No-tillage Seeding in Conservation Agriculture

Second Edition

This book is dedicated to the scientists and students whose work is reviewed, together with their long-suffering families. Such people were driven by a desire to make no-tillage as sustainable and risk-free as possible, and in the process to make food production itself sustainable for the first time in history. The odds were great but the results have been significant and will have far-reaching consequences.

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C.J. Baker, K.E. Saxton, W.R. Ritchie, W.C.T. Chamen, D.C. Reicosky, M.F.S. Ribeiro, S.E. Justice and P.R. Hobbs

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Foreword to the Second Edition

The Food and Agriculture Organization (FAO) has a history of supporting the development and extension of conservation agriculture cropping systems. No-tillage seeding is one of the key operations of conservation agriculture; no-till seeding, together with the principles of cover crops and crop rotation, constitute conservation agriculture. The availability of suitable technology and equipment is a necessary precondition for making conservation agriculture work. Special equipment is required not only for direct seeding and planting, but also for the management of crop residues and cover crops.

The earlier book, entitled *No-tillage Seeding: Science and Practice*, by Baker, Saxton and Ritchie, was, at the time of its publication, one of the most comprehensive publications covering the engineering aspects of no-tillage seeding as well as the agronomic and environmental background for no-tillage farming. It has been valuable as a reference for scientists and students, and also as a guide for practitioners. A case was reported where a farmer after reading this book bought a no-till planter and converted his farm to no-till.

This new book, *No-tillage Seeding in Conservation Agriculture*, provides a broader picture of the equipment used in conservation agriculture cropping systems. It includes chapters on material not previously covered, for example, the management of crop residues and cover crops, preparation for the no-tillage seeding operation, and controlled-traffic farming as a complementary technology. There are also new chapters describing no-tillage seeding technologies for small-scale farmers. Technology developments from South America and South Asia are described, including manual equipment, draught-animal equipment and equipment for power tillers. The subject of greenhouse gases as driving forces for climate change is also discussed in a chapter on carbon sequestration under no-tillage farming systems.

We hope that this book contributes to a better understanding of the engineering components of conservation agriculture. It is also our wish that it helps with the introduction and expanded application of this technology. Conservation agriculture is a valuable approach to cropping that can lead to more productive, competitive and sustainable agricultural systems with parallel benefits to the environment and to farmers and their families.

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Rome, November 2005

Preface

And he gave for his opinion, that whoever could make two ears of corn or
two blades of grass to grow upon a spot of ground where only one grew before,
would deserve better of mankind, and do more essential service to
his country than the whole race of politicians put together.

Jonathan Swift, *Gulliver's Travels* (1726)
'A Voyage to Brobdingnag'

The authors of this book describe and analyse no-tillage technologies, particularly those related to no-tillage seed drilling, from a variety of accumulated experiences over the past 40 years. Most of us set out to discover why no-tillage did not always work and how to overcome these obstacles. The more we learned the more appealing no-tillage farming became. The understanding and system science have now been acquired and tested to the point where we are ever more confident it represents the future of farming.

Some of the reported research started from knowledge that none of the traditional drills, planters or opener technologies used for tillage farming then provided a fail-safe methodology for untilled, residue-covered soils. Inevitably that resulted in new machine designs and evaluations, and combined associated technologies. The guiding premise was that every functional part of any new design had to have a verifiable scientific reason and performance, which often resulted in a long evolution.

No functional assumptions were made. All commonly held ideas about what seeds required were challenged or discarded and new experiments set up to determine their requirements specifically in untilled soils. This new knowledge was combined with whatever existing knowledge proved still to be applicable. In other cases the rules for tilled soils simply did not apply, or were proved wrong, when applied to untilled soils. Undisturbed soils were found to provide different resources and challenges from those of tilled soils, thus requiring different approaches to seed sowing.

Other authors report what happened to soil when ploughing ceases. Everyone by now knows that no-tillage is good and ploughing is bad for the soil, but what are the causal mechanisms and can the improvements or damage be quantified? Can the gains be further improved by techniques such as controlled-traffic farming? Still other authors studied available equipment and management methods and relate these to no-tillage systems and applications, large and small. Only when the capabilities of modern no-tillage equipment are understood and fully integrated into a crop production enterprise can it be fully quantified and realistic local recommendations made.

