage is the only means of land preparation for seasonal cropping with semi-aquatic crop plants such as rice.

Wet tillage destroys the soil structure, induces stratified layering of soil particles of different densities (mass per unit volume), controls soil erosion by permitting a layer of standing water over it, prolongs the saturated condition of the soil, reduces loss of plant nutrients by leaching, prevents cracking of the soil and thus prevents the tearing of crop roots and their injury converts soil pH towards neutrality, reduces weed emergence and growth, facilitates uniform leveling of the field, hastens transplanting operations easily and smoothly as well as the establishment of seedlings and modifies the agro-ecological system.

4. Puddling – a special tillage operation for transplanted rice: Puddling is an essential practice for transplanted rice culture and is widely practiced although it is high-energy consuming. Puddling is mixing soil with water to render it impervious. The soil structure is destroyed; aggregates lose their identity and soil is converted into a structurally homogenous mass of fine aggregates and textural separates. There are two phases in the puddling operation: increase in the soil moisture content and the mechanical operation. When moisture content increases, there is decrease in cohesion within the aggregates, resulting the clay to swell and become soft. The degree of puddling depends on the cultural practices and the nature of the soil. High clay content facilitates puddling and high organic matter content increases the soil's resistance to puddling. An important difference between the dryland and puddled soil is the presence of oxidized and reduced soil layer in the puddled soil system. Energy requirerment for puddling with tractor is about 300 hp /ha and bullock power may require 100 hp/ha.

Rice growth and yield are higher when grown under submerged conditions. Maintaining standing water throughout the crop period is not possible without puddling. The soil layer with high moisture below the plough sole is compacted due to the weight of the plough. The soil particles separated during puddling settle later. The sand particles reach the bottom, over which silt particles settle and finally clay particles fill the pores, thus making impervious layer over the compacted soil. Puddling is done with several implements depending on the availability of equipment and nature of the land. Soils with bulk density less than 1.0 g/cc are considered as problem soils as puddling with animal-drawn implements is difficult. The feet of the animals sink very deep during puddling. Under such a situation, puddling is done with spades by manual labour. Most of the farmers use wetland plough or worn out dryland plough or mould board plough. Wetland puddler consists of a series of blades attached to a beam at an angle. When it is worked, the soil is churned and puddling operation is completed quickly compared to the country plough. Generally, green manure is applied to rice field which is incorporated by green manure trampler.

Wetland rice thrives best with water standing at the soil surface and low redox potential in the surface soil layers. Puddling of soil aims at creating these conditions. It consists of repeatedly working the soil with ponded water until larger clods in the upper several centimeters of the soil are broken down into small aggregates and individual particles. This process reduces the soil strength of the puddled layer.

(i). Changes in porosity and permeability: Puddling destroys soil aggregates, increases bulk density, decreases the proportion of transmission pores and hydraulic conductivity, and, therefore, decreases percolation rates. Depending on soil texture and aggregate stability, puddling breaks down the initial macrostructure and microstructure, and increases the finer fraction of soil.

Lowering of the percolation rate is generally beneficial for enhancing water and nutrient use efficiencies in rice. However, some percolation is considered essential to leach down the toxins produced by anaerobic decomposition of organic matter, to maintain favourable range of redox potential, to regulate soil temperature, and to improve N use efficiency. Japanese researchers suggest that for a rice yield of more than 6 t/ha, percolation rate must be 10 to 25 mm/day and should never be less than 1 mm/day.

(ii). Changes in water retentivity: At low soil water potentials, puddled soil generally retains more water than unpuddled soil. Also because of reduction in transmission pores, puddled soil releases water more slowly than the unpuddled. Greater retention and slower release of water prolong the period for which the puddled soil remains wet compared with the unpuddled, which may delay the sowing of crops following rice.

(iii). Soil strength: Puddling generally reduces the soil strength in the puddled layer but increases it in the sub-surface layers. Rice roots are very sensitive to soil strength. Rice roots fail to penetrate the soil when penetrometer resistance exceeds 1 MPa. Therefore, the depth of the soft puddled layer controls the rooting depth, nutrient and water uptake, and yield of rice.

(iv). Advantages and limitations of puddling: Puddling reduces the non-capillary pore space and a close packing of soil particles is obtained which, in turn, decreases hydraulic conductivity and free percolation of water. Due to reduction in hydraulic conductivity, drainage from a puddled soil may be 1000 times slower than from a granulated soil. Puddling enables improved weed control and provides congenial soil condition for easy transplanting. Reduced soil condition due to puddling provides the required physical, chemical and biological conditions for the growth of the rice plant. Rice grown on puddled soil may be less affected by drought because of higher moisture retention than in a non-puddled soil. Puddled soil has 2.5% higher efficiency in water use than a non-puddled soil.

Water requirement for land preparation with puddling is high (150 mm). A shift from a wetland puddled soil to dryland soil requires major alteration in the physical condition of the soil. Conversion from puddled to well granulated soil conditions requires that the moisture content falls below the lower limit of plasticity.

(v). Soil compaction: Soil compaction is the simple tillage practice adopted to meet the physical requirements of the soil for rice growth. In this system, the soil is first ploughed and harrowed, fertilized and brought to optimum moisture content. Heavy rollers or tractors with loaded wheels are passed repeatedly over the soil until the desired density is achieved. The soil is then flooded and crop transplanted. Rice seeds can also be drilled directly into the compacted soil with a suitable drill. Such a system of cultivation is especially useful for dry land rice where nutrient and water conservation are important. During compaction, soil particles move to a closer state of contact and there is change in the bulk density. Plant available water in the soil increases since water is retained at high suction. Compaction may alter the composition of soil if pore spaces are reduced sufficiently. Compaction affects the thermal characteristics of the soil and there is increase in thermal conductivity. Soil strength increases with increasing compaction. Soil compaction facilitates mobility of nutrient ions to roots by both diffusion and mass flow.

(vi). Tillage Management for crops following rice: Degraded soil structure in the surface and dense sub-surface layers caused by repeated puddling create serious constraints for the growth of upland crops following rice. These include a short turn-around period between successive crops, increased soil strength and restricted rooting, low infiltration and poor internal drainage, lower charging of the profile, and post-seeding aeration/water stress. These unfavorable soil conditions reduce the yield of crops following rice. The magnitude of yield decline in wheat following wetland rice has been linked to intensity of puddling. High-intensity deeper puddling, though effective in reducing percolation losses of water in coarse-textured soils, is not always advisable for rice-wheat systems, as it is likely to accelerate formation of a plough pan.

Puddling narrows the range of soil moisture for efficient workability. In areas where the fields are sufficiently wet at rice harvest and heavy rains (threatening aeration stress) are not expected during the growing season of wheat, it may be desirable to plant the crop timely without any tillage. In these situations, the major advantage from direct drilling of wheat comes from earlier sowing of the crop. When there is enough time and the soil is well drained, wheat yields are higher with conventional tillage compared to direct drilling on the same date, even in the absence of weeds.

In a study at New Delhi, different types of tillage implements were used for land preparation of wheat in rice-wheat cropping system. Bulk density at sowing was much lower with chiseling along with roto tilling or disc harrowing; although the effects were leveled off at harvest (Table 3). The beneficial effects of reduced bulk density were observed on increased root length and higher productivity. Evidently, these practices required more energy compared with conventional practices.

Table 3: Influence of tillage on soil properties and wheat productivity in rice-wheat system at New Delhi

Treatment	Bulk density (g/cc)		Root length density (cm/cm^3)		Grain yield (t/ha)	Energy requirement (MJ/ha)
	At sowing	At harvest	0-15 cm	15-30 cm		
No tillage	1.48	1.55	2.50	1.99	3.79	785
Chiseling	1.41	1.56	3.71	2.69	3.87	2040
Roto tilling	1.43	1.56	2.75	2.02	3.95	1800
Chiseling + roto tilling	1.30	1.52	3.95	2.76	4.42	3045
Disc harrowing	1.35	1.49	2.99	2.57	4.28	1390
Chiseling + disc harrowing	1.28	1.45	3.69	2.99	4.40	2645

(Source: Indian Journal of Agricultural Sciences, 2000)

Implements and Their Usage

A large number of implements are used for different tillage operations. Based on the operations for which they are designed, the implements are classified into different groups:

1. Implements for Ploughing: In the early stage of civilization, primitive man would have first developed a plough just to stir the soil. Modern ploughs are used to open the soil and pulverize it. Ploughs are also used to incorporate the crop residues and manures. Ploughing is done at varied depth depending on the type of crops grown and the condition of the field. Implements may be animal-drawn or power-operated.

(i). Desi or country plough: The most important tillage implement used all over India is the country plough or *desi* plough. The shape of the plough is more or less similar throughout the country. However, the size varies depending upon the soil type in which the plough is operated. According to the size of the cattle engaged in a particular region, the plough size varies. Most of the *desi* ploughs are light in weight and can be easily carried on the shoulders. In the regions of black cotton soils (vertisols), heavier ploughs are normally used.

(ii). Mould board Plough: The mould board plough is an improved tillage implement over the country plough. This is probably one of the first implements to be introduced from abroad to India. The advantage of using the mould board is that a layer of soil is separated from the underlying sub-soil and is inverted. Thus, any vegetation or manure present on the surface is buried under. A soil layer is brought to the surface, where it is exposed to the action of weathering agents and other implements. As a result, the soil gets pulverized. Heavier mould board ploughs can work even in very hard soils.

