# Critical Steps To No-Till Adoption

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## Abstract

Adoption of the no-tillage system can not be accomplished without beforehand planning and needs to follow certain steps to be successful. Lack of knowledge on how to do it is the most common reason for failure. Farmers need to acquire the basic knowledge before attempting to try the technology on their own farms and plan the change well in advance. Soil tests have to be performed and deficiencies corrected, aiming at a balanced nutrient and pH status. Soils with bad drainage have to be avoided. Rough and uneven surfaces can make accurate seeding impossible; therefore the soil needs to be leveled before starting no-tillage. If present, soil compactions have to be eliminated before starting no-tillage, because we are aiming at a permanent no-tillage system, impeding us to use tillage equipment at a later stage. It is well known that no-tillage produces worst results when practiced on bare soils, therefore the maximum amount possible of crop residues has to be produced to guarantee the success of the system. Only after having met the previous requirements should a farmer buy a specialized no-till seeder/planter and attempt to start practicing the no-tillage technology. Also it is advisable to start on a small area first and gain experience on how to do it, before applying the technology on the whole farm. It is well known that no-tillage does not work when using monoculture and that the success of the technology is based on site specific crop rotations that also include cover crops. Therefore adequate crop rotations have to be planned and put in place. As the no-tillage system is being developed and continually improved through research and farmer's experiences, farmers have to be prepared to learn constantly paying special attention to new developments at the local and at the global level.

## Introduction

After a slow start in the 1960s to the 1980s no-tillage adoption has really taken off in the 1990s and today there are more than a hundred million hectares under this technology. Pioneer farmers in the early days had little information available on how to do it, the manufacturing industry had little experience on how to build appropriate machines and only a few herbicides were available to control weeds. Today the situation has changed so that experience, knowledge, research results, machines and adequate herbicides at reasonable prices are available to farmers for practicing the technology in the right way. Compared to the early adopters, farmers today have a wide array of appropriate technology, equipment and inputs to start no-tillage.

In order to be successful in the no-till adoption process farmers need to have an adequate level of knowledge and make sure that all aspects of the no-till production systems are being considered. Farmers tend to initiate no-tillage with purchasing a no-till planter, but this is only step number 7 in the adoption process. Starting no-tillage without enough information on **how to do it** is the most common cause of failure in the system! Failures are then blamed on the new system instead of blaming it on the lack of knowledge of farmers (or researchers) themselves. Only after acquiring a good knowledge of all the components of the system should a farmer then purchase a no-till planter. In order to make an adequate start into a no-till system ten critical factors should be considered (Derpsch, 2004).

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## Top ten critical factors for no-tillage adoption

1. Improve your knowledge about the system, especially in weed control and plan for the change to permanent no-tillage at least 1 year in advance
2. Analyze your soil (aim for a balanced nutrient and pH status)
3. Avoid soils with poor drainage
4. Level the soil surface
5. Eliminate soil compaction issues before starting no-till
6. Produce the largest possible amount of mulch cover
7. Buy a no-till seeding machine
8. Start on 10 percent of your farm
9. Use crop rotation and green manure cover crops
10. Be prepared to learn constantly and watch for new developments.

### 1. Improve your knowledge about the system, especially weed control

Once the barrier of mental change has been overcome and the new paradigms of agricultural production accepted, every person that wants to succeed with the no-tillage system will have to learn as much as possible about this new production system. In order to avoid failures, farmers, researchers and extensionists need to have an adequate level of knowledge before going into no-till and make sure that all aspects of the production system is being considered. Farmers tend to start with buying a no-till planter, but that should be done later in the adoption process. Starting no-tillage without enough information on how to do it is the most common cause of failure in the system! Failures are then blamed on the new system instead of blaming it on lack of know-how of farmers (or researchers) themselves. Improving knowledge and management skills is not only essential for farmers, but also for employees, tractor drivers, etc.

To change from conventional tillage to no-tillage requires careful planning at least 1 year before implementation. The last tillage operation before changing to permanent no-tillage has to be performed in such a way that the surface of the fields is level. No-tillage commences with choosing an adequate crop before starting no-tillage. The harvest of the previous crop should leave enough residues on the soil surface. Plan on an adequate crop sequence. It is easier to start no-tillage after a crop in which good weed control can be achieved. This can be a cash crop or a green manure cover crop. Combine harvesters have to be equipped with straw and chaff spreaders to ensure even distribution along the whole cutting width. If the machines do not have this equipment, farmers will need to bale or burn the straw. Starting no-till on a field where the straw has been burned is the worst possible condition and removing the straw is the second worst condition.

