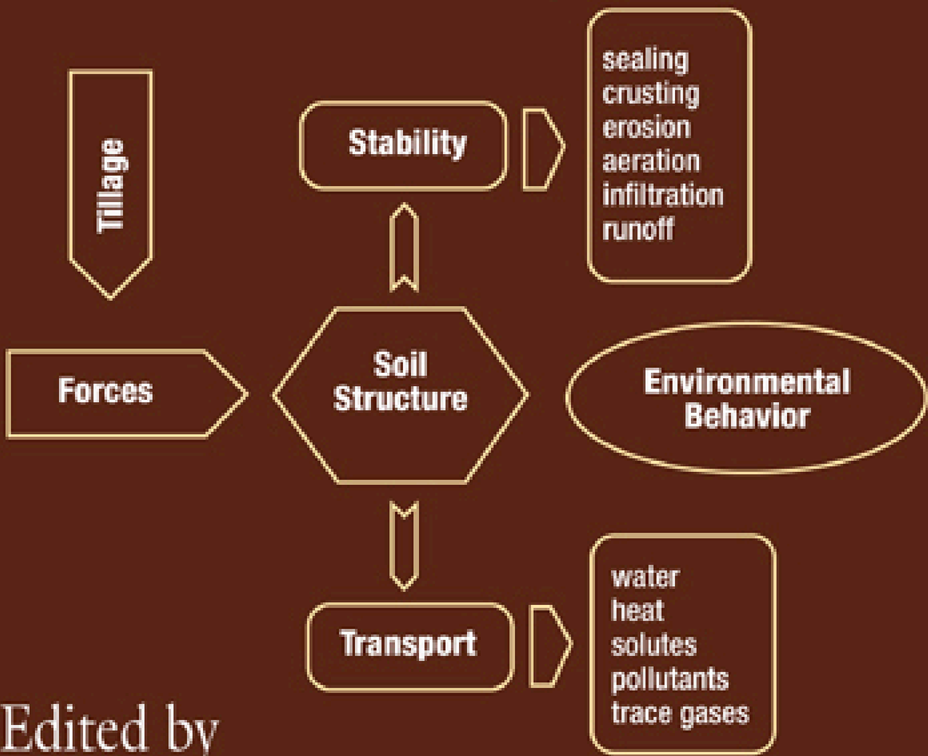
# Soil Tillage in Agroecosystems




Edited by
Adel El Titi

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# Soil Tillage in Agroecosystems

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# Preface

Soil management has been the main feature of land use since humans settled the land and started to grow crops thousands of years ago. In those prehistoric days, soil-management objectives were simple: to sustain soil fertility and secure food productivity. The long evolutionary pathway that led to our modern world has teemed not only with inventions, discoveries, and technological developments but also with theories and assumptions about handling agricultural soils that have not changed the paramount need for soil management in agricultural land use. On the contrary, emerging knowledge, in particular with regard to the environmental impacts of today's intensive production systems, has imposed further objectives for consideration. Soil erosion, nonpoint environmental pollution, and declining ecosystem stability have all been subjects of worldwide public concern, scientific input, and political debate for many decades.

Soil tillage is, and will remain, the guiding component of soil management and consequently has far-reaching implications for agroecosystems. Understanding structures and functions of soil ecosystems under various tillage/no-tillage practices is an essential requirement for any future farming concepts. This book emphasizes these aspects in all 12 chapters, highlighting both the short- and long-term effects of soil-cultivation practices on the soil ecosystem below and above the soil surface. Chapter 1 presents the main tillage concepts, describes available farm machinery, and highlights aspects of the energy needs and costs of various soil-management technologies. Chapter 2 emphasizes soil-management effects on soil structural features, including physical and hydrological criteria, to evaluate various tillage techniques with regard to soil structural stability, water storage, preferential flow, and leaching. Chapter 3 examines tillage impacts on soil microphytes in pedoecosystems. Shifts in microbial activity and biomass under distinct soil-management concepts, ranging from no-tillage to annual plowing, are analyzed, focusing on mycorrhizal fungi, rhizobia, amonifiers, and nitrifiers. Chapter 4 considers the implications of changed soil environments induced by the different tillage regimes for soil nutrient cycling and reservoirs. Particular attention is given to the breakdown of soil organic matter, mineralization processes, and the long- and short-term effects of the various soil-cultivation methods in common use.

Responses of field vegetation and the field-associated fauna under different tillage practices are the subject matter of the following chapters. Chapter 5 highlights tillage-system implications for seed-germination patterns for both weed and crop seeds. Interactions between tillage-induced seed position in the soil profile and seed behavioral responses to light, temperature, soil moisture, and gases are explored in detail in this chapter. Shifts in the germination pattern of weeds result in changed weed communities. Chapter 6 reviews the impacts of different tillage regimes on weed infestation incidence, species diversity, and tillage-induced shifts in weed communities of arable fields. The ecological, economic, and societal aspects of the functions of wild flora within crop ecosystems are explored. Chapter 7 provides a comprehensive overview of tillage impacts on plant pathogens, with a consideration of the main arable crop species. The review and conclusions are embedded within the concept of the whole farming system. Likewise, Chapter 8 addresses the influences of tillage on slugs, known to be of increasing significance in humid temperate zones. Responses of slug antagonists to the different tillage strategies are reviewed, and integrated slug-management tactics are outlined. The interactions between tillage practices and earthworms constitute the foundation of Chapter 9. The significance of earthworms in soil formation, structural stability, water permeability, and other criteria make it essential to safeguard their benefits in agroecosystems. Much like earthworms, the roles of selected groups of soil-inhabiting fauna are stressed in Chapter 10, with an emphasis on mesostigmatic Acarina (mites), Collembola (springtails), Dipteran larvae, and nematodes, and the responses of these groups and the alternation in their antagonistic interactions with other soil coinhabitants. Chapter 11, which addresses tillage effects on epigeal predatory fauna, completes the discussion of tillage impacts on beneficial fauna. Supported by extensive and updated documentation on the tillage effects on carabids, staphylinids and spiders are discussed, and appropriate conclusions are drawn. Chapter 12 concludes by evaluating tillage effects with a view to long-term ecosystem stability, soil fertility, and functioning.

This book offers a broad and comprehensive view of the interrelations of multifaceted tillage practices and the biological, chemical, and physical components of soil ecosystems. Tillage effects are highlighted within the context of the whole farming system to stress that these other components greatly affect the responses of soil ecosystems to tillage practices. This understanding is essential to assess the role of tillage concepts in future farming system design aimed at maintaining resources, sustaining productivity, and minimizing environmental pollution. For farming and nonfarming communities the healthy functioning of agroecosystems is an essential symbol of stability and environmental safety. I hope that this book may contribute to the realization of these objectives.

**Adel El Titi**

# Acknowledgments

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**Adel El Titi**

# About the Editor

**Adel A. El Titi, Ph.D.**, is a senior researcher in integrated pest management, entomology, and integrated farming systems and head of section IPM–arable crops at the State Institute for Plant Protection in Stuttgart, Germany.