Collectively these authors have provided a comprehensive overview of what makes a successful no-tillage enterprise work. This includes machinery design and operating principles, the interactions of machines with the soil, the importance of parallel inputs, such as herbicides, pesticides and controlled traffic, and the management of the system as a whole, including quantifying the importance of soil carbon and tracking carbon dioxide emissions as a function of soil disturbance. They have also provided a guide to experimental procedures for evaluation of variables.

The book is not intended to be a blueprint on how to design any one style of no-tillage machine, component or system. It is a record of the comparative performances of several different machine design options and management practices, tested under controlled scientific conditions, and how these have been found to integrate into a whole no-tillage system. Much of the information is about the biological performance of machines and soils, since both primarily perform biological functions. But mechanical performance is not ignored either. The interface between the two is particularly important.

The reader is invited to place his or her own value on the relevance of the data presented. The relevance some of the authors placed on the data led to the design of the disc version of a winged opener, called Cross Slot®. Others will see different things in the data. However, independent research and field experience have increasingly shown that the data and the conclusions drawn from them have been remarkably accurate and prophetic.

The relevance of the book is that it illustrates that there are now ways and means to make no-tillage more fail-safe than tillage and to obtain crop yields not only equal to those from tillage but, in many cases, superior. Untilled soils contain greater potential to germinate, establish and grow plants than tilled soils ever did. And, of course, they are much more environmentally friendly. The problem for humankind has been to learn and understand how to harness that potential. We hope this book goes some way towards achieving that objective.

The book expands on the first edition, entitled *No-tillage Seeding: Science and Practice* (Baker, Saxton and Ritchie, ISBN 0 85199 103 3, first published by CAB International in 1996 and reprinted in 2002).

1 The ‘What’ and ‘Why’ of No-tillage Farming

C. John Baker and Keith E. Saxton

No farming technique yet devised by humankind has been anywhere near as effective as no-tillage at halting soil erosion and making food production truly sustainable.

Since the early 1960s farmers have been urged to adopt some form of conservation tillage to save the planet’s soil, to reduce the amount of fossil fuels burnt in growing food, to reduce runoff pollution of our waterways, to reduce wind erosion and air quality degradation and a host of other noble and genuine causes. Charles Little in *Green Fields Forever* (1987) epitomized the genuine enthusiasm most conservationists have for the technique. But early farmer experience, especially with no-tillage, suggested that adopting such techniques would result in greater short-term risk of reduced seedling emergence, crop yield or, worse, crop failure, which they were being asked to accept for the long-term gains outlined above.

Farmers of today were unlikely to see many short-term benefits of their conservation practices. Leaving a legacy of better land for future generations was one thing, but the short-term reality of feeding the present generation and making a living was quite another. Not unreasonably, short-term expediency often took priority. Although some countries already produce 50% or more of their food by no-tillage (e.g. Brazil, Argentina and Paraguay), it is estimated that, worldwide, no-tillage currently accounts for only some 5–10% of food production. We still have a long way to go. Certainly there have been good, and even excellent, no-tillage crops, but there have also been failures. And it is the failures that take prime position in the minds of all but the most forward-looking or innovative farmers.

Tillage has been fundamental to crop production for centuries to clear and soften seedbeds and control weeds. So now we are changing history, not always totally omitting tillage (although that is certainly a laudable objective) but significantly altering the reasons and processes involved. Most people understand tillage to be a process of physically manipulating the soil to achieve weed control, fineness of tilth, smoothness, aeration, artificial porosity, friability and optimum moisture content so as to facilitate the subsequent sowing and covering of the seed. In the process, the undisturbed soil is cut, accelerated, impacted, inverted, squeezed, burst and thrown, in an effort to break the soil physically and bury weeds, expose their roots to drying or to physically destroy them by cutting. The objective of tillage is to create a weed-free, smooth, friable soil material through which relatively unsophisticated seed drill openers can travel freely.

During no-tillage, few, if any, of the processes listed above take place. Under no-tillage, other weed-control measures, e.g. chemicals, must substitute for the physical disturbance during tillage to dislodge, bury or expose existing weeds. But part of the tillage objective is also to stimulate new weed seed germination so that fresh weeds get an 'even start' and can therefore be easily killed in their juvenile stages by a single subsequent tillage operation. No-tillage, therefore, must either find another way of stimulating an 'even start' for new weeds, which would then require a subsequent application of herbicide or avoid stimulating new weed growth in the first place.