No-tillage is a completely different production system and one of the biggest changes is in weed control. In the old tillage systems, generally no special knowledge is needed about specific weeds because tillage implements bury and kill most every weed. This is not the case in no-tillage. In the no-tillage system the farmer has to know each weed occurring on his farm by name and also has to know which herbicide can be used to control each specific weed to avoid competition with the crops. The best way of learning about the different weeds occurring on the farm is consulting experts (farmers, extensionists, researchers) or special books. In the

ideal case these books will have a brief description of all the weeds occurring in one country (or region), show a picture of the seeds, seedlings and the mature weed when flowering or setting seeds. The book should list all the herbicides available in the country and the sensitivity of the described weed to the herbicide (e.g. no action, sensitive, very sensitive). These publications have been produced in countries like Brazil, Argentina, U.S.A. and are a very practical guide to get better acquainted with each weed.

Parallel to this is a need to improve knowledge of herbicides. This is sometimes a difficult task when the only sources of herbicide information are pamphlets and catalogues from the different manufacturing companies. With so many herbicides available in some countries the selection of material is huge. It is good to have a book available describing all the herbicides in a country that can be used in a no-tillage system. Such a book should describe the characteristics of each herbicide, precautions when using it, how to use it, list sensitive weeds and weeds that are not affected by the herbicide, and explain how application rates of a certain herbicide should be used to effectively target a specific weed. Attention has to be given to crop rotation. Herbicides have to be chosen that do not harm other crops in the rotation. Comprehensive herbicide books have been produced in Brazil, Argentina and Paraguay and probably in many other countries. They should be reviewed and reprinted frequently, as new herbicides appear on the market and others are taken off on a yearly basis. If these publications are not available then other ways of acquiring knowledge of weeds and herbicides have to be found, i.e. consulting researchers and practitioners with good knowledge about these subjects, attending special courses, conferences, etc.

When changing to no-tillage, spraying equipment becomes the most important machinery on the farm. A farmer can afford to run an old tractor, but should always be careful to operate a properly functioning spraying equipment. If this is not the case he should buy a new one. Special attention has to be given to the nozzles and the best nozzles on the market should always be used, even if expensive. *Cheap brass nozzles belong in the garbage!* They wear out in about 40 hours of spraying. Good nozzles save time and money and pay themselves very quickly. There is a large variety of nozzles offered by specialized companies and specialized advice is needed on which nozzle to use. The equipment part of spraying is relatively easy because many companies produce excellent sprayers. The most difficult task in farming today is to regulate a sprayer in such a way that it will have the exact, intended output of product and water. Most people graduating from agricultural schools at present are not able to do this adequately. The operation of calibrating a sprayer should be done days before the intended date of spraying and take as much time as necessary to achieve the exact output needed. This means that each nozzle has to be checked and calibrated individually and all nozzles varying more than 10% from the average output need to be replaced. Replace nozzles with the same type, number and color. Even the most sophisticated computer driven spraying system cannot correct mistakes in nozzle selection.

For proper calibration of spraying equipment it is recommended to develop special forms, where each step is indicated in an easy to understand way. These forms have been developed in Brazil and Paraguay. The specialized literature mentions several formulas to be applied to achieve the exact output, but often these formulas are difficult to understand for field workers and many times they fail to explain the link between one formula and the other. What one really wants to know when spraying is: what nozzles do I need to use and how many liters of a certain product do I need to put in a sprayer filled with x liters of water and at what speed I need to drive in order to apply exactly (for example) 2 liters $ha^{-1}$ of a certain product with 100 liters of water per ha? Failure in having adequate weed control is often blamed on herbicides, while the real problem was a badly calibrated boom sprayer. Excessive doses of herbicides may lead to phytotoxicity of the crop, lower yields and high production costs. Too low a rate will result in unsatisfactory control of weeds. Again, yield losses are the result. If it is decided to spray again to improve weed control, this will result in higher costs.

Water quality is an important factor when spraying. The water used for spraying has to be clean and should not contain any silt which may deactivate some herbicides. While in the

old days 400 to 600 liters of water were recommended for spraying herbicides, currently the tendency is to apply as little as possible. Glyphosate, for instance, works much better with 50 to 100 liters of water per ha than with more. Some herbicides work best at a low pH of water, so additives may be needed to lower the pH. To get all the factors right is a complex issue, which needs a high degree of attention and a good understanding of all the factors.

The next thing a no-till farmer has to master is calibrating a no-tillage machine so as to disturb the soil as little as possible and plant the seeds uniformly at the exactly predetermined depth. This seems to be, at first glance, a simple task, but many times it has been necessary to call the mechanics of the manufacturer or the distributor of a no-tillage planter, before the machine could operate satisfactorily. Besides this, management aspects particular to the farm, crop and operations have to be taken into account.