In 1965, he received his B.S. in plant protection from the University of Cairo, Egypt, Diplom Agric in 1968, and Ph.D. in 1972 from the University of Göttingen in Germany. Dr. El Titi is a fellow of various national and international organizations and working groups. With the multidisciplinary on-farm research project of Lautenbach, Germany, he pioneered an applied research track in agriculture aimed at the development and implementation of an integrated farming system in arable crops. Focusing on soil pests he addressed long-term implications of soil tillage regimes for both soil fauna and weed communities. Dr. El Titi chaired the IOBC/WPRS Commission on Integrated Production and Endorsement of Guidelines for 7 years and for 12 years has served on the editorial boards of various scientific journals including *Agriculture, Ecosystems and Environment* and *Journal of Sustainable Agriculture*. He is the author of some 75 papers and 3 book chapters, coeditor of a book, and editor of 25 radio and 5 TV broadcasts on the topic of IFS. Dr. El Titi has served the EU Commission as consultant and evaluator, mainly on sustainable concepts of agriculture, and taught at the University of Kassel as an external lecturer on soil ecosystems, supervised Ph.D. studies at the Universities of Tübingen, Heidelberg, Hohenheim, and Weihenstephan in Germany. His annual IPM courses offered to state extension officers represented a significant contribution to the dissemination of information about IPM/IFS in southwest Germany. As an invited speaker he has contributed to various international conferences and symposia. Dr. El Titi has received numerous research grants from national and EU sources and served as coordinator of international interdisciplinary research projects on sustainable approaches in European agriculture.

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# Contents

# CHAPTER 1

# Techniques of Soil Tillage

**Karlheinz Köller**

## CONTENTS



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## 1.1 CONCEPTS OF SOIL TILLAGE IN AGRICULTURE

Soil tillage is defined as mechanical or soil-stirring actions exerted on soil to modify soil conditions for the purpose of nurturing crops. The aim of these actions is to provide a suitable environment for seed germination and crop root development while suppressing weeds, controlling soil erosion, and maintaining adequate soil moisture.

Soil tillage has a long history, with technologies that developed over many thousands of years.[1] It started with simple animal-drawn wooden tillage tools, evolved through various designs of cultivation implements, and culminated in the invention of the well-known Roman plow.[2]

The "progressive" techniques developed over time were designed to cut and mix the soil to some degree, but it was not possible to cultivate soil in excess of 15 to 20 cm in depth. The Roman plow was still used until several decades ago. Surprisingly, the Roman plow is still a reliable tillage implement in some traditional forms of agriculture in many develping countries.

The Roman plow era was followed by a new development, guided by the invention of "rough inverting plows" by Jefferson in 1796. He succeeded in developing a formula of the moldboard plow and patented a "cast iron plow," which became available in farm machinery markets in the1830s. In 1837, John Deere produced the first plow manufactured entirely with steel.

The few revolutionary developments in tillage equipment of the last millennium were simply the results of the modifications, improvements, and technical evolution of former tillage machinery designs. Technological evolution was closely associated with a remarkable increase in crop production, in particular in western countries, making farmers in these countries the most efficient (successful!) producers in the world.

Some of the progressive changes of tillage technologies have been successfully adopted, whereas others have declined in use. However, some early developments in tillage technologies may provide solutions for tackling the global problems of developing more sustainable farming and land management, particularly in the tropics and subtropics regions due to their increasing soil degradations. This vision is based on the historical development of world farming. The main objective of any agricultural business continues to be to sustain production, profitability, and, consequently, farm income. Tillage practices that do not match these requirements, i.e., cost-effectivness, positive yield responses, amelioration of soil conditions, etc., will therefore not be favored by farmers.

In response to increasing costs of fossil energy, devastating soil erosion, intensive use of fertilizers and pesticides, and environmental concerns in connection with water pollution and general operational costs, innovative farming technologies are urgently needed. Recent progress in soil tillage systems has shifted toward less intensive, ecosystem-oriented soil-cultivation technologies. Conservation tillage practices, covering a wide range of minimal cultivation intensity (i.e., less frequent and shallower cultivation techniques), seem to predominate over many other tillage alternatives (Table 1.1). In order to understand how soil tillage interacts with soil, common definitions are used. The tillage literature classifies soil-cultivation systems according to their impact on the placement and distribution of previous crop residues in soil. Based on the level or organic residues left on the soil surface, two different tillage types can be identified—conventional tillage and conservation tillage.

### 1.1.1 Conventional Tillage

Conventional tillage (also called intensive tillage) comprises all tillage types that leave less than 15% of crop residues on the soil surface after planting the next crop, or less than 1100 kg/ha of small grain residue throughout a critical erosion period. Generally, such tillage techniques include plowing or intensive tillage.

Conventional moldboard plowing followed by secondary tillage operations is still used as the preferred tillage option for soils with internal drainage problems, e.g., clay soils with poor structure or for pure sandy soils. Farmers can be locked into a cycle of continuous plow tillage. The justification for this common practice varies from yield security, residue-free soil-surface-improved seedbed preparation, and drilling (especially where precision drilling of crops is used), to weed control and burying weed seeds.

On the other hand, results of various investigations from almost all world climatic zones suggest that plowing often reveals common soil-related problems such as soil compaction, soil erosion, deteriorated water percolation, and high energy and time requirements. Increasing energy costs along with soil erosion strongly supports the search for alternative tillage techniques. Soil research of the last millennium repeatedly underlines the idea that the moldboard plow can no longer be considered the only basic implement for soil cultivation. Where soil is at risk from erosion, plowing should be used only for good specific agronomic reasons, with recent relevant scientific developments and knowledge taken into account.[4]

### 1.1.2 Conservation Tillage

Conservation tillage is any tillage and planting system that covers 30% or more of the soil surface with crop residue after planting. It is generally designed to reduce soil erosion. According to this definition, conservation tillage includes no-tillage, ridge-tillage, mulch tillage, and any systems with 30% residue remaining after planting.[5] Where soil erosion by wind is the primary concern, any system that maintains at least 1100 kg/ha of flat, small-grain residue equal on the surface throughout the critical wind erosion period[3] is highly recommended.

**Table 1.1 Conservation Tillage Trends from 1990 to 2000–Cropland Area (millions of planted hectares)**

| Tillage System | 1990 | 1992 | 1994 | 1996 | 1998 | 2000 |
|---|---|---|---|---|---|---|
| No-till/ strip-till* | 6.8 (6.0%) | 11.4 (9.9%) | 15.7 (13.7%) | 17.4 (14.8%) | 19.3 (16.3%) | 20.6 (17.5%) |
| Ridge-till* | 1.2 (1.1%) | 1.4 (1.2%) | 1.5 (1.3%) | 1.4 (1.2%) | 1.4 (1.2%) | 1.3 (1.1%) |
| Mulch-till* | 21.6 (19.0%) | 23.2 (20.2%) | 23.0 (20.0%) | 23.3 (19.8%) | 23.4 (19.7%) | 21.1 (17.9%) |
| Conservation tillage Subtotal | 29.6 (26.1%) | 35.9 (31.4%) | 40.2 (35.0%) | 42.0 (35.8%) | 44.2 (37.2%) | 43.0 (36.5%) |
| Reduced-till 15–30% cover | 28.7 (25.3%) | 29.7 (25.9%) | 29.6 (25.8%) | 30.3 (25.8%) | 31.6 (26.2%) | 24.3 (20.6%) |
| Intensive-till (< 15% cover) | 55.3 (48.7%) | 48.9 (42.7%) | 45.1 (39.3%) | 45.2 (38.5%) | 43.0 (36.2) | 50.4 (42.8%) |
| Total | 88.3 | 114.5 | 114.9 | 117.5 | 118.8 | 117.6 |

* No-till, strip-till, ridge-till, and mulch-till are considered forms of conservation tillage.