In his keynote address to the 1994 World Congress of Soil Science, Nobel Prize-winner Norman Borlaug estimated that world cereal production (which accounts for 69% of world food supply) would need to be raised by 24% by the year 2000 and doubled by the year 2025. More importantly, Borlaug estimated that grain yields would need to increase by 80% over the same time span because creating new arable land is severely limited throughout the world. Until now, yield increases have come largely from increased fertilizer and pesticide use and genetic improvement to the species grown. The challenge is for no-tillage to contribute to future increases, while simultaneously achieving resource preservation and environmental goals. But this is only going to happen if no-tillage is practised at advanced technology levels.

The notion of sowing seeds into untilled soils is very old. The ancient Egyptians practised it by creating a hole in untilled soil with a stick, dropping seeds into the hole and then closing it again by pressing the sides together with their feet. But it was not until the 1960s, when the herbicides paraquat and diquat were released by the then Imperial Chemical Industries Ltd (now Syngenta) in England, that the modern concept of no-tillage was born because now weeds could be effectively controlled without tillage.

For the preceding decade it had been recognized that, for no-tillage to be viable, weeds had to be controlled by some other method than tillage. But the range of agricultural chemicals then available was limited because of their residual effects in the soil. A delay of several weeks was necessary after spraying before the new crop could be safely sown, which partly negated saving of time, one of the more noteworthy advantages of no-tillage compared with tillage. Paraquat and diquat are almost instantly deactivated upon contact with soil. When sprayed onto susceptible living weeds, the soil beneath is almost instantly ready to accept new seeds, without the risk of injury.

This breakthrough in chemical weed control spawned the birth of true no-tillage. Since then, there have been other broader-spectrum translocated non-residual chemicals, such as glyphosate, which was first introduced as Roundup by Monsanto. Other generic compounds, such as glyphosate trimesium (Touchdown) and glufosinate ammonium (Buster), were later marketed by other companies, which have expanded the concept even further.

In other circumstances non-chemical weed control measures have been used. These include flame weeding, steam weeding, knife rolling and mechanical hand weeding. None of the alternative measures has yet proved as effective as spraying with a translocated non-residual herbicide. These chemicals are translocated to the roots of the plant thereby affecting a total kill of the plant. Killing the aerial parts alone often allows regeneration of non-affected plant parts.

The application of any chemicals within agricultural food production correctly raises the question of human and biological safety. Indeed, many chemicals must be very carefully applied under very specific conditions for specific results, just like any of the modern pharmaceuticals that assist in cures and controls. Through careful science, and perhaps some good fortune, glyphosate has been found to be non-toxic to any biological species other than green plants and has been safely used for many years with virtually no known effects other than the control of undesired plants.

An even more recent development using genetic modification of the crops themselves has made selected plant varieties immune to very specific herbicides such as glyphosate. This unique trait permits planting the crop without weed concerns until the crop is well established and then spraying both the crop and the weeds with a single pass. The susceptible weeds are eliminated and the immune crop thrives, making a full canopy that competes with any subsequent weed growth, usually through to harvest. Only selected crops such as maize and soybean are currently commonly used in this fashion, but they have already attained a very significant percentage of the world's acreage. With this success, other important food and fibre crops are being modified for this capability.

What is No-tillage?

As soon as the modern concept of no-tillage based on non-residual (and mostly translocated) herbicides was recognized, everyone, it seems, invented a new name to describe the process. 'No-tillage', 'direct drilling' or 'direct seeding' are all terms describing the sowing of seeds into soil that has not been previously tilled in any way to form a 'seedbed'. 'Direct drilling' was the first term used, mainly in England, where the modern concept of the technique originated in the 1960s. The term 'no-tillage' began in North America soon after, but there has been recent support for the term 'direct seeding' because of the apparent ambiguity that a negative word like 'no' causes when it is used to describe a positive process. The terms are used synonymously in most parts of the world, as we do in this book.

Some of these names are listed below with their rationales, some only for historical interest. After all, it's the process, not the name, that's important.

Chemical fallow, or *chem-fallow*, describes a field currently not cropped in which the weeds have been suppressed by chemical means.