(iii). Disc Plough: Disc ploughs have steel discs of 50-90 cm diameter. The discs are made of high carbon steel and have sharp cutting edge. The discs are set at an angle to the direction of travel. Each disc revolves on an axle. The angle of the disc is adjustable. The discs are mounted on a frame which is supported by wheels. Lever arrangements are provided for lifting the disc and clear off the ground. Depth of penetration of the disc can also be changed by using the lever arrangements. While working, the discs rotate, scoop out furrows, invert the furrow slice and pulverize them thoroughly. The disc ploughs are particularly suitable for soils having hard plough pans. It works well in conditions where mould board plough does not work satisfactorily, particularly in sticky soils. It can be operated for incorporation of stubbles and green manures. Disc ploughs are basically tractor-drawn because of their weight and size.

2. Cultivators and Harrows: These are the secondary tillage implements used after initial ploughing of the soil. With the use of the primary tillage implements, the furrow slice and clods are left unbroken. Cultivators and harrows are used for pulverization and to bring the soil to desired tilth. These implements help in destroying the weeds and mixing manures and fertilizers with the soil.

Cultivators are commonly called tillers. A number of tynes are attached for easy penetration into the soil and break the clods. Cultivators usually have two or three rows of tynes at specified space. Tynes are mounted in such a way that they provide clearance between adjacent tynes through which clods and rubbish can pass freely. Cultivators are of different sizes. The large models are designed for tractor mounting. Small models are walking types drawn by animals. Tractor-drawn cultivators are of two types: (i) cultivator with spring-loaded tynes and (ii) cultivator with rigid tynes.

Disc harrows are suitable for hard ground with grassy weed infestation. It consists of number of concave disc sets or gangs, positioned to move angularly with the direction of travel.

Scrapers are suspended close to the concave surfaces from the frame discs may have plain or serrated edge or both in one gang. The implement is useful in the preparation of land after ploughing, particularly grasslands and virgin lands and also for incorporation of manures. Disc harrows are of three types depending on the arrangements of discs: single action, double action (tandem) and offset harrows.

Different implements penetrate the soil to varying depth, and accordingly influence weed growth, root density and crop productivity. In a study under dry land conditions of central India, there was greater reduction in weed dry matter and increase in root density of pigeon pea with higher depth of ploughing (Table 4). The yield was the highest under sub-soiling, followed by disc plough and mould board plough; while the lowest yield was obtained with country plough due to higher weed dry matter and poor root density.

Table 4: Effect of tillage on rainfed pigeon pea in central India

Tillage	Depth (cm)	Weed dry matter (t/ha)	Root density (g/m^3)	Grain yield (t/ha)
Country plough	0.075	3.00	43.5	0.55
Blade plough	0.100	2.82	46.8	0.66
Disc harrow	0.125	2.66	61.9	0.77
Mould-board	0.200	2.18	92.0	0.87
Disc plough	0.250	1.57	120.5	1.03
Sub-soiler	0.400	1.35	143.5	1.24

(Source: Soil and Tillage Research, 1995)

3. Implements used in Wetlands: Ploughing in the wetlands is done with stagnation of water in the field. This situation is called as puddling which facilitates destruction of soil structure, causes water stagnation in the field. The condition of the soil obtained due to puddling is called as puddle. A semi-pervious hard pan is covered with 10 to 15 cm dense mud and very little free water on the surface. Considerable human energy is utilized in the wetland preparation. Use of implements eases the operation of puddling. Implements for puddling include wetland puddler, helical blade puddler, green manure trampler etc.

4. Leveling Implements: The choice of the implement used for land leveling depends on the quantity of earthwork involved, type of power available, economic feasibility and farm size. Among the different implements available, animal-drawn implements such as leveling board and buck scrapper are normally used. These implements include wooden leveling board, buck scrapper, A-frame ridger, V-ditcher, wooden float etc.

5. Implements for Soil compaction and Breaking clods: Rollers made up of wood, stone or iron are used to consolidate the soil, crush the clods and smoothen the surface. The general principle involved is the rotation of massive material round the axle. These include iron rollers, wooden and stone rollers.

6. Implements for Special Operations:

(i). Bund former: The implement consists of two divergent gathering steel blades fixed to a frame-work with a long wooden shaft pole. Different sizes of bund formers are available. The steel blade gathers loose soil from the surface and forms bunds. Adjustments are provided for increasing or decreasing the size of the bund. The implement is worked along and across the field at suitable intervals so as to form required sizes of beds. Irrigation channels can also be formed by making narrow spaced bunds. The bund former is also used for soil conservation work. Temporary bunds across the field can be formed to conserve moisture and prevent runoff water.

(ii). Ridge plough: This is a double mould board plough having adjustable wings with which the width can be suitably altered at the rear. While working, the implement lays earth on both sides equally and an open furrow is formed in the middle. An area of about 0.8 to 1.0 ha can be covered in a day. The bund former or ridge plough may be animal-drawn or tractor-drawn.

(iii). Bed-furrow former: It is a tractor-drawn implement capable of forming alternate beds and channels simultaneously in one pass. The unit is made of strong iron sheet welded together in the same profile as the beds are required to be formed. It is provided with suitable brackets for hitching it to the three point linkage of the tractor for easy and efficient operation. It is possible to cover 3 ha/day of operation.

(iv). Rotovator: This is also called as rotary plough or rotary cultivator. This is a tractor-mounted or power tiller drawn implement. This performs the primary and secondary tillage operations simultaneously so as to prepare a fine seed-bed in a single pass. The drive sprockets transmit the rotary power to the rota-axis through a chain drive. As the machine is drawn along the tyne, the soil is broken. The implement can also be effectively utilized for stubble mulching.

(v). Chisel ploughs: Chisel ploughing is not a method of ploughing but is a heavy cultivating operation. Chisel ploughs are used to break the hard pan or plough sole, improve the moisture holding capacity and pull out deep-rooted weeds. This implement is used in reclaiming rough lands and orchards. The implement is heavily structured requires considerable power to pull it.

(vi). Sub-soiler: Sub-soiler is used to penetrate the soil deeper than with conventional cultivation machinery. This helps to break-up the layers of soil which have become compacted due to the movement of heavy machinery or as a result of ploughing. Sub-soilers may have one or more heavy tynes which break through the impervious layer. Normal depth of work is approximately 50 cm. The operation of sub-soiler should be carried out under very dry condition to get maximum fissuring of the soil.

7. Sowing/Planting Implements:

(i). Seed drills: A number of mechanical seed drills are now available. These are animal as well as power operated. There are provisions for sowing and fertilizer application simultaneously. A mechanical seed drill consists of: (i) frame, (ii) seed box, (iii) seed dropping mechanism, (iv) furrow opener, (v) covering device and (vi) transport wheels. Seed drills having automatic drilling of seeds are also available.

(ii). Seed planter: The planter is normally used for seeds of larger size. Row to row spacing and intra-row spacing are fixed. The main functions of the planters are: (i) to open the furrow, (ii) meter the seed, (iii) deposit the seed in the furrow, (iv) cover the seed and (v) compact the soil. A planter normally consists of: (i) hopper, (ii) seed metering device, (iii) knock-out arrangement, (iv) cut off mechanism, (v) furrow opener and (vi) other accessories.

(iii). Tractor-drawn seed planter: Different models consist of seed boxes along with cup feed type seed metering mechanisms. These are mounted on the cultivator frame. Seeds are dropped in the furrows opened by the cultivator shovels. Detachable side wings are fixed to the existing shovel type furrow opener of the cultivator which helps in placing the seed at the required depth.

(iv). Rice transplanter: Various types of rice transplanters have been developed. The International Rice Research Institute, Philippines, has developed a manually-operated rice transplanting machine. The mat type rice nursery grown in compartments is required for transplanting. The machine consists of seedling tray, tray movement mechanism, frame with skid, seedling pickers and a handle. Seedlings are picked from the tray by the seedling picker when the handle is pushed forward. The seedlings are planted in the puddle when the handle is further pushed down. The seedling tray moves sideways positioning the next batch of seedlings to be picked up by the pickers. The machine is pulled to the next station to repeat the cycle. At a time, 4-8 rows can be transplanted depending on the model of the machine. It is possible to cover 0.15 - 0.25 ha in a day of 8 hours with the help of 4-5 labourers.

8. Weeders:

(i). Dryland weeders: These weeders are manually operated and used for removing weeds in line-sown crops under dryland conditions. The weeders are star and peg type depending on the shape of the roller attached at the foot of the long handle. Peg types are used for black, clay and clay loam soils, and star types for loam and sandy loam soils.

(ii). Rotary weeders: This is a hand-operated implement used for weeding in planted rice fields. There are two small toothed conical rollers or drums mounted on a frame provided with a handle. Each roller consists of about 5 toothed blades. At the time of working, it is pushed and pulled alternatively by the operator in between rows. A float provided at the anterior part guides the implement smoothly at the time of working and prevents it from sinking into the puddle. An area of about 0.2 ha can be covered in a day. Weeds in the intra-row spacing between the rice plants can be removed by hand.

Comparative performance of zero till drill, strip till drill, bed planter, rotary till drill and conventional drill for rice and wheat sowing in western Uttar Pradesh are presented in Table 6. Zero, strip and rotary till drilling and bed planting of rice were time (74-79%), labour (64-71%), fuel (67-85%), cost (65-81%), energy (67-85%) and also irrigation water (2-39%) saving compared to conventional sowing. The irrigation water saving under bed planting in rice and wheat was 39 and 34% respectively compared to conventional sowing.

Table 6: Performance parameters of different tillage machines in western U. P.