*Source:* From CTIC National Crop Residue Management Survey, 2000.

**Table 1.2 Total Area Under No-Tillage in Various Countries (hectares)**

| Country | 1998/99 |
|---|---|
| U.S.A. | 19,347,000 |
| Brazil | 11,200,000 |
| Argentina | 7,270,000 |
| Canada | 4,080,000 |
| Australia | 1,000,000 |
| Paraguay | 790,000 |
| Mexico | 500,000 |
| Bolivia | 200,000 |
| Chile | 96,000 |
| Uruguay | 50,000 |
| Others | 1,000,000 |
| Total | 45,533,000 |

*Source:* From Derpsch, 2001.

#### *1.1.2.1 No-Tillage*

With no-tillage, the soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers, or tine openers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control. Other common terms used to describe no-tillage are direct seeding, zero-till, slot-till, and slot planting. In 2000, no-tillage was used on more than 21 million of the 120 million hectares planted in America, or 17.5%, a threefold increase in no-tillage acreage since 1990. No-tillage has gained increasing prominence in other countries as well (Table 1.2).

#### *1.1.2.2 Ridge-Tillage*

With ridge-tillage, the soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed 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, cultivation, or both. Ridges are rebuilt during cultivation.

#### *1.1.2.3 Mulch-Tillage*

With mulch-tillage, the soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is accomplished with herbicides, cultivation, or both.

#### *1.1.2.4 Zone-Tillage and Strip-Tillage*

Although these are popular terms in some areas, they are not used as official survey categories because they are considered modifications of no-tillage, mulch-tillage, or "other tillage types." Less than 25% row width disturbance is considered no-tillage. More than 25% row width disturbance is considered mulch-till or "other tillage type" depending on the amount of residue left after planting.

#### *1.1.2.5 Reduced-Tillage*

Tillage types that leave 15–30% residue cover after planting, or 1200 to 2400 kg/ha of small grain residue equivalent throughout the critical wind erosion period, are included in reduced-tillage techniques.

#### *1.1.2.6 Other Tillage Types*

Other tillage types are those tillage and planting systems that may meet erosion-control goals with or without other supporting conservation practices (i.e., strip cropping, contouring, terracing, etc.).

## 1.2 MACHINERY FOR SOIL CULTIVATION

Among available soil-cultivation machinery, many different basic operations of soil tillage can be distinguished; the main ones are stubble cultivation, deeper soil-loosening cultivation, and shallower cultivations for seedbed preparation.

### 1.2.1 Stubble Cultivation

It is generally agreed that stubble cultivation is useful in both conventional and conservation tillage systems. The aim of stubble cultivation is to create favorable conditions for germination of weed seeds and crop volunteers that can be destroyed or removed before or at planting. To achieve this goal shallow cultivations are required. However, to avoid the build-up of straw mats, it is essential to incorporate the remaining chopped straw into soil prior to drilling. Chisel plows (Figure 1.1), cultivators, and disk harrows (Figure 1.2) are widely used for stubble cultivation. Cultivators fitted with additional disk runners have taken on increasing importance in recent years. These implements consist of a frame with two transverse bars and winged shares fitted to them. Hollow disk attachments that follow behind the cultivators level the soil surface. Cage rollers are used for firming up the soil surface. These implements ensure good straw incorporation.

**Figure 1.1** Cultivators fitted with additional disk runners have gained increasing importance.

**Figure 1.2** Disk harrows provide a good mixing of soil and straw.

According to published research,[6,7] combinations of chisels with forerunning disks and disks and rotary spade harrow were tested at multiple locations over several years to evaluate their suitability for stubble cultivation and conservation tillage, taking into account the efficiency of straw incorporation and power requirements. Straw soil cover was used as an indicator of straw incorporation. The studies revealed considerable differences between the single implements. The disk harrow mixed soil and straw to a significantly higher degree than the rotary spade harrow and cultivator-disk combination, resulting in a considerably smaller amount of straw left on the soil surface. In addition, more efficient straw incorporation was observed as the working speed of the rotary spade harrow increased. The disk harrow/cultivator combination brought previously incorporated straw back to the soil surface, with the result that a large amount of straw remained on the surface. As soil-erosion risk diminishes with increasing amounts of straw remaining on the surface, implements with such characteristics are desirable for regions vulnerable to erosion. Specific draught-power requirements per meter of working width are almost the same for the combination and the disk harrow. Due to superficial soil cultivation the rotary spade harrow has lower specific power requirements. The first pass (for stubble cultivation) shows the amount of straw remaining on the surface to be highly dependent on the driving speed. Increased driving speed results in better straw incorporation and, consequently, in a lower amount of straw remaining on the surface. During the second pass, which mainly targets volunteers and weed control as well as basic tillage, different speeds result in only slight differences with regard to the amount of straw covering the soil.

### 1.2.2 Soil Loosening

Soil compaction caused by heavy machinery and vehicles often requires a deep-tillage operation to loosen and break the soil. The implements used for conventional tillage include moldboard, chisel, and disk plows. Depending on their mode of operation, plows are divided into one-way and two-way or reversible plows, moldboard and disk plows, mounted/integral or semimounted/semi-integral plows, and drawn plows.

Mounted plows are attached to a tractor's three-point hitch or implement quick-coupler, and the entire plow is carried by the tractor during transport. Utilization of a quick-coupler allows hitching by backing to the plow, lifting, and then latching the coupler automatically or manually depending on the design. Mounted plows require no transport wheels or axles and are limited in size by tractor hydraulic-lift capacity and front-end stability, though models are available with up to six plow bodies.

Semimounted plows are attached to hitch links of tractors with lower-link draft sensing. The front end of a semimounted plow is carried and controlled by the tractor linkage, and the rear of the plow rides on a furrow transport wheel, which is guided by a rod from the front hitch point or through a closed-circuit hydraulic system between the plow hitch crossbar and the tailwheel. A remote hydraulic cylinder raises and lowers the rear of semimounted plows, which independently causes more uniform headlands, particularly with larger plows.