Chemical ploughing attempted to indicate that the weed control function usually attributed to ploughing was being done by chemicals. The anti-chemical lobby soon de-popularized such a restrictive name, which is little used today.

Conservation tillage and *conservation agriculture* are the collective umbrella terms commonly given to no-tillage, minimum tillage and/or ridge tillage, to denote that the inclusive practices have a conservation goal of some nature. Usually, the retention of at least 30% ground cover by residues after seeding characterizes the lower limit of classification for conservation tillage or conservation agriculture, but other conservation objectives include conservation of money, labour, time, fuel, earthworms, soil water, soil structure and nutrients. Thus, residue levels alone do not adequately describe all conservation tillage or conservation agricultural practices and benefits.

Disc-drilling reflects the early perception that no-tillage or direct drilling could only be achieved with disc drills (a perception that proved to be erroneous); thus some started referring to the practice as disc-drilling. Fortunately the term has not persisted. Besides, disc drills are also used in tilled soils.

Drillage was a play on words that suggested that under no-tillage the seed drill was in fact tilling the soil and drilling the seed at the same time. It is not commonly used.

Minimum tillage, *min-till* and *reduced tillage* all describe the practice of restricting the amount of general tillage of the soil to the minimum possible to establish a new crop and/or effect weed control or fertilization. The practice lies somewhere between no-tillage and conventional tillage. Modern practice emphasizes the amount of surface residue retention as an important aim of minimum or reduced tillage.

No-till is a shortening of no-tillage and is not encouraged by purists, for grammatical reasons.

Residue farming describes conservation tillage practices in which residue retention is the primary objective, even though many of the 'conservation tillage' benefits previously mentioned may also accrue.

Ridge tillage, or *ridge-till*, describes the practice of forming ridges from tilled soil into which widely spaced row crops are drilled. Such ridges may remain in place for several seasons while successive crops are no-tilled into the ridges, or they might be re-formed annually.

Sod-seeding, *undersowing*, *oversowing*, *overdrilling* and *underdrilling* all refer to the specific no-tillage practice of drilling new pasture seeds into existing pasture swards, collectively referred to as pasture renovation. The correct use of the term oversowing does not involve drilling at all, but rather is the broadcasting of seed on to the surface of the ground. Each of the other listed terms involves drilling of the seed.

Stale seedbed describes an untilled seedbed that has undergone a period of fallow, usually (but not exclusively) with periodic chemical weed control.

Strip tillage, or *zone tillage*, refers to the practice of tilling a narrow strip ahead of (or with) the drill openers, so the seed is sown into a strip of tilled soil but the soil between the sown rows remains undisturbed. 'Strip tillage' also refers to the general tilling of much wider strips of land (100 or more metres wide) on the contour, separated by wide fallowed strips, as an erosion-control measure based on tillage.

Sustainable farming is the end product of applying no-tillage practices continuously. Continuous cropping based on tillage is now considered to be unsustainable because of resource degradation and farming inefficiencies, while continuous cropping based on no-tillage is much more likely to be sustainable on a long-term basis under most agricultural conditions. Some discussions of 'sustainability' include broader considerations beyond the preservation of natural resources and food production, such as economics, energy and quality of life.

Zero-tillage was synonymous with no-tillage and is still used to a limited extent today.

The most commonly identified feature of no-tillage is that as much as possible of the surface residue from the previous crop is left intact on the surface of the ground, whether this be the flattened or standing stubble of an arable crop that has been harvested or a sprayed dense sward of grass. In the USA, where the broad category of conservation tillage is generally practised as an erosion-control measure, the accepted minimum amount of surface covered by residue after passage of the drill is 30%. Most practitioners of the more demanding option of no-tillage or direct seeding aim for residue-coverage levels of at least 70%.

Of course, some crops, such as cotton, soybean and lupin, leave so little residue after harvest that less than 70% of the ground is likely to be covered by residue even before drilling. Such a soil, however, can be equally well direct drilled as a fully residue-covered soil in the course of establishing the next crop. Thus it is also regarded as true no-tillage. What is no-tillage to one observer may not be no-tillage to another, depending upon the terms of reference and expectations of each observer.