Parameters	Conven-tional drill	Zero till drill	Bed planter	Strip till drill	Rotary till drill
Area sown (m^2)	4,000	4,000	4,000	4,000	4,000
Effective working width (mm)	1,980	1,980	1,500	1,980	1,760
Operating speed (km/hr)	3.7	3.8	3.7	3.2	3.8
Effective field capacity (ha/hr)	0.50	0.50	0.42	0.45	0.40
Field efficiency (%)	79	72	71	73	79
Width of headland (m)	2	2	2	2	2
Time of sowing (hr)	9.5	2.0	2.4	2.2	2.5
Fuel consumption (l/ha)	48.8	7.1	8.6	8.75	16.1
Labour requirement (h/ha)	21	4.0	5	4.5	5.5
Cost of sowing (Rs./ha)	2,456	466	578	610	873
Energy requirement (MJ/ha)	2,784	407	493	501	916

(Source: Conservation Agriculture – Status and Prospects, 2005)

Emerging Tillage Systems

The conventional tillage systems are aimed at weed control, and preparation of seed-bed and root-bed. These systems include disruption, inversion, pulverization, and mixing of soil in the seed/root zone. The extent to which any of these processes actually occur in the field depends on the type and method of application of tillage implements and the initial soil properties/conditions.

In conventional tillage, the soil is opened with mould-board plough for primary tillage. The soil mass is broken into a loose system of clods of mixed sizes. Subsequently, a fine seed-bed is prepared by secondary tillage in which crushing of clods, repacking, incorporation of plant residues, fertilizers, smoothing of soil surface etc., is done. In this process, energy is often wasted and sometimes, soil structure is destroyed.

Summer tillage has been an age-old practice to open the soil to desiccating temperatures to manage perennial weeds, soil-borne pests and diseases. However, in the recent past, the concept of tillage to manage weeds, particularly the annual weeds, is under serious review. While shallow tillage helps in breaking the dormancy of weed seeds by exposing seeds to light, deep tillage protects the weed seeds by burying them deep in the soil horizon.

It is now increasingly realized that extensive tillage is not ideal. Compaction of soils, the need for soil conservation, environmental concerns and the increased cost of energy and labour has caused a new appraisal of our concept about tillage. The primary objective of tillage to control weeds consumes around 50% of the energy required for tillage. Until herbicides became available in 1940s, tillage for weed control was an integral part of crop production. With the dramatic improvements being made in the field of herbicide technology, the necessity of soil manipulation for weed control has decreased. Herbicides to kill weeds are more effective and eliminate extra trips over the field, which results in both fuel (energy) and labour saving.

The conventional tillage system is generally discredited for increasing erosion risk, accelerating organic matter decomposition, and deteriorating soil structure. Therefore, conventional tillage is now giving place to newer concepts of conservation tillage in some regions of the world.

The concept of minimum tillage was started in USA. The immediate cause for introducing minimum tillage was the high cost of tillage due to steep rise in oil prices in 1974. Efforts were made to know whether several tillage operations carried out in the field are necessary or not. In addition, there are problems associated with clean cultivation. Repeated use of heavy machinery destroys structure, causes soil pans and leads to erosion. The needs of planting zone (row zone) and water management zone (inter-row zone) are different. In row crops, it is sufficient to provide fine tilth in the row zone for creating conditions optimal for sowing and conducive to rapid and complete germination and seedling establishment. In the inter-row zone, secondary tillage is not done and it should be rough and cloddy where soil structure is coarse and open so that weeds may not germinate and more water infiltrates into the soil.

This concept has now drawn the attention of many researchers and farmers. A suggestion recommends a rotation in tillage (deep plough every several years; less tillage other years) as an improvement in the management. Moreover, in the present era of globalization and changing WTO regime, it is important to reduce the cost of cultivation to make the farm produce competitive in the international market. One of the areas where cost can be reduced is the expenditure on tillage, which accounts for 30-35 % of the total cost of production.

For centuries, conventional agricultural practices around the world encouraged extensive soil tillage that leaves the soil bare and unprotected from the ravages of erosion. During the last three decades, two technological developments have allowed many farmers to avoid this problem by managing their soils with greatly reduced tillage or no-tillage at all. First came the development of herbicides that could kill weeds chemically rather than mechanically. Second, farmers and equipment manufacturers developed machinery that could plant crop seeds even if the soil was covered by plant residues. These developments obviated two of the main reasons that farmers tilled their soils. Farmer interest in reduced tillage heightened as it was shown that these systems produced equal or even higher crop yields in many regions while saving time, fuel, money-and soil. The latter attribute earned these systems the name of conservation tillage.

Conservation tillage is generally followed in western countries to reduce loss of soil and water through minimal cultivation thus leaving a large amount of plant residues on the soil surface. The plant residues protect the soil against the beating action of rain drops, keep the surface of the soil open and increase the infiltration of water compared to a bare soil. Soil structure and organic matter content in the soil are improved and the productivity level is maintained. Under these conditions, sowing operations are carried out with little disturbance to the crop residues.

Since conservation tillage systems were initiated, hundreds of field trials have demonstrated that these tillage systems allow much less soil erosion than do conventional tillage methods. Surface runoff is also decreased, although the differences are not as pronounced as with soil erosion. These differences are reflected in the much lower C factor values assigned to conservation tillage systems. Conservation tillage also significantly reduces the loss of nutrients dissolved in runoff water or attached to sediment.

The various types of emerging tillage systems are discussed below:

(i) Conservation tillage: Conservation tillage is a form of non-inversion tillage that retains protective amounts of residue mulch on the surface throughout the year. In 1984, the U.S. Soil Conservation Service redefined conservation tillage as any tillage and planting system in which at least 30 per cent of the soil surface is covered by residue after planting in order to reduce soil erosion by water. Crop residues left on the soil surface reduce soil erosion and conserve soil moisture.

In India, residue management is very important in rice-wheat cropping system because large quantities of crop residues are left on soil surface, especially where combines are used for crop harvest. Management of these residues has become a major problem for farmers. Burning of residues in the field after combine harvest is the common practice followed by the farmers. Burning can result in up to 80% loss of tissue N by volatilization besides a significant source of air pollution. Incorporation of residue into soil after harvest is possible in conventional tillage. However, this incorporation leads to a decrease in yield of subsequent crop because of N immobilization. In conservation tillage, large amount of crop residues are left on the soil surface. Several workers have reported that presence of crop residues suppressed weeds and did not result in an increase in herbicide applications. Retaining crop residues on the soil surface, rather than burning them or incorporating them by tillage, increases organic carbon and total soil N in the surface soil. The higher level of carbon and nitrogen in the surface layers are attributed to slower residue decomposition, slower oxidation of soil carbon and less erosion.

(ii). Stubble mulch tillage: The traditional methods of tillage developed in temperate moist climates based on mould-board plough, often increase soil erosion when adopted indiscriminately in arid land cultivation. An approach was developed for keeping soil protected at all times whether by growing a crop or by crop residues left on the surface during fallow periods. The stubble-mulch farming is a year-round system of managing plant residues with implements that undercut residue, loosen the soil and kill weeds. Soil is tilled as often as necessary to control weeds during the interval between two crops. Good management of stubble mulch farming system begins with the harvest of the crop. Sweeps or blades are generally used to cut the soil up to 12 to 15 cm depth in the first operation after harvest and the depth of cut is reduced during subsequent operations. When unusually large amount of residues are present, a disc type implement is used for the first operation to incorporate some of the residues into the soil. This hastens decomposition but still keeps enough residues on the soil.

(iii). Ridge tillage: Ridge tillage is a conservation system in which crops are planted on top of permanent 15-20 cm high ridges. About 30% soil coverage is maintained, even though the ridges are scrapped off a bit for planting and then built-up again by shallow tillage to control weeds. With this method, the soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seed-bed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation.

(iv). Minimum tillage: Minimum tillage is aimed at reducing tillage to the minimum necessary for ensuring a good seed-bed, rapid germination, a satisfactory stand and favourable growing conditions. Tillage can be reduced in two ways: by omitting operations which do not give much benefit when compared to the cost, and by combining agricultural operations like seeding and fertilizer application.

Minimum tillage involves the minimum quantum of tillage required for crop production or for meeting the tillage requirements under existing soil and climatic conditions. In this, the operations are considerably reduced to the minimum required for seed-bed preparation. In situations where crop residues are left *in situ* in the field for decomposition, this method is normally followed. Minimum tillage is comparatively easy to adopt in coarse and medium-textured soils, and is practiced for a period of 2-3 years. Minimum tillage practices have the advantages of cost effectiveness and time saving in field preparation. A saving of about 50-58% of fuel can be made in minimum tillage compared to conventional tillage. This system is particularly advantageous in heavy clay and clay loam soils where it is often difficult to create optimum conditions in the seed zone. However, weeds may become over-abundant and reduce the yield levels in the course of time.

Minimum tillage has certain advantages: (i) improved soil conditions due to decomposition of plant residues *in situ;* (ii) higher infiltration caused by the vegetation present on the soil and channels formed by the decomposition of dead roots; (iii) less resistance to root growth due to improved structure; (iv) less soil compaction by the reduced movement of heavy tillage vehicles; and (v) less soil erosion compared to conventional tillage. However, these advantages are evident on coarse and medium-textured soils and appear after two to three years of practicing minimum tillage.

There are certain disadvantages of minimum tillage which are not insurmountable. Seed germination is lower with minimum tillage. Further, more N has to be added as rate of decomposition of organic matter is slow. Nodulation is affected in some leguminous crops like peas and broad beans. Sowing operations are difficult with ordinary equipment. Further, continuous use of herbicides cause pollution problems and dominance of perennial problematic weeds.