A drawn or pull-type plow is a complete unit attached to the tractor drawbar. Most models are designed for transport or lowered for plowing by remote hydraulic cylinders. Drawn plows have front and rear furrow wheels and one land wheel, which transports the plow and offers accurate plowing depth control. The rear wheel is usually held rigid during the plowing but is allowed to caster for easier turning when the plow is raised. However, many larger plows have guidable front and rear furrow wheels for better workability. Large drawn plows mostly require that the hitch be adjustable or interchangeable to permit on-land or on-furrow operation of the right rear tractor wheel. This results in pulling two plows with a tandem hitch, which consequently helps utilize the full power of a large-wheel or crawler tractor.

However, some large plows currently available have a flexible frame instead of tandem plows to permit uniform plowing over uneven surfaces.

Reversible plows are equipped with two sets of plow bodies, right and left hand, which are alternated at each end of the field and all furrows are turned in the same direction. They are used to reduce working time and are especially favorable on smaller or asymmetrically-shaped fields.

Mounted reversible plows with moldboard bodies are the most widespread in western Europe (Figure 1.3) and are offered with up to six (double) plow bodies with different working widths, clearance, and bottom distances. On very large farms, semimounted reversible plows (Figure 1.4) with up to 14 moldboard bodies with working widths of 5 m or more are receiving increasing attention. Even though they

**Figure 1.3** The use of mounted reversible plows is widespread in western Europe.

**Figure 1.4** Semimounted reversible plows are growing in importance.

are heavier, more expensive, and have higher draught requirements than one-way plows, reversible plows have been adopted because they offer considerable advantages over their counterparts in terms of operability and quality.

Optimal plow setting along with the lowest tractor-power requirements is a prerequisite for good work quality. Spindles and turnbuckles (and hydraulic systems) are used to adjust settings to tractors with different track and tire widths and to adjust for cultivation under diverse terrain conditions (slopes).

For more than 20 years, plows with infinitely variable working width (so-called adjustable plows) have been available in various custom types, in addition to standard models. The position of the plow bodies that are variably fitted to the frame can be modified using infinitely variable central hydraulics or spindles. This allows the working width to be altered. The cutting width of the individual bottoms can be adjusted within a range of 25 to 50 cm.

### 1.2.3 Loosening without Inversion

In order to reduce costs of the main tillage operation and the following seedbed preparation, especially on clay soils, it is recommended that soil be loosened prior to the main cultivation operation without turning. The simplest approach for soil loosening without inversion or mixing is to just break up soil and leave it in natural layers. All crop residues would remain on soil surface, providing an efficient tool for erosion control. If an even soil surface is required, the loosening tines should be equipped with broad duckfoot or winged shares. Special implements like the “paraplow” (Figure 1.5) result in similar positive effects, and such tools are preferred for soil loosening in conservation tillage systems. The appropriate engine power requirement depends on soil conditions, adjustments, and operating depth.

**Figure 1.5** Special implements like the “paraplow” provide sufficient soil loosening without turning and mixing.

Typically, this is between 18 and 26 kW for each loosening tool. Conventional chisel plows are not suitable for this work; they are recommended for operations up to a maximum working depth of approximately 20 cm. Implements for deeper loosening (up to 35 cm) must have sufficient clearance in order to operate trouble free at larger operating depths and with large amounts of crop residue. Prerequisites for a reasonable loosening effect are dry soils and a minimum clay content of approximately 20%.

Up till now, no specific values have been derived to indicate a measurable optimum for soil loosening with regard to plant development. Soil loosening beyond seeding depth should always be questioned with regard to both needs and necessity. If an indispensable need is identified, the intervention must be timed to fit soil moisture conditions. When there is a real need, it should be done under dry soil conditions with turning implements.

### 1.2.4 Seedbed Preparation

As has been already mentioned, presowing tillage interventions target weed and volunteer control, removal of previous crop residues from soil surface layers, in very limited cases working-in of residual herbicides, and, more importantly, preparation of seedbeds with a fine soil crumb structure. For the preparation of seedbeds on tilled sandy or light loamy soils a high-quality seedbed can be achieved in just one pass (Figure 1.6). This is econmically profitable in most cases. Simple tine harrows combined with crumbling rollers are sufficient in most cases.

Power-take-off (PTO)-driven implements (Figure 1.7), which are popular in western Europe, are used for preseeding tillage after plowing but are economical to use only on heavy loam and clay soils.

**Figure 1.6** For seedbed preparation on lighter soils, one pass with a drawn harrow is sufficient.

**Figure 1.7** In western Europe, PTO-driven harrows are very popular for seedbed preparation after plowing on heavy soils.

## 1.3 SOIL CONSERVATION TILLAGE TECHNIQUE

The essential basic requirement of conservation tillage is not to turn soils upside down. Depending on working depth and intensity, more or less residues of the previous or cover crops remain on the soil surface. The most prominent characteristic of this tillage type is the reduction of cultivation intensity and omission of soil turning. The soil-protecting effect of the crop residue reduces erosion risk, improves structural stability and trafficability, and limits compaction while reducing operation costs. Residue management is a key element in successful conservation tillage.

### 1.3.1 Residue Management

Grown crop species have a direct effect on both the target method and amount of residues. For example, small grains have the potential to produce large quantities of straw and chaff that must be managed prior to any tillage or sowing operation.

Width of combine header or swather cut has a direct effect on the type of residue management. Additional management is required as widths increase. For example, a swather width of 13.7 m put through a combine with a standard chopper that spreads the straw only 4.5 m results in a straw concentration three times as heavy as that of a full-width spread. With a 5 t/ha crop the straw concentration in the spread pattern is equivalent to the straw production in a 15 t/ha crop. Under those conditions, even the highest clearance seeding equipment will not achieve the required quality of seed placement. Similarly, the chaff row behind the combine will be much heavier when compared to a smaller header. The same trend appears with straight cutting, but if cutting height is higher than with swathing, the straw management problem is reduced proportionately.

Post-harvest stubble height has many effects on a direct seeding system. These include snow trapping capability and reduction of evaporation. In addition, it can also affect the ease with which seeding equipment passes through stubble stands. In regions where snow contributes to annual precipitation, snow trapping can increase yields. Tall stubble ranges in heights from 30 to 60 cm. Standing stubble reduces wind velocity at ground level and reduces evaporation by about 40% from wet soil surfaces compared to bare soil surfaces. This can reduce plant stress and may result in higher yields compared to tilled stubble. Excessive stubble height can create problems in direct seeding systems, especially with hoe- or shank-type seeding equipment. Seeding equipment, including those with high clearance, will have problems with tall standing stubble as the stubble will wrap around the shanks and plug the machine, preventing seed escape. High moisture content in the straw, which often occurs in the morning or evening hours, compounds the plugging problems. A rule commonly applied to the use of high-clearance equipment is that the stubble height should not exceed the row space of the drilling machine. With disk-type seeding equipment, tall standing straw reduces sowing problems as there are less crop residues on the soil surface to cause hairpinning. Lodged straw will cause seed placement problems with both disk- or shank-type equipments.