The most fundamental criterion common to all no-tillage is not the amount of residue remaining on the soil after drilling, but whether or not that soil has been disturbed in any way prior to drilling. Even then, during drilling, as will be explained later, such a seemingly unambiguous definition becomes confused when you consider the actions of different drills and openers in the soil. Some literally till a strip as they go, while others leave all of the soil almost undisturbed. So the untilled soil prior to drilling might well become something quite different after drilling.

This book is focused on the subject of 'no-tillage' in which no prior disturbance or manipulation of the soil has occurred other than possibly minimal disturbance by operations such as shallow weed control, fertilization or loosening of subsurface compacted layers. Such objectives are entirely compatible with true no-tillage. Any disturbance before seeding is expected to have had very minimal surface disturbance of soil or residues.

Depending on the field cropping history and the available seeding machine capability, it may be necessary to perform one or more very minimal-disturbance functions for best crop performance. The most common of these needs is the application of fertilizer when that function can not be made part of the seeding operation. Early no-tillage seeding trials often simply broadcast the fertilizer over the soil surface expecting it to be carried into the soil profile by precipitation, but two things became readily apparent. First, only the nitrogen component was moved by water, leaving the remaining forms, such as phosphorus and potassium, on or near the soil surface. And even then preferential flow of soluble nitrogen down earthworm and old root channels often meant that much of it bypassed the juvenile roots of the newly sown crop (see Chapter 9).

Secondly, emerging weeds between the crop plants readily helped themselves as the first consumers of this fertilizer and 'outgrew' the crop. Subsurface placement is now the only recommended procedure, often banded near the seeding furrow or emerging crop row.

Where herbicides are less available, it may prove more economical to perform a weeding pass prior to seeding to reduce the weed pressures on the emerging crop. If used in conservation agriculture, this operation must be very shallow and leave the soil surface and residues nearly intact ready for the seeding operation. Typical implements that can achieve this quality of weed control are shallow-running V-shaped chisels or careful hand hoeing.

Historical compaction arising from many years of repetitive tillage often cannot be undone 'overnight' by switching to no-tillage. While soil microbes are rebuilding their numbers and improving soil structure, a process that may take several years even in the most favourable of climates, historical compaction may still exist. Temporary relief can often be achieved by using a subsoiling machine that cracks and bursts subsurface zones while causing only minor disturbance at the surface.

But sometimes overly aggressive subsoilers cause so much surface disturbance that full tillage is then required to smooth the surface again. This seemingly endless negative spiral must be broken if the benefits of no-tillage are to be gained. All that is required is a less aggressive or shallow-acting subsoiler that allows no-tillage to take place after its passage without any further 'working' of the soil surface layer.

Another effective method is to sow a grass or pasture species in the compacted field and either graze this with light stocking or leave it ungrazed as a 'set-aside' area for a number of years before embarking on a no-tillage programme thereafter without tillage. A rule of thumb for how many years of pasture are required to restore soil organic carbon (SOC) and ultimately the structural damage done by tillage was established by Shepherd *et al.* (2006) for a gley soil (Kairanga silty clay loam) under maize in New Zealand soils as:

> Where tillage has been undertaken for up to 4 consecutive years, it takes approximately 1½ years of pasture to restore SOC levels for each year of tillage.
>
> Where tillage has been undertaken for more than 4 consecutive years, it takes up to 3 years of pasture to restore SOC levels for each year of tillage.

The rate of recovery of soil structure lags behind the recovery rate of SOC. The more degraded the soil, the greater the lag time.

Why No-tillage?

It is not the purpose of this book to explore in detail the advantages and disadvantages of either no-tillage or conservation tillage. Numerous authors have undertaken this task since Edward Faulkner and Alsiter Bevin questioned the wisdom of ploughing in *Ploughman's Folly* (Faulkner, 1943) and *The Awakening* (Bevin, 1944). Although neither of these authors actually advocated no-tillage, it is interesting to note that Faulkner made the now prophetic observation that 'no one has ever advanced a scientific reason for ploughing'. In fact, long before Faulkner's and Bevin's time, the ancient Peruvians, Scots, North American Indians and Pacific Polynesians are all reported to have practised a form of conservation tillage (Graves, 1994).

None the less, to realistically focus on the methods and mechanization of no-tillage technologies, it is useful to compare the advantages and disadvantages of the technique in general as measured against commonly practised tillage farming. The more common of these are summarized below with no particular order or priority. Those followed by an * can be either an advantage or a disadvantage in differing circumstances.