**2. Analyze your soil (aim at a balanced nutrient and pH status)**

Routine soil inspection and analysis, aiming at a balanced nutrient and pH status is a very necessary component to achieve good results in the no-till system. If low values of some elements are found, then corrective fertilization and liming has to be done in order to achieve at least medium nutrient levels, and with time, high levels of nutrients in the soil.

"In no-tillage a plow layer is no more existent, giving way to another layer enriched with organic plant residues, altering the dynamics of the organic matter of the soil and the nutrient cycling" (Sá, 1993). Therefore soil analysis after about 5 years of continuous no-tillage should be taken from a 0-10 cm, no longer from 0-20 cm depth. If a more detailed analysis is needed then soil samples can be taken at a depth of 0-5, 5-10 and 10-20 cm. Furthermore a new calibration of soil analysis is needed.

Nutrient deficiencies have to be corrected before starting no-tillage. If soils are poor in phosphorus then correction with high doses of this element have to be done. When high levels of this element are reached some authors recommend that 50% of phosphorus fertilizer be applied with the seeding machine while the other half is broadcast. If analysis shows P levels higher than 15 ppm these authors recommend that all the phosphorus be applied broadcast (Crovetto, 1996). Also potassium and calcium levels should be in the upper acceptable range.

Soils that have been no-tilled for many years show a higher concentration of phosphorus in the upper soil layer. This has not been shown to be negative on plant production. The contrary has been the case, since fertilization with phosphorus can be reduced after many years of no-tillage. In no-tillage the upper soil layer in general has high moisture content and low temperatures, allowing roots to grow right to the soil surface under the mulch. Thus, roots show good uptake of phosphorus in this layer. It is counter productive to try to mix this concentrated phosphorus, placed on the soil surface, into the soil profile with a plow or other tillage implements, because the greater contact of phosphorus with the soil particles will, in general, lead to a strong binding and P fixation in the soil, limiting phosphorus for plant use.

Often soils are acidic and may have toxic aluminum levels. If this is the case, farmers should apply lime the year before starting with no-tillage because this is the last opportunity for mechanical incorporation. The concepts of liming and fertilization have greatly changed in Latin America since shifting to no-tillage systems. Experience has shown that most things learned at university about fertilization and liming should be revised, and new concepts of fertility management for no-till systems need to be developed and applied. *The main principle to keep in mind is that farmers should fertilize their soils rather than their crops.*

Lime does not need to be incorporated with tillage implements. Research performed in Brazil has shown that farmers can apply lime without incorporating, and found lime moves into deeper soil layers, especially when applied in combination with green manure cover crops. In such cases, farmers should apply a small quantity of lime each year, instead of applying large amounts only once. Miyazawa et al. (2002), working on a Typic Haplorthox (U.S. soil taxonomy) found that the effect of lime without plant residues was limited to the upper 10 cm of profile. Lime with plant residues changed pH, $Ca_{ex}$, $Mg_{ex}$ and $Al_{ex}$ in the soil profile. The efficacy of plant residues on lime mobility followed the order: black oats (*Avena strigosa*

Schreb) > rye (*Secale cereale* L.) > mucuna (*Mucuna pruriens*) > leucaena (*Leucaena leucocephala* L. de Wit). Wheat residue had no effect on the mobility of lime.

One important factor that influenced the quick growth of no-tillage in South America is the fact that farmers, in general, do not believe in the necessity of incorporating lime with tillage implements after no-tillage has been started. As previously mentioned, surface application of lime in combination with specific cover crops (black oats, oilseed radish *Raphanus sativus)* allows the mobility of lime in the soil profile. This is still something of intensive debate in the U.S.A. Also, in the U.S.A. many researchers, extensionists and farmers believe that one has to plow every so often to redistribute phosphorus that concentrates on the soil surface in the no-till system. This is not the case in South America, where farmers have learned that the concentration of this element in the soil surface is not a problem at all for obtaining high yields of crops in a sustainable way.

These three factors, lime incorporation, phosphorus redistribution and compaction, are probably the main reasons why farmers in the U.S. till the soil once in a while in no-till systems. Under this situation of rotational tillage the soil is constantly in the transition phase and farmers never get to experience the full benefits of a no-till system. *One has to remember that it takes about 5 years of continuous no-tillage to get positive effects on soil quality and that it takes about 20 years to reap the full benefits of the system* (See Fig. 3, "Evolution Scale of the No-tillage System" in Chapter 1 of this publication).

Farmers in Brazil, Argentina or Paraguay would only in exceptional cases consider plowing or tilling the soil to mix phosphorus in the soil profile, incorporating lime or even loosening soil compaction. The high percentage of permanent no-till (> 90% of all conservation agriculture practiced) demonstrates this. In this context one should also remember that Brazil has soils of low pH and high aluminum saturation often occurs.