The quantity of straw produced by a crop is a function of the crop species and variety as well as environmental conditions. Cereal grains such as barley, wheat, and rye tend to produce large quantities of straw that do not break down substantially during threshing. Careful attention to management of this type of residue is required for successful direct drilling. Other crops, such as oilseed rape, mustard, short vine peas, and lentils, produce much less residue, and much of the straw may break down during threshing. Crops that break up during threshing often produce large amounts of chaff; this requires combine attachments to adequately spread chaff.

Rotary combines produce shorter straw compared to conventional combines and may not require chopping. The latter produce long straw. Consequently, combine-mounted choppers are needed to cut long straw into manageable lengths. Both types of combines require additional straw spread capacity when used with wide swaths or straight cut headers, and both systems require chaff spreading in a direct seeding system.

Choppers and spreaders have a major effect on residue management. Not all original equipment choppers and spreaders do an adequate job of straw spreading, especially at high yield levels and with increasing cutting widths.

Requirements for reasonable residue management have been widely studied, and attempts were made to describe them scientifically. These studies indicated that straw and chaff should be spread evenly over the whole cutting width.

For most farmers, the most efficient and cost-effective residue management remains at the back of the combine.

#### *1.3.1.1 Harrowing*

Harrowing can be an effective method for spreading straw. For best results, harrowing should be done as soon as possible after combining and it should take place in windy, warm conditions when straw moisture content is low. Spring harrowing is less effective than in autumn due to remaining straw in the stubble field.

High-speed harrowing will increase the spread of straw but may also knock down more stubble than at lower speeds. Harrowing does not move chaff; therefore, chaff spreading must be handled at the combine.

#### *1.3.1.2 Shredding*

Shredding refers to the cutting and chopping of standing stubble in a mowing type of operation following harvesting. There are benefits to tall stubble in a direct seeding system; however, tall stubble also creates sowing constraints. Mowing stubble in spring encourages winter snow trapping, which in turn benefits tall stubble and minimizes seeding problems associated with long stubble. Currently, there are two types of shredders on the market. The rotary shredder uses a rotary action mower with blade modifications for additional chopping. The other type of machine is a flail-type shredder. Both systems appear to do a good job of shredding under typical tall-stubble conditions. Depending on the type of residue being shredded and whether or not stones are present, maintenance costs can be significant with shredding machines.

### 1.3.2 No-Tillage

The term *no-tillage* describes a primary tillage operation performed without any preliminary soil tillage. Establishing a complete crop stand is the basic requirement of any direct-drilling system. The main concern is selection of the most adequate site-matching sowing machine. This requires knowledge of the specific conditions on the drilling site and experience of how the machine will perform under specific field conditions to achieve the least amount of soil disturbance and trouble-free operation, even in soils covered with large amounts of crop residues. The no-tillage system is enjoying increasing worldwide adoption—across climate zones, countries, and crops.[5,8,9]

#### *1.3.2.1 No-Tillage Requirements*

Soil type and texture, stones, and the actual soil moisture content may determine or limit the ability of a sowing machine to place crop seeds at optimum target depths and ensure seed–soil contact. The machine should be capable of use under the widest range of soil conditions that may occur on a farm. In addition, the packing system (soil consolidation after seeding) must meet various requirements. It should not overpack on wet and heavy soils but must also be capable of doing an adequate job on lighter soils.

The fertilizer nitrogen source on the farm and the preferred application method will also have an impact on equipment choice. Fertilizers in no-tillage systems may be applied separately as a banding, broadcast, or side or midrow banded operation, placed with the seed or in a combination of these methods. There are a number of nitrogen fertilizer types available including granular, liquid, or anhydrous ammonia.

Direct drilling usually requires more power than sowing in tilled fields. In addition, there are significant differences in draft energy requirements for the various commercially available direct-drill machine types. Equipment that separately bands fertilizer during the seeding operation has significantly higher power requirements compared to machines that place seed and fertilizer in a single row. Other factors that affect draft include opener type, soil moisture, soil texture, the specific number of openers, and operating speed.

Direct-seeding equipment must be designed to operate in heavy residue conditions and in soils that have a much wetter surface as compared with conventional tillage systems. The direct-seeding implement must create an ideal environment for seed germination and quick seedling establishment within the row while leaving the opposite conditions between the seed rows.

Additional requirements of direct-drilling equipment include residue clearance, uniform soil penetration, good depth control, desired row spacing, acceptable width of seed row, reduced soil disturbance and stubble knockdown, adaptability to seed and fertilizer delivery systems, efficient soil openers, precise fertilizer placement, simplicity of design, and acceptable equipment cost.

#### *1.3.2.2 No-Tillage Equipment*

More than 100 manufacturers worldwide offer no-tillage machines and accessories. There are different technical concepts for no-tillage machines, either with disk or tine openers, and a large variety of different components like preseeding and post-seeding tools, so that the machines can be adapted to different conditions.[9]

Although no-tillage drilling machines may perform well in fully tilled seedbeds, they were designed for planting in no-tillage, reduced-tillage, or other conservation tillage systems where sod, large amounts of surface residue, or hard soils would limit conventional types of drills. A no-tillage drilling machine should cause the least amount of soil disturbance, place seeds at the desired seeding depth, and cover the seeds with soil and firming sufficiently to encourage good seed-soil contact. It should operate trouble-free under both dry and wet soil conditions, independent of crop residue. Direct-drilling equipment is offered in a wide variety of configurations, each with its own advantages and disadvantages depending on crop type, soil type, and other factors.

#### *1.3.2.3 Drills with Disk Openers*

No-till drills with disk opener can be equipped with up to three disks per seeding unit. The disks are smooth, toothed, or curved. While curved disks can loosen and mix the soil substantially, smooth disks do not loosen the soil within the seeding area. Mostly the soil under the seed furrow is compressed evenly. In dry regions, this is favorable since minimal soil disturbance reduces risk of water loss, and the firm soil under the seed furrow improves water retention near the seed. Under wet conditions, compacted soil under the seed furrow is unfavorable since water percolation in the seed furrow can be reduced. Thus, oxygen supply in the seed furrow is reduced, which can affect plant growth. Under wet soil conditions on heavy loam or clay soils, the seed furrow may also not close properly.

The advantage of disk openers is that they operate well under heavy crop residue conditions. However, on smooth soils the straw can be pressed into the seed furrow, leaving the seeds without soil contact ("hairpinning"), which reduces germination and establishment. These problems are often observed in wet soils with poorly distributed fresh cereal crop residues following dry weather periods. These problems are significantly reduced with corn crop residues. Finally, it is important to note that the disks penetrate only because of the weight of the load placed onto the soil. To achieve the desired drilling depth under most conditions each disk should have a loading capacity of up to 2000 N; that means a no-till drill with disk openers should have an unloaded weight of at least one metric ton per meter working width.

#### *1.3.2.4 Double-Disk Drills*

This type of drill uses pairs of disk openers of equal size that converge at the front lower edge and form a V shape for opening the soil. With the introduction of zero-till sowing practices in the 1970s, the conventional double-disk drill proved inadequate for direct drilling in untilled seedbeds. Insufficient disk pressure prevented soil penetration without presowing tillage. In addition, the double-disk drill caused hairpinning (punching straw and chaff into the seed row), resulting in poor emergence especially when combined with poor penetration.