In Chapter 2 we shall expand on the advantages (benefits) of no-tillage, particularly those derived either directly or indirectly from enhancement of SOC levels, and in Chapter 3 we shall examine the risks of no-tillage in more detail.

Advantages

Fuel conservation. Up to 80% of fuel used to establish a crop is conserved by converting from tillage to no-tillage.

Time conservation. The one to three trips over a field with no-tillage (spraying, drilling and perhaps subsoiling) results in a huge saving in time to establish a crop compared with the five to ten trips for tillage plus fallow periods during the tillage process.

Labour conservation. Up to 60% fewer person-hours are used per hectare compared with tillage.

Time flexibility. No-tillage allows late decisions to be made about growing crops in a given field and/or season.

Increased soil organic matter. By leaving the previous crop residues on the soil surface to decay, soil organic matter near the surface is increased, which in turn provides food for the soil microbes that are the builders of soil structure. Tillage oxidizes organic matter, resulting in a cumulative reduction, often more than is gained from incorporation.

Increased soil nitrogen. All tillage mineralizes soil nitrogen, which may provide a short-term boost to plant growth, but such nitrogen is 'mined' from the soil organic matter, further reducing total soil organic matter levels.

Preservation of soil structure. All tillage destroys natural soil structure while no-tillage minimizes structural breakdown and increases organic matter and humus to begin the rebuilding process.

Preservation of earthworms and other soil fauna. As with soil structure, tillage destroys humans' most valuable soil-borne ally, earthworms, while no-tillage encourages their multiplication.

Improved aeration. Contrary to early predictions, the improvement in earthworm numbers, organic matter and soil structure usually result in improved soil aeration and porosity over time. Soils do not become progressively harder and more compact. Quite the reverse occurs, usually after 2–4 years of no-tillage.

Improved infiltration. The same factors that aerate the soil result in improved infiltration into the soil. Plus residues reduce surface sealing by raindrop impact and slow down the velocity of runoff water.

Preventing soil erosion. The sum of preserving soil structure, earthworms and organic matter, together with leaving the surface residues to protect the soil surface and increase infiltration, is to reduce wind and water soil erosion more than any other crop-production technique yet devised by humans.

Soil moisture conservation. Every physical disturbance of the soil exposes it to drying, whereas no-tillage and surface residues greatly reduce drying. In addition, accumulation of soil organic matter greatly improves the water-holding capacity of soils.

Reduced irrigation requirements. Improved water-holding capacity and reduced evaporation from soils lessen the need for irrigation, especially at early stages of growth when irrigation efficiency is at its lowest.

*Moderating soil temperatures.** Under no-tillage soil temperatures in summer stay lower than under tillage. Winter temperatures are higher where snow retention by residue is a factor, but spring temperatures may rise more slowly.

Reduced germination of weeds. The absence of physical soil disturbance under no-tillage reduces stimulation of new weed seed germination, but the in-row effect of this factor is highly dependent on the amount of disturbance caused by the no-tillage openers themselves.

Improved internal drainage. Improved structure, organic matter, aeration and earthworm activity increase natural drainage within most soils.

Reduced pollution of waterways. The decreased runoff of water from soil and the chemicals it transports reduces pollution of streams and rivers.

Improved trafficability. Untilled soils are capable of withstanding vehicle and animal traffic with less compaction and structural damage than tilled soils.

Lower costs. The total capital and/or operating costs of all machinery required to establish tillage crops are reduced by up to 50% when no-tillage substitutes for tillage.

*Longer replacement intervals for machinery.** Because of reduced hours per hectare per year, tractors and advanced no-tillage drills are replaced less often and reduce capital costs over time. Some lighter no-tillage drills, however, may wear out more quickly than their tillage counterparts because of the greater stresses involved in operating them in untilled soils.

*Reduced skills level.** While achieving successful no-tillage is a skilful task in itself, the total range of skills required is smaller than the many sequential tasks needed to complete successful tillage.

Natural mixing of soil potassium and phosphorus. Earthworms mix large quantities of soil potassium and phosphorus in the root zone, which favours no-tillage because it sustains earthworm numbers and increases plant nutrient availability.

Less damage of new pastures. The more stable soil structure of untilled soils allows quicker utilization of new pastures by stock with less plant disruption during early grazing than where tillage has been employed.