(v). Reduced tillage: Reduced tillage is defined as any combination of tillage operations, which do less tillage than all the operations used in conventional tillage. Reducing the number of operations may be accomplished by eliminating ploughing or one pass with a disc or it may be almost a no-till operation with only single disking or pass with wide sweep e.g. rotary tillage. The terms minimum tillage and reduced tillage are sometimes used as synonyms. In case of reduced tillage as well, there is use of primary tillage in conjunction with special planting techniques to reduce or eliminate secondary tillage operations. The factors in favour of reduced tillage systems are primarily to reduce erosion of soil, save time in operation and save in cost of fuel.

(vi). Zero tillage: This is an extreme form of minimum tillage. Primary tillage is completely avoided and secondary tillage is restricted to seed-bed preparation in the row zone only. It is also known as no-till and is resorted to where soils are subjected to wind and water erosion, timing of tillage operation is too difficult, and requirements of energy and labour for tillage are too high. Zero tilled soils are homogenous in structure with more number of earthworms. The organic matter content increases due to less mineralization. Surface runoff is reduced due to the presence of mulch. The favourable effects of zero tillage on soil physical properties are apparent after two years of its practice.

With no-tillage systems, we can expect 50 to 100% of the soil surface to remain covered. Well-managed continuous no-till systems include cover crops during the winter and high residue producing crops in the rotation. Such systems keep the soil completely covered at all times and build-up organic surface layers somewhat like those found in forested soils.

No-tillage involves leaving the soil undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seed-bed or slot created by coulters, row cleaners, disk openers, in-row chisels, or roto-tillers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control. In zero tillage, herbicide functions are extended. Before sowing, the vegetation present has to be destroyed for which broad-spectrum, non-selective herbicides with relatively short residual effect like paraquat, glyphosate etc. are used. During subsequent stages, selective and persistent herbicides are needed. The herbicides applied should not cause injury to the succeeding crop.

In no-tillage system, herbicide application, planting and harvesting are the only cultural operations that are followed during crop cultivation. This method has been successfully adopted for planting grasses and legumes. Tilling and seeding are done in one operation. Non-selective broad-spectrum herbicides are used to kill a sod (grass, grass legume) or residue from previous crop.

Higher dose of N has to be applied as mineralization of organic matter is slow in zero tillage. Large population of perennial weeds appears in zero-tilled plots. Higher number of volunteer plants and build-up of pests are the other problems.

The extreme example of zero tillage is sod seeding, a technique widely used by rice farmers in southern Australia. Sod seeding involves sowing of rice directly on a well-grazed pasture sward with a sod-seeder and with minimum disturbance of the soil. The pasture is heavily grazed by sheep before sowing. Field is irrigated before sowing, if the soil is too hard for sod seeding. After sowing, the field is irrigated, flushed or grazed. The sheep may graze some rice tops but those soon recover. Advantages of this system are reduced cost of production, improved utilization of pastures and less soil disturbance. Non-specific herbicides like paraquat are used to control weeds. This technique is called as 'chemical sod seeding'.

The effects of zero, minimum (reduced) and conventional tillage were evaluated in barley-rice cropping system under dryland ecosystem (Table 7). These practices influenced weed growth and available soil N, leading to variable crop productivity. The yields of both crops decreased under no tillage but remained more or less unaffected under minimum and conventional tillage. Residue management increased N availability under all tillage practices and gave higher productivity than without residue. There was no effect of residue on weed growth under minimum and conventional tillage, but had a marked influence under zero tillage conditions.

Table 7: Effect of different tillage and residue management practices on barley-rice cropping systems under dryland agro-ecosystem

Treatment	**Barley**			**Rice**		
	Grain yield (t/ha)	Weed dry weight (t/ha)	Available N (µg/g soil)	Grain yield (t/ha)	Weed dry weight (t/ha)	Available N (µg/g soil)
Conventional tillage without residue	1.40	2.22	12.6	0.92	1.90	11.6
Conventional tillage with residue	1.98	2.31	14.9	1.13	1.80	14.4
Minimum tillage without residue	1.67	2.38	12.6	0.92	1.76	13.5
Minimum tillage with residue	2.17	2.30	15.6	1.17	1.61	16.6
Zero tillage without residue	0.64	4.11	7.8	0.67	3.16	7.8
Zero tillage with residue	1.00	2.35	8.2	0.76	2.85	9.6

(Source: Experimental Agriculture, 2005)

Adoption of Conservation Tillage Systems

Conservation tillage systems are currently adopted on nearly 100 million ha worldwide. Six countries have more than 1 million ha area under no tillage systems (Table 8). South America has the highest adoption rates, and has more area under permanent no-till and permanent soil cover. United States is the leading country, followed by Brazil, Argentina, Canada, Australia and Paraguay. Adoption of no-tillage systems for sowing of winter-season crops including wheat planted after rice has shown tremendous increase in South Asia in the last few years (Figure 2).

In the United States, conservation tillage has become increasingly popular, being used on nearly two-fifths of the nation's cropland. Conservationists project that as much as 60% of the cropland in the United States will be managed with some kind of conservation tillage by 2010. Already, 80% or more of the cropland in a few areas is managed with conservation tillage. No-tillage systems, especially, have spread to nearly all regions and are now used in some form on almost half of all the conservation tillage hectares. The no-till system has been used continuously on some farms since about 1970 (more than 20 to 30 years without any tillage). No tillage and other conservation systems are also being used in other parts of the world. One of the most significant examples of no-tillage expansion has been in southern Brazil. Thousands of small-scale soybean and maize farmers have successfully adapted cover-crop-based no-tillage systems using animal traction or small tractors.

Table 8: Extent of adoption of no-tillage system worldwide (2004-05)

Country	**Area under no-tillage (million ha)**
USA	25.30
Brazil	23.60
Argentina	18.27
Canada	12.52
Australia	9.00
Paraguay	1.70
Bolivia	0.55
South Africa	0.30
Spain	0.30
Venezuela	0.30
Uruguay	0.26
France	0.15
Chile	0.12
Colombia	0.10
China	0.10
Indo-Gangetic plains (India, Bangladesh and Nepal)	1.90
Others (Estimate)	1.00
Total	95.48

(Source: Proceedings of Third World Congress on Conservation Agriculture: Linking Production, Livelihoods and Conservation, 2005)

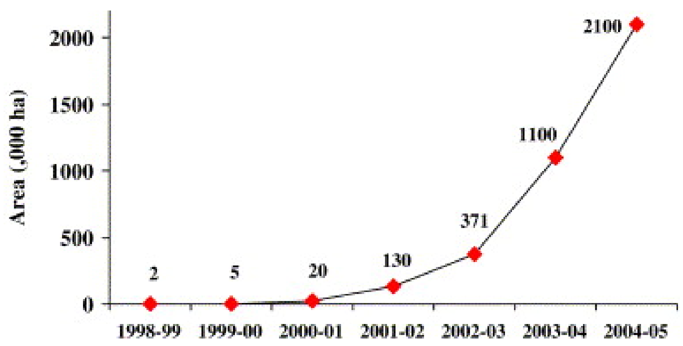

Figure 2: Increase in area under zero-till winter season crops including wheat planted after rice in South Asia

Modern tillage methods are not suitable as such for Indian conditions due to several reasons. In USA, straw and stubble are left over in the field. In India, it is a valuable fodder for the cattle and fuel for the homes. Use of heavy machinery in India is limited and, therefore, problem of soil compaction is rare. Minimum tillage can be practiced under Indian conditions by reducing the number of ploughings to the minimum necessary. A single tillage operation over a hectare with a country plough requires 40 km walk on rough land. Unnecessary repeated harrowings can be avoided after harvesting of crops in dryland areas.

In India, minimum tillage practice is adopted under intensive cropping in some situations. Groundnut-groundnut-sesame cropping system is predominantly followed in north-eastern zone of Tamil Nadu. After the harvest of second crop of groundnut, sesame seeds are broadcast sown. Harvest of groundnut at optimum moisture condition is almost equal to a ploughing operation. After sowing of sesame, one ploughing is done to cover the seeds and provide a firm seed-bed.

Zero tillage in rice-wheat system in India: In rice-wheat cropping system, field preparation is difficult for sowing wheat. Tilling land is a laborious and time-consuming operation. It has been estimated that on an average about 30% of the total expenditure of crop production is incurred on the tillage operations. Tillage operations vary depending upon soil types (light/heavy), source of power (bullocks/tractor), type of previous crop and method of disposal of crop residue of preceding crop (burning, removal or incorporation). In heavy textured soils 6-8 operations are common. The tillage operations are difficult particularly in medium and heavy-textured soils of rice-wheat system, which have been termed as ‘difficult to handle' soils by experts and farmers. Moisture stress in these soils results in deep (more than 50 cm) and wide (1-5 cm) cracks and higher moisture content makes the soil sticky and plastic, and thus difficult to manage. With increased combine harvest of rice, residues pose problem in tillage resulting in delayed sowing.

Sowing of wheat is generally delayed because of several reasons: (i) late harvest of preceding rice crop, (ii) taking catch crop after rice, (iii) long turn around time between the rice harvest and wheat sowing, (iv) excessive tillage and soil moisture problem (too wet or too dry); (v) lack of animal or mechanical power for ploughing, and (vi) priority of farmers given on threshing and handling rice crop before preparing land for wheat.

Late sowing of wheat has been ranked as the first constraint of rice-wheat production system in north-west India. In case wheat is sown after 25th November, the yield decreases at the rate of 30-35 kg/ha/day. Around 15-33% reduction in grain yield of wheat has been estimated due to delayed sowing. Late sowing reduces not only yield but also the efficiency of the inputs applied. Normally the small and medium farmers cultivate their fields for the sowing of wheat by hiring tractors. On an average, these farmers spend up to Rs.2000-2500/ha for the preparation of field and sowing of wheat.