This problem was solved with the addition of heavy disk pressures, achieved by using higher opener trip settings and building heavier drills that could be ballasted for better penetration. The heavy-duty double-disk press drills perform adequately with good straw and chaff management, but in very heavy residue conditions where the disks are not able to cut through the heavy material, performance is reduced.

#### *1.3.2.5 Single-Disk Drills*

Single-disk drills consist of gangs of large diameter single disks running at approximately a 7° angle to the travel direction. The single disk acts as a cutting coulter and opens a narrow slot for the seed. The seed is dropped into the slot from the side of the opener. One type of single-disk machine uses gravity for seed and fertilizer delivery and can band fertilizer midrow between every second set of seeding disks in addition to applying seed-placed fertilizer. This type of machine uses gauge wheels to control seeding depth and to minimize soil disturbance. The opener coulter is followed by an adjustable-pressure packer wheel. Seeding disks are mounted in two rows, with the midrow banding disks positioned forward of the seeding disks in a third row. The pneumatic single-disk system places seed in a manner similar to that of the gravity system but fertilizer is placed 25 mm beside and 25 mm below the seed with a single disk, which also closes the seed row. Seed depth is controlled by moving the disk gangs up or down in relation to the frame. Packer wheels are mounted on the rear of the machine and carry part of the weight of the machine. This type of equipment uses two rows of disks mounted under a heavy wing-type cultivator frame. Both types of single-disk drills can provide high levels of disk pressure for good soil penetration and cutting of residues. Maintaining the sharpness of the disks improves the cutting and penetration action of the disks. The single-disk


**Figure 1. 8** Single-disk drills require good residue management for maximum seedling emergence.

drills do a much better job of direct drilling into untilled soil than the double-disk drills. Good residue management, especially chaff management, is required for maximum seedling emergence with these drills (Figure 1.8).

#### *1.3.2.6 Triple-Disk Drills*

The triple-disk drill consists of gangs of heavy-duty disk openers preceded by cutting coulters. The cutting coulters are offered in smooth, rippled, or serrated configurations, and their purpose is to cut through residue and slice the soil to allow for proper placement of seed with the disk openers. Triple-disk drills have high trip pressures (especially on the cutting coulter) to allow good penetration and residue cutting. The cutting coulter should be kept sharp to obtain the best residue cutting. Triple-disk drills are much improved in penetration and trash cutting compared to the heavy-duty double-disk drill and perform about the same as the single-disk drill. Good residue management, especially chaff management, is required for good seedling emergence with these drills.

#### *1.3.2.7 Hoe Drills*

Hoe drills including air drills come in a wide variety of configurations and sizes. Most drills are rugged in design and have few moving parts and on-row packing. Major differences in residue clearance and opener trip force result in hoe drills that range from excellent to unacceptable in typical direct-seeding conditions. Factors that affect the ability of a hoe drill to direct seed into untilled soil under heavy residue conditions include opener trip force, number of ranks, horizontal distance between ranks, and minimum vertical clearance under the machine. Most hoe drills have enough opener trip force to seed in direct-seeding conditions. Some of the older machines that were not designed for seeding into stubble do not have enough

**Figure 1.9** Hoe drills do a good job of direct seeding if the machine has adequate residue clearance.

spring pressure to maintain opener position in hard soil conditions. They are not suitable for direct-drilling operations. If opener deflection does not occur, the hoe drill does an excellent job of accurate seed placement for optimum germination and emergence. Residue clearance is a major feature to consider when choosing hoe drills. Three- and four-rank hoe drills clear residue much better than the older two-rank drills, which plug easily. Speed of operation is a critical factor with hoe drills; speeds above 8 km/h will disturb large amounts of soil and the rear openers will throw soil into the furrows of the leading rows. Draft requirements of hoe drills are usually higher than with disk drills depending on soil type, moisture conditions, and opener design. Hoe drills will do an excellent job of direct seeding provided that the machine has adequate residue clearance and sufficient spring trip pressure to maintain the correct opener position (Figure 1.9).

#### *1.3.2.8 Mulch Seeder*

Combinations of seedbed-preparing implements and seed drills (commonly referred to as one-pass cultivators) became very popular in the last few years as they perform tillage and seeding operations in a single pass, thereby reducing the number of trips across a field. They can generally be equipped and adjusted to leave crop residue on the soil surface rather than burying it in the soil. Seeding on mulch requires machines equipped with conventional seeders and predominantly special mulch tillers that combine disks or coulters and chisel plow in one machine, which is typically used for primary tillage. Problems occasionally occur in the presence of large quantities of straw. The working depth is controlled by packer rollers. Blockage can be a problem in wet soils interspersed with straw.

**Figure 1.10** Air seeders have gained acceptance in areas where grain is cropped in large areas of land.

### *1.3.2.9 Air Seeders*

Air seeders were developed for seeding small grain and the concept has gained acceptance in areas where grain is cropped in large areas of land, in particular in Australia, Canada, and the United States (Figure 1.10). The air seeder consists of two separate units—a tillage tool, such as a chisel, field cultivator, or sweep blades, and a seed tank—operating together to form one seeding implement. This combination allows the field operations of tilling, seeding, and fertilizing to be accomplished in one pass. The equipment is commonly modified for direct seeding and has the basic components of any seeding machine including furrow opener and seed-metering and seed-placing devices. Cultivators were initially designed to work for primary and secondary tillage, and most are capable of working in high levels of crop residue. Heavy- and medium-duty cultivators are heavy enough to penetrate in untilled ground. Light-duty cultivators do not have the penetration ability to work in full direct-drill situations. If the cultivator could be used to till an unworked stubble field to the depth required for seeding and fertilizing, it can be used for direct seeding.

When double-shoot openers are installed on a cultivator, tillage forces may be even higher than deep-banding fertilizer with sweeps in wet clay soils. In these situations, heavy-duty cultivator trip forces will be required to hold the opener in the soil, and implement draft will be high. Where stones are a problem, increasing the weight of the opener above the weight of the sweeps will cause extra wear to the trip mechanism. After tripping over a rock, the shank generally slams back into position abruptly. Any extra weight or increased length to the tip of the shank exerts extra force on the trip and shank attachment mechanism. When a very heavy opener is used and the soil contains a lot of rocks, severe damage to trips may occur in a relatively short time. In general, the heavier trip mechanisms will handle the heavier openers with fewer problems, but because of the higher tripping force rocks will cause more opener damage, and increased maintenance should be expected. The main concept to keep in mind in modifying an air seeder is to try to make the cultivator seeding tool more like a drill. This is done by replacing the cultivator sweeps with narrow hoe openers, adding on-row packers or opener/packer units, and, when necessary and possible, improving depth control and ground-following capability. Conversion of a rigid hitch to a floating hitch will generally produce the most significant improvement in ground-following capability.

Air seeders equipped with knives, narrow hoes, or narrow sweeps and on-row packing are an excellent way to get started in direct drilling. Residue clearance and soil penetration are excellent with these machines, and optimum seed placement can be achieved with machines equipped with floating hitches, flexible frames, and good depth control.