More recreation and management time. The time otherwise devoted to tillage can be used to advantage for further management inputs (including the farming of more land) or for family and recreation.

Increased crop yields. All of the above factors are capable of improving crop yields to levels well above those attained by tillage – but only if the no-tillage system and processes are fully practised without short cuts or deficiencies.

Future improvements expected. Modern advanced no-tillage systems and equipment have removed earlier expectations of depressed crop yields in the short term to gain the longer-term benefits of no-tillage. Ongoing research and experience have developed systems that eliminate short-term depressed yields while at the same time raising the expectation and magnitudes of yield increases in the medium to longer term.

Disadvantages

*Risk of crop failure.** Where inappropriate no-tillage tools and weed- or pest-control measures are used, there will be a greater risk of crop yield reductions or failure than for tillage. But where more sophisticated no-tillage tools and correct weed- and pest-control measures are used, the risks will be less than for tillage.

*Larger tractors required.** Although the total energy input is significantly reduced by changing to no-tillage, most of that input is applied in one single operation, drilling, which may require a larger tractor or more animal power, or conversely a narrower drill.

New machinery required. Because no-tillage is a relatively new technique, new and different equipment has to be purchased, leased or hired.

*New pest and disease problems.** The absence of physical disturbance and retention of surface residues encourages some pests and diseases and changes the habitats of others. But such conditions also encourage their predators. To date, no pest or disease problems have proved to be insurmountable or untreatable in long-term no-tillage systems.

Fields are not smoothed. The absence of physical disturbance prevents soil movement by machines for smoothing and levelling purposes. This puts pressure on no-tillage drill designers to create machines that can cope with uneven soil surfaces. Some do this better than others.

Soil strength may vary across fields. Tillage serves to create a consistently low soil strength across each field. Long-term no-tillage requires machines to be capable of adjusting to natural variations in soil strength that occur across every field. Since soil strength dictates the penetration forces required to be applied to each no-tillage opener, variable soil strength places particular demands on drill designs if consistent seeding depths and seed coverage are to be attained.

*Fertilizers are more difficult to incorporate.** General incorporation of fertilizers is more difficult in the absence of physical burial by machines, but specific incorporation at the time of drilling is possible and desirable, using special designs of no-tillage openers.

Pesticides are more difficult to incorporate. As with fertilizers, general incorporation of pesticides (especially those that require pre-plant soil incorporation) is not readily possible with no-tillage, requiring different pest-control strategies and formulations.

*Altered root systems.** The root systems of no-tillage crops may occupy smaller volumes of soil than under tillage, but the total biomass and function of the roots are seldom different and anchorage may in fact be improved.

*Altered availability of nitrogen.** There are three factors that affect nitrogen availability during early plant development under no-tillage:

The decomposition of organic matter by soil microbes often temporarily 'locks up' nitrogen, making it less plant-available under no-tillage.

No-tillage reduces mineralization of soil organic nitrogen that tillage otherwise releases.

The development of bio-channels in the soil from earthworms and roots causes preferential flow of surface-applied nitrogenous fertilizers into the soil, which may bypass shallow, young crop roots.

Each (or all) of these factors may create a nitrogen deficiency for seedlings, which encourages placing nitrogen with drilling. Fortunately some advanced no-tillage drills have separate nitrogen banding capabilities that overcome this problem.

*Use of agricultural chemicals.** The reliance of no-tillage on herbicides for weed control is a cost and environmental negative but is offset by the reduction in surface runoff of other chemical pollutants (including surface-applied fertilizers) and the fact that most of the primary chemicals used in no-tillage are 'environmentally friendly'. Small-scale agriculture may require more hand weeding, but with greater ease than with tilled soils.

*Shift in dominant weed species.** Chemical weed control tends to be selective towards weeds that are resistant to the range of available formulations, requiring more diligent use of crop rotations by farmers and commitment by the agricultural chemical industry to researching new formulations.

*Restricted distribution of soil phosphorus.** Relatively immobile soil phosphorus tends to become distributed in a narrower band within the upper soil layers under no-tillage because of the absence of physical mixing. Improved earthworm populations help reduce this effect and also cycle nutrient sources situated below normal tillage levels.

*New skills are required.** No-tillage is a more exacting farming method, requiring the learning and implementation of new skills, and these are not always compatible with existing tillage-related skills or attitudes.