In zero tillage technology, seeds are sown in a single tractor operation using specially designed seed-cum-fertilizer drill without any field preparation in the presence of anchored rice residue at optimum to slightly wetter soil moisture regime. Paraquat is applied to kill stubbles and other vegetation. Wheat is drilled in between the rice stubbles and weeds in wheat are controlled by post-emergence herbicide application. Zero-till drilling of wheat is becoming very popular in Indo-Gangetic Plains of our country under rice-wheat system. The incentive for a change from conventional tillage to zero-tillage has come from three directions: improved profitability, productivity and sustainability of rice-wheat cropping system. With the dramatic improvement being made in the field of herbicides, the necessity of soil manipulation for weed control has decreased. With the adoption of zero tillage, the operation cost of seeding could be brought down from Rs. 2000-2500/ha to Rs. 400-500/ha. Besides, there is saving of labour and time.

The advantages of zero tillage are as follows:

1. Zero tillage significantly reduces cost of production. Farmers quote a figure of about Rs. 2000-2500/ha less cost because of saving in diesel and labour.
2. Reduced tillage also means less tractors wear and tear maintenance costs.
3. Zero tillage increases the yield by 5-15% over the conventional system.
4. Zero tillage uses a seed and fertilizer drill and thus improves germination and plant stand over traditional broadcasting system and improves fertilizer efficiency through better placement. Less water is used in zero tillage, and therefore, there is less leaching of nitrogen.
5. Zero till sowing reduces the incidence of *Phalaris minor* to the tune of about 40-50% because of less soil disturbance.
6. It takes less time for water to flow across the field in zero tillage compared to normal tilled plots for the first irrigation. That means farmer can save water and just as important don't apply too much water that often leads to waterlogging and yellowing of the crop.
7. If surface residue management is combined with zero tillage, there is no need to burn the residue and this helps reduce air pollution and addition of greenhouse gases to the environment.
8. The organic matter content of zero-till soils may stay higher than that with conventional tillage because of slower organic matter decomposition.
9. Zero tillage reduces diesel consumption by 40-70 litres per ha depending upon soil condition and thus, reduces the CO_2 emission in the environment (2.6 kg CO_2 production/litre of diesel burnt).
10. In zero tillage, anchored residues are left standing, which promote the population of beneficial insects since it provides a good habitat for their survival and less insect problems.
11. Zero till should mean less carbon oxidation during ploughing and possibly some carbon sequestration especially if residue management is good.
12. Zero tillage reduces soil erosion and land degradation.
13. Saving in time in seedbed preparation.
14. Advancement in sowing time over conventional system by 2-4 weeks depending upon the type of soil.

There are indications of some negative impact of zero tillage technology like increase in soil density, reduced infiltration rate and pore space, increased incidence of broad-leaved weeds *(Rumex* spp., *Malva* spp.), grasses (wild oat) and perennials *(Cynodon dactylon, Paspalum distichum)* and damage of wheat seedlings by pink stem borer of rice. Higher crop residues sometimes interfere in sowing. The seedling establishment in zero tillage is 20% less than in conventional methods. Under such conditions, it is necessary to ensure optimum soil moisture at sowing, use 20-30% more seed and fertilizer, and adopt suitable herbicide for weed control for realizing optimum productivity (Table 9).

Table 9: Effect of tillage and weed management on weed growth and grain yield of wheat at Karnal

Tillage	Weed growth (g/m^2)		Grain yield (t/ha)	
	Control	Metribuzin	Control	Metribuzin
Surface seeding	397.0	69.5	2.88	3.08
Zero tillage	288.0	37.8	3.97	5.09
Rotary tillage	201.8	25.2	4.70	5.67
Conventional tillage	257.2	28.3	4.64	5.09
FIRBS (3 rows)	277.5	12.8	4.89	5.52
Reduced tillage	393.8	49.8	4.31	5.13
CD (0.05)	61.4		0.22	

(Source: New Paradigms in tillage technologies for wheat production, 2003)

Other Resource Conserving Techniques

(i). FIRB System: Furrow-irrigated raised-bed planting system (FIRBS) is a method where crops are sown on raised beds. This system was introduced in India in 1995 on the pattern of wheat grown in the Yaqui valley of Mexico. Generally, 2-3 rows of wheat are sown on the top of bed, 70 cm wide and irrigation is done through the furrows. The inter-row bed space is used to control weeds by mechanical weeding during the early vegetative growth of weeds. In the crop sequences where wheat follows soybean, maize or cotton, this system of reduced tillage can be followed by reshaping the same beds without opening up the soil for field preparation. In addition to improved weed management, the bed planting method improves input-use efficiency. This technology is suitable for almost all types of soils, except black cotton soils.

The FIRB system results in considerable saving of irrigation water compared with conventional sowing. In a study at Karnal, the total post-seeding irrigation water requirement was about 25 cm in conventional tillage, whereas zero tillage required about 3% less irrigation water (Table 10). Irrigation water saving was more than 30% in case of FIRB system of wheat cultivation. The average yield of wheat was 6.04 t/ha under FIRB system compared with 6.41 t/ha under zero tillage (Table 11). The total water use was 30 cm in FIRB, 37 cm in conventional tillage and 36 cm in zero tillage. Thus, the water-use-efficiency was the highest under FIRB and the lowest under conventional system of field preparation.

Table 10: Savings on irrigation water under different tillage options

Tillage options	Water applied at each irrigation (cm)					Total irrigation (cm)	Irrigation water saving (%)
	Pre-germination	I	II	III	IV		
Conventional		6.54	6.25	5.90	5.94	24.63	-
FIRBS	2.40	3.67	3.90	3.75	3.43	17.15	30.38
Zero tillage		6.50	6.09	5.60	5.68	23.87	3.10

(Source: Decade of Research on Zero Tillage and Crop Establishment, 2005)

Table 11: Yield and water use efficiency under different tillage options in wheat

Tillage options	Source of water (cm)			Water use (cm)	Water saving (%)	Grain yield (t/ha)	Water use efficiency (kg/ha-mm)
	Irrigation	Rainfall	Profile depletion				
Conventional	24.63	6.69	5.68	37.01	-	63.05	17.03
FIRBS	17.15	6.69	5.87	29.71	19.72	60.35	20.31
Zero tillage	23.87	6.69	5.49	36.05	2.58	64.06	17.77

(Source: Decade of Research on Zero Tillage and Crop Establishment, 2005)

The advantages of FIRB system are as follows:

- Pre-seeding emergence of *Phalaris minor* can be stimulated by giving a light irrigation, followed by weed control with non-selective herbicides or cultivation.
- Reshaping the beds before sowing the wheat can kill the first flush of weed seedlings, which is largely responsible for early weed competition. If reshaping of bed is not possible, pre-seeding weed control can be achieved by using non-selective herbicides.
- Effective mechanical weed control can be done in the inter-bed zone, thereby, reducing the dependence on selective herbicides.
- Post-emergence herbicides can safely be used without damaging the wheat crop.
- The soil on the bed surface dries quickly, which reduces the germination and growth of *Phalaris minor.*
- This system reduces the cost of cultivation by reducing the use of seed, fertilizer and water.
- Reduces crop lodging.

Testing of crop establishment methods at farmers' participatory sites in eastern Uttar Pradesh indicated that inclusion of short-duration pigeonpea is more remunerative as both crops gave higher yield and net returns under bed planting (Table 12). Establishment of other pulses like lentil, chickpea, peas, lathyrus and mungbean through zero till or raised bed planting increased the yield equivalent and returns as compared to conventional rice-wheat system. These results showed that farmers in region stand to gain by practicing zero tillage and bed planting techniques.

Table 12: Average yield and net return of crops under different tillage systems on farmers' fields in eastern Uttar Pradesh

Crops	Grain yield (t/ha)			Net returns (Rs./ha)		
	Zero tillage	Bed planting	Conventional tillage	Zero tillage	Bed planting	Conventional tillage
Early pigeonpea	1.15	1.28	0.90	13,900	14,160	8,181
Kharif maize	2.60	3.65	2.35	2,350	6,963	358
Rabi maize	4.25	4.86	3.66	8,213	10,415	4,215
Pea	2.28	-	1.95	21,840	-	11,850
Lentil	1.70	1.78	1.50	21,800	22,360	1,750
Chickpea	2.00	1.99	1.86	23,200	23,045	-
Lathyrus	1.45	-	1.31	12,050	-	20,830
Summer mungbean	0.45	0.48	0.39	3,738	4,300	10,030

(Source: Decade of Research on Zero Tillage and Crop Establishment, 2005)

(ii). Rotary tillage technology: Rotary tillage technology is a tractor-driven version of the rotavator attached to Chinese power tiller, which pulverizes the soil, places the seed and fertilizer at appropriate depth and does planking in a single operation. With this machine, the soil can be pulverized to a depth up to 10 cm and thus, the existing weeds and germinating weed seedlings also get killed. The machine is capable of cutting and incorporating the weeds as well as residues left by the previous crop, which will result in reducing the environmental pollution due to burning being adopted by the farmers. The incorporation of the weeds and crop residue will increase the organic matter status of the soil and the accompanying changes in the physical and chemical health of the soil, resulting in the sustainability of the system. Behind the rotavator, a standard nine-row seed-cum-fertilizer drill is fitted to simultaneously place the seed and fertilizer at appropriate depths. Since the number of operations can be reduced from 6 or 8 to one, the total saving of energy and time can be 70-80%.