## 1.4 POST-SEEDING IMPLEMENTS

Post-seeding implements are used to cover seeds with soil and to improve soil contact with the seeds. Often, they are used to control the working depth of the openers. The most frequent post-seeding implements of direct-seeding drills are pressure rolls. With some drills the pressure rolls are directly behind the disk opener and press the seeds into the open seeding furrow. More frequently, pressure rolls run on the soil surface over the seeding furrow. Additionally, they are usually used for depth control of the disk openers. Pressure rolls are offered in various forms (smooth, bars, fingers, etc.) and of different manufactured materials (steel, cast iron, plastic, rubber, etc.).

Rollers or packers behind the disk openers serve as pressure rolls for pressing the seeds slightly, covering seed with soil, and also for depth control. Rollers or packers are rarely built rigidly over the entire work width of the direct seeding machines, but are divided into segments. Some direct-seeding machines are also equipped with closing tools for covering the seeds with soil. At present, there is still no direct-drilling machine that can continuously produce high-quality work under all conditions. The biggest problems are moist soils and large amounts of fresh crop residue, so the farmer must select the most suitable drill for his specific site location.

In summary, the following points should be considered when selecting a machine: stable and simple design, low susceptibility to trash blockage, sufficient weight, limited soil loosening, susceptibility to wear, sufficient coverage of seeds, simple handling, even seed depth, and good seed–soil contact. If possible, they should be tested and evaluated in comparative field demonstrations.[9]

### 1.4.1 Modes of Action

Changes in soil physical properties can be expected when converting to use of conservation tillage (see Chapter 2). Increases in soil organic matter content, soil porosity, soil macropores, and soil infiltration rates appear when fields are managed by conservation tillage. No-tillage reduces water runoff and improves further soil structural parameters.

Soil quality is a measure of the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Soil quality is evaluated with the help of indicators, which may be physical, chemical, and biological characteristics.

When oxygen is added to the plow depth, as in conventional tillage methods, biological activity increases temporarily, and microorganisms rapidly decompose organic matter. This high rate of biological activity in a system of low residue inputs decreases soil organic matter, decreasing the quality of the soil. A no-till system with crop rotations or cover crops balances this decomposition with inputs of fresh organic matter from crop roots and residues, providing a more stable system. As a result, organic matter levels are maintained, or even increased, and biological activity is improved. High respiration with high inputs indicates good soil quality. Earthworm activity in the soil improve water movement, break down residues, distribute residues, improve nutrient availability, and enhance soil structure and soil stability. While not essential to high-quality soil, earthworms usually indicate a healthy system with favorable moisture conditions. Conventional tillage usually suppresses earthworms in soil.

Aggregate stability quantitatively measures soil vulnerability to destructive forces such as water or wind. Like respiration, soil stability is correlated with organic matter levels. Because of its weak structure, excessively tilled soil will lose integrity, or fall apart quickly, and crust when exposed to rainfall. Soil with more organic matter and surface residue, however, will remain stable and will not crust. The key for improving soil structural stability is to produce plenty of roots and residue and leave it intact.

Infiltration rate, or the rate at which water moves into soil, correlates with organic matter levels, earthworm density, and soil porosity. Good infiltration reduces erosion and helps keep vital topsoil and organic matter in place. In addition, water that infiltrates into soil is unlikely to run off fields and carry soil, nutrients, and chemicals to nearby water sources. In high-residue situations, no-till systems can have infiltration rates four to eight times greater than conventional tillage systems. Any process that changes the soil–water balance may affect the movement and accumulation of salts in the soil; when excess water on the soil surface evaporates, salts accumulate on the surface. Practices to reduce excess salts include irrigation management, crop rotation, manure application, and conservation tillage, all of which improve infiltration and permeability.

Permanent use of conservation tillage systems is likely to reduce nitrate loss from soil through leaching. An understanding of the soil quality is an essential step to making management decisions that improve soil productivity. Conservation practices, including no-tillage, weed and pest management, and crop nutrient management, can help increase organic matter and infiltration rates, support earthworm populations, and maintain ideal soil chemical conditions. Improving soil quality is a critical step to improving and enhancing soil and water quality, generating greater profits, and securing a brighter future on the farm.

Soils that have undergone no-tillage cultivation for several years differ substantially from plowed areas and develop properties similar to those of grassland soils.

Crop residues protect soil from erosion and enhance soil biological activity. In consequence, the humus content rises and abundance and diversity of beneficial soil organisms increase. Earthworm studies (see Chapter 9) on no-tillage fields demonstrated up to tenfold higher abundance 3 to 4 years after conversion. A stable macropore system with high pore continuity is formed by roots and earthworms, encouraging soil aeration. Due to the reduction in tillage and the presence of a mulch layer on the soil surface, losses of water are significantly reduced, so that more water is available for the plant on no-till plots, with increasing yield potential in dry regions. With the stable, continuous macropore system, water infiltration under no-till environments is about twice that on plowed plots, substantially reducing water runoff and soil erosion.

Many soil microorganisms, both beneficials and pathogens, are known to be sensitive to changes in aeration, pore-size distribution, and soil-water status, which can be affected by passing vehicles. The bearing capacity and the trafficability of no-tilled fields is substantially better than that of plowed surfaces, since the soil structure is significantly more stable.

Finally, no-tillage reduces energy cost and $CO_2$ inputs to the atmosphere. According to estimates, the amount of carbon that is fixed organically in soil is twice as high as the quantity of carbon in the atmosphere. The extension of crop production during the nineteenth and twentieth centuries has caused the percentage of atmospheric $CO_2$ to increase due to the cultivation of woodland as well as to slash-and-burn farming. Generally, intensive tillage causes the emission of large amounts of $CO_2$. Measurements were conducted to establish the amount of $CO_2$ released into the atmosphere within 5 h after cultivation with different implements.[10] The highest values were measured after plowing (81.3 $g/m^2$). Conservation tillage with different implements reduced emissions to 25 $g/m^2$. The lowest $CO_2$ emissions (5.9 $g/m^2$) were measured on the direct-drilling plot. It is predicted that, if soil-protecting methods were applied to cultivation of 76% of the soil in the U.S. alone, 400 million tons of carbon could be fixed in the soil by 2020.[11] Significant savings of $CO_2$ emissions could be achieved if minimum tillage or direct drilling were practiced on a global scale.[14] Therefore, the changeover to conservation tillage and direct drilling can make a contribution to the reduction of $CO_2$ emissions.