Increased management and machine performance. There is only one opportunity with each crop to 'get it right' under a no-tillage regime. Because no-tillage drilling is literally a once-over operation, there is less room for error compared with the sequential operations involved in tillage. This places emphasis on the tolerance of no-tillage drills to varying operator skill levels and their ability to function effectively in suboptimal conditions.

*No-tillage drill selection is critical.** Few farmers can afford to own several different no-tillage drills awaiting the most suitable conditions before selecting which one to use. Fortunately more advanced no-tillage drills are capable of functioning consistently in a wider range of conditions than most tillage tools, making reliance on a single no-tillage drill for widely varying conditions both feasible and a practical reality.

Availability of expertise. Until the many specific requirements of successful no-tillage are fully understood by 'experts', the quality of advice to practitioners from consultants will remain, at best, variable. Local, successful no-tillage farmers often become the best advisers.

*Untidy field appearance.** Farmers who have become used to the appearance of neat, 'clean', tilled seedbeds often find the retention of surface residues ('trash') 'untidy'. But, as they come to appreciate the economic advantages of true no-tillage, many such farmers gradually come to see residues as an important resource rather than 'trash' requiring disposal.

*Elimination of 'recreational tillage'.** Some farmers find driving big tractors and tilling on a large scale to be recreational. Others regard it as a chore and health-damaging. Farmers in developing countries regard tillage as burdensome or impossible.

Figure 1.1 shows some of the likely short- and long-term trends that might arise as a result of converting from tillage to no-tillage.

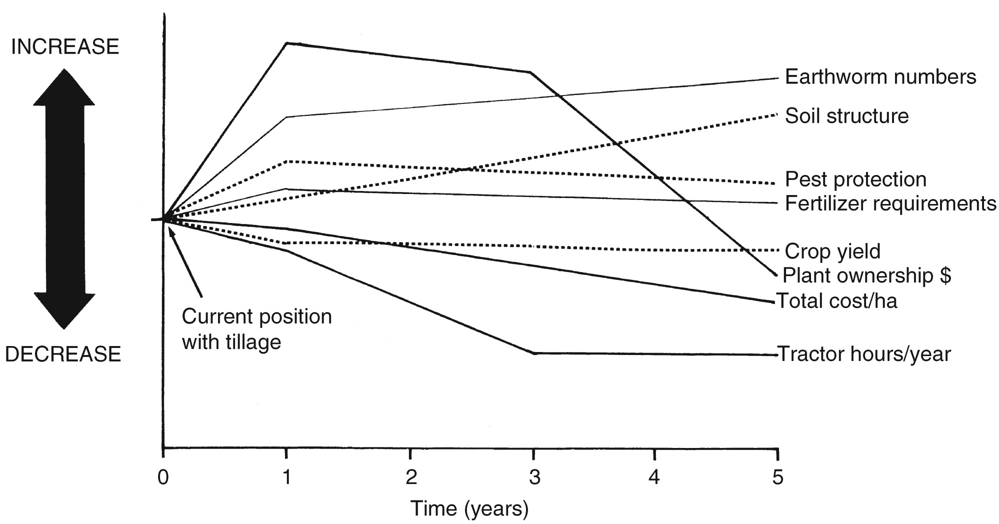

Fig. 1.1. The likely short- and long-term trends that might arise as a result of converting from tillage to no-tillage (from Carter, 1994).

Each identified item or process progresses over the years from stopping tillage as the effects of no-tillage take precedent. The realization is that the effects of no-tillage are developed as the soil and its physical and biological characteristics change. The result of these combined processes has been observed and documented in nearly every soil and climate worldwide, to the point of becoming common knowledge. It is in this transition stage that many who convert to no-tillage farming become disillusioned and sceptical that the benefits will in fact occur.

Summary of the 'What' and 'Why' of No-tillage

No-tillage farming is a significant methodology shift in production farming as performed over the past 100 years of mechanized agriculture. It intuitively requires new thinking by the producers of the 'what' and 'why' to change the processes. Only by encompassing the full scope of 'why' we should change from an enormously successful food production system shall we move forward with confidence to develop 'what' a modern no-tillage farming system should incorporate. The short-term advantages far outweigh the disadvantages, and in the longer term it involves no less than making world food production sustainable for the first time in history.