The trials conducted on farmers' fields in Haryana showed that maximum and minimum cost of production and energy requirement for growing wheat was observed in conventional and zero tillage system, respectively (Table 13). The other options found effective in reducing the cost after zero till was rotary tillage as single tractor operation was required in this option also. This cost saving of 13.32% in zero tillage and 11.6% in rotary tillage was mainly due to the difference in the cost of tillage operations as wheat was grown in a single operation in both the options. Net returns were maximum under rotary tillage, following by zero tillage and minimum in case of FIRB system. This was possible due to higher grain yield under rotary tillage condition than under zero tillage.

Table 13: Economics and energetics of various tillage options for wheat after rice in Haryana

Parameters	Conventional tillage	Zero tillage	FIRB system	Rotary tillage
Cost of equipment (Rs.)	13,000	13,000	16,000	42,000
Grain yield (t/ha)	5.48	5.49	5.05	60.06
Straw yield (t/ha)	9.31	9.45	8.17	10.45
Gross income (Rs./ha)	36,189	36,331	33,257	40,069
Cost of production (Rs./ha)	13,101	11,675	12,450	11,906
Cost of sowing (Rs/.ha)	1,593	167	1,605	398
Net returns (Rs./ha)	23,088	24,656	20,807	28,163
Energy requirement (MJ/ha)	33,653	30,576	21,504	31,056
Specific energy (MJ/kg)	2.28	2.05	2.38	1.88

(Source: New Paradigms in tillage technologies for wheat production, 2001)

(iii). Ridge tillage system: Ridge tillage system is a form of conservation tillage that appears to overcome many of the soil micro-environmental, soil compaction and weed control problems associated with other conventional and untilled systems. In this system, the crop is planted on ridges formed during the previous growing season. During planting, the surface (5 cm) of the ridge is scraped into the inter-row valleys. Seeds that were shed on the ridge in the previous season are thus moved to the valleys where seedlings can be destroyed by inter-row cultivation. At layby, when crop plants are at least 40 cm tall, the truncated soil is excavated from the furrows and moved back to the ridge crests. Such soil management may affect weeds, weed control and crop-weed interactions.

(iv). Surface seeding: It is the most simplest no-tillage system being promoted in areas like eastern India, Nepal and Bangladesh, where wheat sowing in lowland rice fields gets delayed considerably due to excess soil moisture. In this system, seeds (wheat, legumes and other crops) are broadcast on wet soil in standing rice crop (about a week before harvesting) or on wet/muddy soil after rice harvest. This system is also called *utera* or *paira* cropping. In Cauvery delta zone of Tamil Nadu, pulse seeds are sown when the soil is in wet condition 7-10 days prior to harvest of rice. Similarly, linseed and lathyrus are cultivated in eastern part of India under *paira* condition (rice fallow).

The major benefit of surface seeding is that no equipment is needed and any farmer can adopt this technique. Heavy-textured soils are more suitable than light-textured soils for surface seeding. There are areas where land preparation is very difficult and costly, and often results in a cloddy tilth. The key to success with this system is having the correct soil moisture at seeding. While less moisture can reduce the germination, high moisture can cause rotting of seeds. Rice straw mulch after seeding ensures better germination.

Conservation Tillage and Soil Properties

When soil management is converted from conventional to conservation tillage (especially no-tillage), numerous soil properties are affected, mostly in favourable ways. The changes are most pronounced in the upper few cm of soil. Generally, the changes are the greatest for systems that produce the most plant residue (especially maize and small grains in humid regions), retain the most residue coverage, and cause the least soil disturbance.

(i). Physical properties: Macro-porosity and aggregation are increased as active organic matter builds up, and earthworms and other organisms establish themselves. Infiltration and internal drainage are generally improved, as is soil water-holding capacity. The enhanced infiltration capacity of no-till managed soils is generally quite desirable, but in some cases it may lead to more rapid leaching of nitrates and other water-soluble chemicals. Residue-covered soils are generally cooler and moister. This is an advantage in the hot part of the year, but may be detrimental to early crop growth in the cool spring of temperate regions.

In cool regions, soils with restricted drainage may yield somewhat less using conservation tillage, because soil conditions are wetter and cooler than with conventional tillage. Reduced yields have discouraged the adoption of conservation tillage in these regions. However, limited pre-planting tillage over the crop rows, or ridge tillage are conservation tillage systems that allow at least part of the soil to warm faster and largely overcome these problems.

(ii). Chemical properties: No-tillage systems significantly increase the organic matter content of the upper few cm of soil. During the initial four to six years of no-till management, the build-up of organic matter results in the immobilization of nutrients, especially N. This is in contrast to the mineralization of nutrients that is encouraged by the decline of soil organic matter under conventional tillage. Eventually, when soil organic matter stabilizes at a new higher level, nutrient mineralization rates under no-till increase. Higher moisture and lower oxygen levels may also stimulate denitrification. These processes sometimes result in the need for greater levels of N fertilization for optimum yields during the early years of no-till management.

In no-tillage systems, nutrient elements tend to accumulate in the upper few cm of soil as they are added to the soil surface through crop residues, animal manures, chemical fertilizers, and lime. However, research indicates that because of the surface mulch, crop roots (like those of trees in the untilled forest environment) have no trouble obtaining nutrients from the near-surface soil layers.

Without tillage to mix the soil, the acidifying effects of nitrogen oxidation, residue decomposition, and rainfall are concentrated in the upper few centimeters of soil, the pH of which may drop more rapidly than that of the whole plough layer in conventional systems. In humid regions, this acidity must be countered by application of liming materials to the soil.

(iii). Biological properties: The abundance, activity and diversity of soil organisms tend to be greatest in conservation tillage systems characterized by high levels of surface residues and little physical soil disturbance. Earthworms and fungi, both important for soil structure, are especially favoured. However, organic residues left on the surface in no-till are actually more slowly decomposed than those incorporated by conventional tillage. No-till residues are in less intimate contact with the soil particles so their breakdown is delayed, and they remain as a protective surface barrier for a longer period of time.

Tillage and Crop Yields

Crop performance under different tillage systems depends upon site-specific soil and climatic constraints and allied management practices. For example, tillage interacts with irrigation and fertilization for crop yields, and water and nutrient use efficiencies. Tillage affects water, air, and energy dynamics in the soil-atmosphere system, and tillage-induced changes in the edaphic environment also influence growth and yield of crops. Crop response to tillage is determined by the resulting soil properties and the growing season weather conditions.

Coarse-textured soils, characterized by low water retentivity and high permeability exhibit a sharp increase in soil strength on drying. Because of low available water storage of the root zone and high potential for leaching of mobile nutrients, crops on these soils are subjected to yield-reducing water and nutrient 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 yield.

In several investigations from Punjab, 40 cm deep chiseling, 35 to 40 cm apart, of sand, loamy sand, and sandy loam soils increased the yields of corn, wheat, mustard, and sunflower as compared to conventional tillage (10 cm deep disking) (Table 14). The benefits of deep tillage vary with crop, soil type, seasonal evaporativity, and allied management practices, namely, irrigation and mulching. The favourable response generally increased with a decrease in soil water retentivity and/or irrigation and an increase in growing season evaporativity. Summer maize responded to deep tillage irrespective of soil type and irrigation regime, but in winter, deep tillage increased yield on low-water-retentive sand only. Mulching and deep tillage had similar effects on summer maize. Both practices increased water accessibility to the crop, though the mode of response differed in the two cases. Increase in wheat yield with deep tillage was also greater on the low-water-retentive soils and in the absence of irrigation. Interestingly, on a very low-water-retentive sand, high wheat yields were achieved only when deep tillage was combined with frequent and light irrigations to combat water stress(es) on this soil. Attainment of comparable sunflower yield with less irrigation in deep tillage than in conventional tillage also shows that deep tillage caused more efficient utilization of water. Deep tillage in a sandy loam soil, having a high-density subsurface layer, markedly increases infiltration rate and pearl millet, sorghum, and castor yields.

Table 14: Effect of conventional (10 cm, disking) and deep (40 cm, chiseling) tillage on yield of different crops in Punjab

Crop / seasonal evaporativity	Soil type	Irrigation regime	Grain yield (t/ha)		Percent response
			Conventional tillage	Deep tillage	
Winter maize/ low	Sandy	Yes	3.9	4.9	53
	Loamy sand	Yes	4.5	5.0	4
Summer maize / high	Sandy	Yes	0.9	2.2	144
	Loamy sand	Yes	1.1	2.2	100
	Sandy loam	Yes	4.0	4.8	20
Wheat / low	Sandy	Yes	2.8	3.3	18
		Yes	3.4	4.6	35
	Loamy sand	No	2.7	3.8	30
		Yes	4.9	5.3	8
	Sandy loam	No	3.2	3.8	19
		Yes	5.2	5.4	4
Sunflower / high	Sandy loam	Yes (6)*	1.3	1.7	31
		(8)	1.8	2.1	17
		(11)	2.1	2.2	5
	Loamy sand	Yes (5)	1.6	2.0	25
		(7)	2.0	2.2	10
		(8)	2.2	2.4	9

Figures in parentheses indicate number of irrigations

(Source: Intensive Cropping – Efficient use of water, nutrients and tillage, 2000)

A conservation tillage system may also affect crop growth and development, depending on many specific factors, such as soil type, climate, cropping pattern, and other attributes of overall farming operations. Conservation tillage systems generally provide yields equal to or greater than those from conventional tillage, provided the soil is not poorly drained and in a cool region. However, during the transition from conventional tillage to no-tillage, crop yields may decline slightly for some years. The decrease in yield with conservation tillage under certain soil and climatic situations occurs because of improper seeding machinery and management skills, low seed-bed (soil) temperatures, change in soil microbial status, reduced availability of plant nutrients, and weed competition. The problems associated with crop establishment in the presence of residue have now been overcome with the development of suitable seed drills. Band placement rather than broadcasting of nitrogenous fertilizers helps increase N use efficiency and prevent yield depression because of N deficiency. However, because of higher incidence of weeds, insects, and diseases under a conservation tillage system, it still requires greater management inputs than clean tillage.