## 1.5 COMPARISON OF FUEL CONSUMPTION AND COST

Apart from soil-protection effects, favorable water balance, and reduced energy cost, acknowledged to be of increasing global significance, conservation tillage systems have clear economic advantages beyond the farm gates. These alone are sufficient to justify the application of conservation tillage technologies, in particular in dry regions. Moving away from plowing could lead to a reduction of approximately 50 to 70% in power and energy use.[12] Depending on soil type and the exact method of cultivating stubbles and seeding operations, corresponding fuel savings would range from 20 to 50 l/ha. In monetary terms, the reduction in variable costs range from US$20 to $60 per hectare. Where use of the plow is eradicated or greatly minimized, in some cases one or more tractors and one or more workers can be saved.[9]

On large farms, the scale of areas requiring cultivation at critical times makes the use of 3- to 4-m-wide, PTO-driven implements for cultivation impractical. With larger working widths and more powerful tractors, no-plow tillage allows large farms to reduce costs considerably. A comparison of the economic potentials of different tillage systems, i.e., conventional and conservation tillage, for large farms is shown in Figures 1.11 and 1.12.[13] Similar savings in labor were obtained in Canada and other countries where a no-till system was favored over a conventional one. Diesel fuel

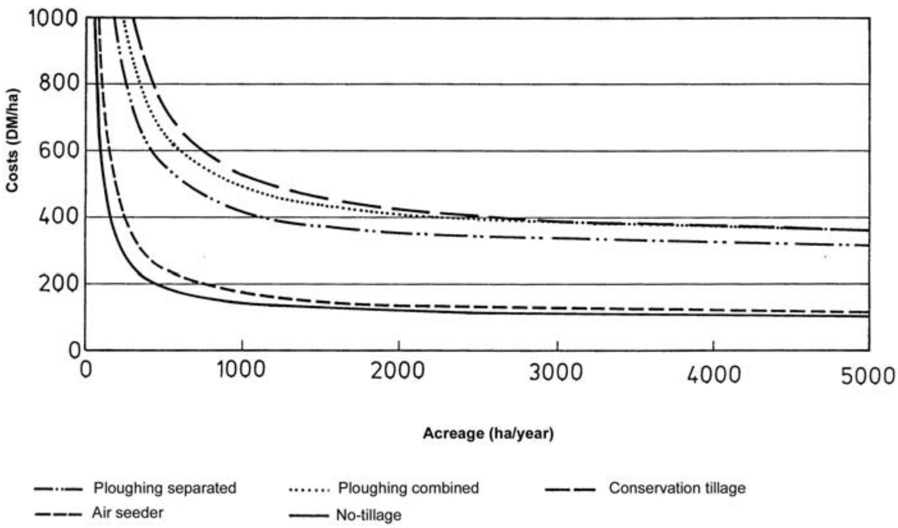


**Figure 1.11** Cost for seedbed preparation in light soils.

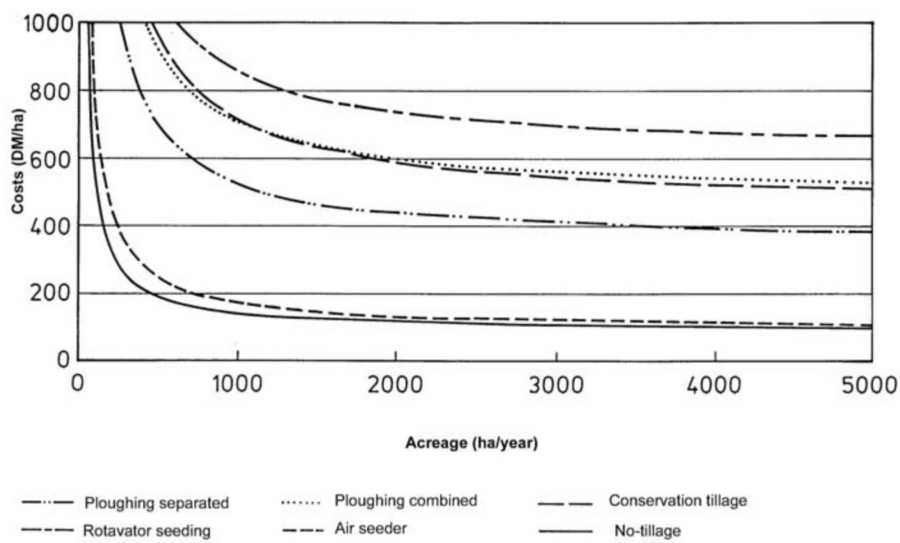


**Figure 1.12** Costs for seedbed preparation in heavy soils.

**Table 1.3 Comparison of Fuel Consumption for Various Tillage Systems, Liters per Hectare**

| Plow | Chisel Plow | Disk | Ridge Plant | No-Tillage |
|---|---|---|---|---|
| 49.43 (100%) | 31.27 (63.25%) | 28.36 (57.38%) | 25.18 (50.94%) | 13.39 (27.08%) |

requirements from a Nebraska University on-farm survey for various tillage and planting systems are presented in Table 1.3. These results are similar to findings for a number of sites.[12]

Results of the economic evaluation of conventional and conservation tillage are presented in Figures 1.11 and 1.12. For farm sizes up to 1000 ha, a rapid decrease in costs for seedbed preparation can be observed for all types of reduced cultivation and for all types of soils. In general, the costs for no-tillage cultivation are significantly lower compared with conventional or conservation tillage. It becomes evident that on large farms, cultivator drilling (air seeder) and direct drilling are the only alternatives to traditional tillage methods using the plow. On farms with several thousands hectares, no-plow tillage with PTO-driven implements—a method often applied in western Germany—is clearly more expensive than conventional tillage with a plow. When considering the economic effects of conversion from tillage to conservation tillage, one should always keep in mind that the changes are part of a complex process. A successful conversion requires precise planning and preparation. An economic evaluation of the conversion requires a full-cost pricing of the complete crop production system. Simple machinery cost calculations or break-even analyses are insufficient.[9]

Although no-tillage holds great potential for saving labor hours and costs, it has gained only relatively little acceptance in Germany and in Europe due mostly to the insufficient capacity of present machinery to deal with large amounts of straw on the soil surface.

## REFERENCES


1. Söhne, W., Bodenbearbeitungs- und Erntetechnik. Ein historischer Abriß von Anbeginn bis heute, DLG-Verlag, Frankfurt, 1992.
2. Herrmann, K., Pflügen, Säen, Ernten. Landarbeit und Landtechnik in der Geschichte, Rowohlt Taschenbuch Verlag GmbH, Reinbek, 1985.
3. CTIC, National Crop Residue Management Survey, 1994, Conservation Technology Information Center, West Lafayette, 1994.
4. Conservation Agriculture, A Worldwide Challenge, *Proc. 1st World Congr. Conserv. Agric.*, Madrid, October 1–5, 2001, Vols. I and II, 2001.
5. Derpsch, R., Conservation tillage, no-tillage and related technologies, in *Proc. 1st World Congr. Conserv. Agric.*, Madrid, October 1–5, 2001 Conservation Agriculture, A Worldwide Challenge, Vol. I, 161–170, 2001.
6. Köller, K., Straw disposal in Germany, *Power Farming*, 62, 10, 12–15, 1983.
7. Köller, K. and Rump, B., Tillage, in *Agricultural Engineering*, Yearbook 2000, 12, 79–84, Landwirtschaftsverlag GmbH, Münster, 2000.
8. Allen, H., *Direct Drilling and Reduced Cultivations*, Farming Press Limited, Ipswich, U.K., 1981.