Improvement in soil quality with prolonged conservation tillage increases the yield potential of crops. Yield benefits from conservation tillage mainly accrue in arid and semi-arid environments, on well-drained soils in warm and temperate regions, and in crops grown in rotation. In sub-humid regions, crops on low-water-retentive coarse-textured soils may also benefit from conservation tillage. Increasing fuel costs have encouraged direct seeding of crops even under clean cultivation. For equivalent yields, no-till crops generally require higher N and water supplies than those under conventional tillage.

Extensive investigations have been made on evaluation of various tillage options in rice-wheat cropping system. In a study at Karnal, four tillage systems were studies in rice viz. puddling by rotavator, puddling by harrow, dry field preparation by rotavator followed by ponding and planking, and dry field preparation by harrow and cultivator followed by ponding and planking. The yield of wheat remained unaffected due to residual effect of tillage practices adopted in rice (Table 15). However, the direct effect of tillage practices resulted in variable yields of wheat. The wheat yield recorded with FIRB system was significantly lower than all other treatments viz. no tillage, rotary till drill, conventional tillage and strip till drill, all of which, resulted in similar yields.

Table 15: Yield of wheat under different tillage options in rice and wheat

	Tillage in rice				
Tillage in wheat	**Puddling by rotavator**	**Puddling by harrow**	**Dry field preparation by rotavator**	**Dry field preparation by harrow**	**Mean**
Zero tillage	53.88	58.88	56.63	57.05	56.61
Rotary till drill	58.70	59.92	61.19	54.36	58.54
FIRB system	48.91	49.40	48.53	48.72	48.89
Conventional tillage	54.99	58.30	54.64	55.79	55.93
Strip till drill	55.69	54.96	56.92	55.47	55.76
Mean	54.43	56.29	55.58	54.28	
CD (0.05)					
Tillage in rice	NS				
Tillage in wheat	3.21				
Interaction	NS				

(Source: Decade of Research on zero tillage and crop establishment, 2005)

Benefits of zero tillage in rice-wheat system as compared to conventional system of cultivation are summarized in Figure 3. The zero tillage option, in general, is less labour and input intensive with almost similar yields, leading to higher associated benefits. As the sowing is done in a single operation, the drudgery to the farmers and farm labourers is reduced considerably, leading to more spare time for other activities.

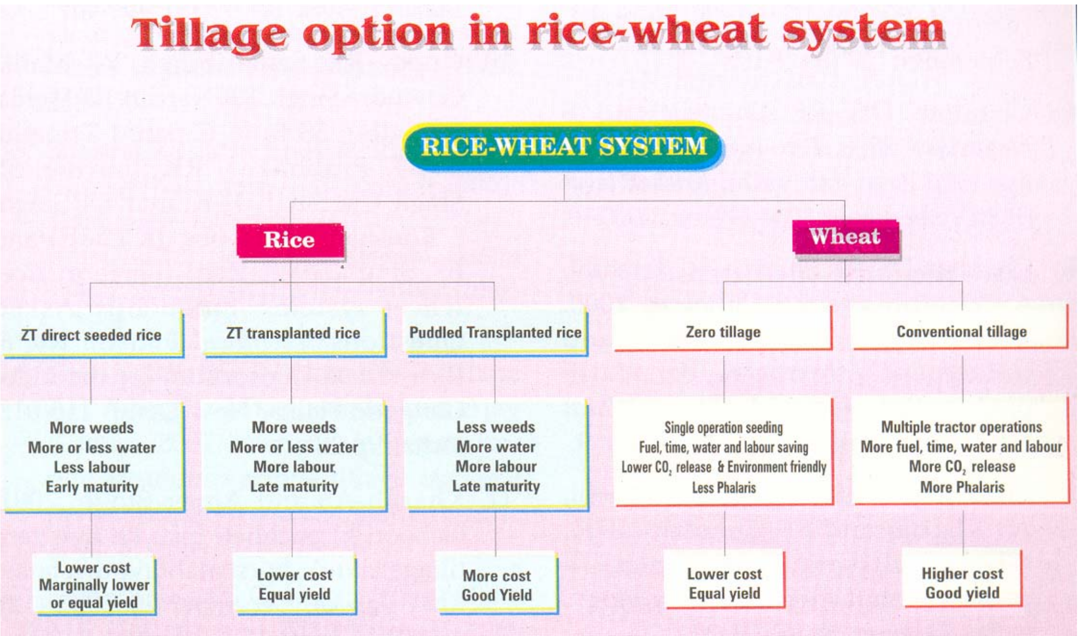

Figure 3: Benefits and limitations of different tillage options in rice-wheat cropping system
(Source: Decade of Research on zero tillage and crop establishment, 2005)

Energy Use in Relation to Tillage

Energy is a critical input in intensive cropping. Tillage is the process of employing human, animal and machine energy to alter the soil environment for weed control, crop establishment, and root proliferation to achieve higher yields and input use efficiency. Water, fertilizers, fuel and pesticides are other major energy inputs in intensive cropping. A highly energy-intensive rice-wheat system in the Indo-Gangetic plains uses more than 52,000 MJ/ha of energy to produce 8.0 t/ha grains. In this cropping system, energy expended in tillage constitutes only 7 percent of the total, compared to 42 percent in irrigation, and 36 percent in fertilizers and manures (Prihar et al., 2000). Although energy expended in tillage is relatively small, it influences the efficiency of energy use in water and nutrients. A three-year field study on tillage, irrigation regimes, and N effects on wheat following rice on a sandy loam soil showed that crop responses to applied N and irrigation were governed by the tillage system. These relations showed that for comparable wheat yields, higher amounts of water and N are required with zero tillage than with conventional tillage. Though the energy required for tillage was less in no tillage than in conventional tillage, total energy requirements in no tillage for a given yield exceeded that in conventional tillage because of higher energy input in water and N. This study suggested that within a given crop production system, energy expended in tillage should not be considered in isolation. Also, one form of energy can be substituted, within certain limits, by another, depending on the availability and price of the input.

Optimizing Tillage Vis-a-Vis Soil, Crop and Climatic Factors

Judiciously used tillage can be a powerful tool in alleviating some soil-related constraints and enhancing crop production, whereas improperly used tillage can lead to degradation of soil, and pollution of water and environment. Tillage needs of a cropping system in a given region depend on the interactions among soil, climate, and management factors. Also, the tillage system must reflect the socio-economic situations in terms of farm size, labour availability, power sources, and technical skills of the farmer. Conventional tillage adds to input costs as labour, power and machinery, deteriorates soil structure by residue removal and organic matter dilution, and subjects the soil to erosion. Conventional tillage system helps to combat compaction, while the conservation tillage tends to increase soil strength.

Depending on the combination of soil, climate, crop, and management factors, a given tillage system may have adverse or beneficial effects on the sustainability of a system. There is a need to assess the site/crop-specific factors limiting potential growth that can be modified through tillage. Relative gains from conservation tillage are determined by the amount of residue available for providing surface cover or for incorporation into soil, topography and internal drainage of soil, amount and pattern of rainfall, soil temperature changes caused by residue cover, availability and cost-effectiveness of herbicides, and availability of suitable machinery for seeding and fertilizer application.

Conservation tillage is possible only if the farmer can afford to leave sufficient crop residue on the field. Unfortunately, in most areas under intensive agriculture, residue is removed for alternate uses, and hence, the requisites of conservation tillage are not met. Wherever feasible, conservation tillage has been found useful on erosion-prone and well-drained soils. In poorly-drained soils in humid areas, conservation tillage has generally given lower yields than conventional tillage because the residue cover at the surface keeps the soil wet and causes aeration stress. Even on well-drained soils, the yield with conservation tillage has been generally equal to or less than that with conventional tillage. Benefits from conservation tillage are greater under semi-arid and sub-humid conditions because it enhances water storage in the root zone. In humid areas, surface cover may create excessively wet soil conditions for crop growth. Also, the gains from conservation tillage are linked with changes in soil temperature caused by residue cover. Since straw mulching reduces soil temperature, conservation tillage will have a favourable effect if early season soil temperatures are higher than optimum. The availability of cost-effective herbicides has enhanced the feasibility of conservation tillage. However, in many intensively cropped regions, conservation tillage may not be possible due to lack of availability and economic viability of herbicides. The success of conservation tillage is also linked with the availability of machines for precision seeding and fertilizer placement through residue. Though such machines are available in advanced countries, they are still out of reach of the resource-poor farmers in the developing countries.

In the overall context, conservation tillage is a necessity for erosion-prone soils and offers long time gains by improving soil quality. During short periods, however, yields with conservation tillage, at best, equal those with conventional tillage. There is a need to balance the short-term loss in production against the long-term gain in productivity with conservation tillage. In certain situations, a combination of various components of the conservation and conventional tillage systems may be more profitable. For an erosion-prone well-drained soil having a high soil temperature during seeding, maintenance of surface residue crop is highly useful. However, if a dense sub-soil layer is also present, it may become necessary to break the same by deep tillage (e.g., by chiseling) to secure efficient use of inputs and high yields. Accordingly, it is suggested to adopt a rotational system of no-tillage with conventional tillage as a solution to take advantage of the two systems.

Ecological and management aspects of changes in weed dynamics due to tillage are varied and complex. In conservation tillage systems, more diverse and intense weed populations often need to be managed with fewer tools. Meeting the combined goals of crop residue management and reduction of herbicide use, while maintaining effective weed management, is a major challenge for weed scientists in the coming years.

In semi-arid regions, it is better to leave crop residues mixed with surface soil than to turn them under. The crop residues prevent erosion and destruction of soil structure by beating rain drops and reduce surface runoff. However, under the temperate humid regions, ploughing with mould board plough gives better yield of maize as compared to other methods of cultivation. Wherever the field is infested with weeds and poorly drained, ploughing improves the crop yield.

Carbon Sequestration under Different Tillage Options

Atmospheric enrichment of CO_2 is currently occurring at an alarming annual rate of 3.3 Pg/yr. It is an important issue for the 21st century as it brings accelerated greenhouse effect. The enhancement of CO_2 in atmosphere is due to emissions from tropical deforestations, changes in land use and agricultural activities, fossil fuel combustion and cement manufacturing. The worlds cultivated soils have lost 20-70% of their original soil organic carbon due to C mining practices of subsistence agriculture and ploughings that accelerate mineralization and depletion due to soil erosion. The historic loss of C from world soils is estimated at about 50-100 Pg, some of which can be resequestered through adoption of suitable management practices such as conservation tillage, crop residue management, cover crops and crop rotations, judicious use of fertilizer and organic amendments, and water management. Soil C sequestration would lead to improvements in soil quality, increase in agronomic/biomass productivity, decrease in soil erodability, and waterways and mitigation of the accelerated greenhouse effect. Sequestration of C in soil through these practices can play a very important role not only in improving the soil quality and productivity on a sustainable basis but also in mitigating the accelerated green house effects.

Conversion to appropriate land use and adopting conservation tillage practices lead to soil organic matter (SOC) sequestration through the following processes:

Aggregation: Increase in stable micro-aggregates through formation of organo-mineral complexes encapsulates C and protects it against microbial activities

Humification: An increase in chemically recalcitrant humic compounds enhances the passive fractions of SOC. A high clay content and relatively higher proportion of high activity clays enhances the retention of recalcitrant SOC fractions.

Translocation into the sub-soil: Translocation of SOC into the sub-soil can move it away from the zone of disturbance by ploughing and other agronomic operations.

Formation of secondary carbonates: Land use and management systems in arid and semi-arid regions that enhance formation of secondary carbonates also lead to SOC sequestration. Leaching of carbonates into the groundwater is another mechanism of SOC sequestration, especially in irrigated soils.

Conservation Agriculture – Status and Prospects

Indian agriculture is entering a new phase. While the major research and developmental efforts in the 'Green revolution' era focused on enhancing production and productivity of selected foodgrains and other crops, the new technologies demand that issues of efficient resource use and resource conservation receive high priority to ensure that past gains can be sustained and further enhanced to meet the emerging needs. Issues of conservation have assumed importance in view of the widespread resource degradation and the need to reduce production costs, increase profitability, and make agriculture more competitive.

The conventional mode of agriculture through intensive agricultural practices was successful in achieving the goals of production, but simultaneously led to degradation of natural resources. The growing concerns for sustainable agriculture have been seen as a positive response to limits of both low-input, traditional agriculture and intensive modern agricultural practices that help to maintain ecological equilibrium and encourage natural regenerative processes such as nitrogen fixation, nutrient cycling, soil regeneration, and protection of natural enemies of pests and diseases as well as the targeted use of inputs. Agricultural systems relying on such approaches are not only able to support high productivity, but also preserve biodiversity and safeguard the environment. Conservation agriculture has come as a new paradigm to achieve goals of sustained agricultural production.

The terms 'Conservation agriculture' and 'Resource conserving techniques' are used as if their meaing were similar. In fact, the RCTs refer to those practices that enhance resource- or input-use efficiency. Zero tillage or reduced tillage practices that save fuel and improve plot level water productivity are considered as RCTs. There are many, many more such practices that save water, nutrients, herbicides and energy. In contrast, conservation agriculture practices refer to the RCTs with the following characteristics:

- Soil cover, particularly the retention of crop residues on the soil surface
- Sensible, profitable rotations, and
- A minimum level of soil movement e.g. reduced or zero tillage.

Over the past 3 decades or so, internationally rapid strides have been made to evolve and spread RCTs like zero and reduced tillage systems, better management of crop residues and planting systems, which enhance nutrient and water conservation. Conservation agriculture which has its roots in universal principles of providing permanent soil cover (through crop residues, cover crops, agroforestry etc.), minimum soil disturbance and crop rotations is now considered the principal road to sustainable agriculture. Thus, it is a way to achieve goals of higher productivity while protecting natural resources and environment. Conservation agriculture is currently practiced in more than 80 million ha worldwide in more than 50 countries and the area is expanding rapidly (Abrol et al., 2005). Resource conserving technologies which include zero till planting of wheat, bed planting of crops, laser-aided land leveling etc. have emerged as a major response to stagnating crop yields and declining profitability of rice–wheat cropping system in the Indo-Gangetic plains.

Evolution and accelerated adoption of zero tillage is a significant step paving way for more comprehensive conservation agriculture systems. The new technologies, on one hand, are exciting the farmers to take up new ways of managing their resources more productively and, on the other and throwing new challenges to the scientific community to solve emerging problems associated with new technologies. Future research and development efforts would need to take a more holistic view of sustainability concerns in developing and promoting technological, policy and institutional options for sustained resource use and profitability of production systems.

References

1. Abrol, I.P., Gupta, R.K. and Malik, R.K. 2005. Conservation Agriculture – Status and Prospects, 232 p. Centre for Advancement of Sustainable Agriculture, NASC Complex, New Delhi.
2. Brady, N.C. and Weil, R.R. 2002. The Nature and Properties of Soils, 960 p. 13th Edition. Pearson Education, Asia.
3. Chauhan, D.S., Sharma, R.K. and Chhokar, R.S. 2003. Comparative performance of tillage options in wheat (*Triticum aestivum*) productivity and weed management. *Indian Journal of Agricultural Sciences* **73**(7): 402-406.
4. Chauhan, D.S., Sharma, R.K., Tripathi, S.C., Kharub, A.S. and Chhokar, R.S. 2001. New paradigms in tillage technologies for wheat production, 16 p. Directorate of Wheat research, Karnal, Haryana.
5. Derpsch, R. 2005. The extent of conservation agriculture adoption worldwide: Implications and Impact. *Proceedings of Third World Congress on Conservation Agriculture: Linking Production, Livelihoods and Conservation*. Nairobi, Kenya, 3-7 October, 2005.
6. Gajri, P.R. and Majumdar, S.P. 2002. Tillage, pp. 125-132. In: Fundamentals of Soil Science. Indian Society of Soil Science, Indian Agricultural Research Institute, New Delhi.
7. Hobbs, P.R. 2006. Conservation Agriculture : What is it and why is it important for future sustainable food production? *Proceedings of an International Workshop on Increasing Wheat Yield Potential.* CIMMYT, Mexico, 20-24 March, 2006.
8. Kushwaha, C.P. and Singh, K.P. 2005. Crop productivity and soil fertility in a tropical dryland agro-ecosystem : Impact of residue and residue management. *Experimental Agriculture* **41**: 39-50.
9. Nitant, H.C. and Singh, P. 1995. Effect of deep tillage on dryland production of redgram (*Cajanas cajan*) in central India. *Soil and Tillage Research* **34**: 17-26.
10. Prohar, S.S., Gajri, P.R., Benbi, D.K. and Arora, V.K. 2000. Intensive Cropping – Efficient Use of Water, Nutrients and Tillage, 264 p. Food Products Press. An Imprint of Haworth Press, Inc., New York.
11. Sharma, A.R., Singh, Ratan and Dhyani, S.K. 2004. Conservation tillage and mulching effects on productivity of maize-wheat cropping system in the western Himalayan region – a review. Indian Journal of Soil Conservation 33(1): 35-43.
12. Sharma, R.K., Chhokar, R.S., Chauhan, D.S., Gathala, M.K., Kundu, V.R. and Pundir, A.K. 2002. *Rotary Tillage – A Better Resource Conservation Technology*, 12 p. Bulletin No. 12, Directorate of Wheat Research, Karnal, Haryana.

13. Sharma, R.K., Tripathi, S.C., Kharub, A.S., Chhokar, R.S., Mongia, A.D., Shoran, Jag, Chauhan, D.S. and Nagarajan, S. 2005. *A Decade of Research on Zero Tillage and Crop Establishment,* 36 p. Directorate of Wheat Research, Karnal, Haryana.
14. Singh, A.K. and Sharma, S.K. 2005. Conservation tillage and crop residue management in rice-wheat cropping system, pp. 23-32. In: Abrol, I.P., Gupta, R.K. and Malik, R.K. 2005. *Conservation Agriculture – Status and Prospects*. Centre for Advancement of Sustainable Agriculture, NASC Complex, New Delhi.
15. Singh, U.P., Singh, Y., Singh, H.P. and Gupta, R.K. 2005. Cropping system options in no / reduced till – surface residue management systems, pp. 79- 85. In: Abrol, I.P., Gupta, R.K. and Malik, R.K. 2005. *Conservation Agriculture – Status and Prospects.* Centre for Advancement of Sustainable Agriculture, NASC Complex, New Delhi.
16. Srivastava, A.P., Panwar, J.S. and Garg, R.N. 2000. Influence of tillage on soil properties and wheat productivity in rice (*Oryza sativa*) – wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agricutural Sciences* **70**(4): 207-210.