### 3. Avoid soils with bad drainage

It is well known that no-tillage does not work on badly drained soils, or if soils suffer from waterlogging. If no-tillage is practiced on these soils it is likely that substantial yield reductions will occur. For this reason farmers should avoid practicing no-tillage under these conditions.

A solution to this problem could be investing in an adequate drainage system before starting no-tillage. Often farmers tend **not** to invest into drainage systems since, in general, it is quite an expensive practice. When the problem of bad drainage and waterlogging is solved, generally no-till can be practiced on these soils.

### 4. Level the soil surface

For a perfect seeding operation it is necessary to level the micro relief of the fields. There are several reasons why the soil surface may not be level.

a) If the harvest of the previous crop has been done with wet soil and the machines have left deep furrows in the field, this is an inadequate situation to start no-tillage. These wheel track furrows have to be eliminated before starting no-tillage. Generally it is necessary to pass a subsoiler shank along the wheel track furrows to eliminate compaction caused by heavy machinery and then a disk harrowing to level the surface.

b) If the previous row crop has been cultivated with a cultivator to eliminate weeds, the field may be left in a rough condition. Often these cultivators throw soil from the middle (between two rows) to the rows, resulting in ridges. This furrow and ridge situation is a very unfavorable condition for seeding at an even depth. These furrows have to be eliminated preferably with an appropriately designed (offset) disk harrow to level the ground. Often X shaped disc harrows tend not to leave an even surface.

c) If the fields have suffered from erosion and have deep or shallow erosion rills, then the field has to be leveled before commencing no-till. Rills do not allow seeding at an even depth and

also cause a lot of wear and tear to the machines. In general, a light or a heavy disk harrow will be sufficient to smooth the field, but depending on the depth of the rills it might be even necessary to plow the field and harrow it to get the soil surface adequately leveled. Of course, one has to consider that intensive tillage exposes the bare soil to erosion again. Sometimes farmers in South America have had to level the soil several years in the row due to persistence of erosion rills, because each time they wanted to start no-tillage again rill erosion occurred. To avoid this, a good erosion control infrastructure needs to be in place on the farm. Not only water erosion but also wind erosion may cause problems of an uneven soil surface.

d) In Latin America the secondary forest is often cleared and turned into pasture. Under pasture conditions an uneven soil surface does not present any management problems. However if this pasture is then turned into no-till agriculture, farmers notice that they need to level the surface first to allow an adequate seeding operation.

Whatever the reasons for an uneven surface, the soil has to be leveled before starting no-tillage. If this is not done, farmers will soon realize that most no-till seeding machines do not perform well in uneven soils, resulting in a bad stand because the seeds deposited in the lower parts are left on the soil surface or planted too shallow for good germination, and on ridges the seeding depth will be too deep. Good planting practices require seeds evenly spaced at an even depth and this requires a level soil surface.

**5. Eliminate soil compaction**

After many years of tillage with the same implements, plow pans or heavy disk pans can develop. In other cases soils have pedogenic (natural) soil compaction. Starting no-tillage without breaking soil compaction will result in poor yields and low profits. Therefore, whenever compaction is present it needs to be removed before going into a no-till system, unless in-row subsoiling is used while seeding. This type of machine has been developed in Auburn, Alabama, by researchers from USDA (Wayne Reeves, personal communication, 2003). In Latin America a chisel plow is enough to break tillage induced soil compactions (in seldom cases a subsoiler).

The question is now what to do if we have practiced no-tillage for several years and somebody tells us that the soil is compacted? Soil compaction in permanent no-tillage is an issue that is discussed repeatedly in Latin America. We have found that in general researchers have a different perception than farmers in looking at this problem. Since researchers have very sophisticated tools to measure compaction and easily demonstrate that soils are denser under no-tillage than under conventional tillage, we have seen that many researchers view compaction as a very serious problem in no-tillage systems. We observe that in general scientists and researchers in Latin America tend to overstate the problem of soil compaction. In contrast to researchers, farmers in Latin America measure compaction not in terms of soil density (g $cm^{-3}$) or penetration resistance but in terms of crop response and yields. If yields are as good (or better) in no-tillage than in conventional tillage, farmers do not care about compaction. Farmers also measure compaction in terms of penetration of seeding equipment. If soils are too hard to allow adequate penetration to the cutting elements of a planter, then farmers are going to have a poor stand. However the reason for bad penetration may also be due to poor design or lack of weight of the seeding machine, or the soil might be too dry.

For the purpose of evaluating farmers perception on the problem of soil compaction, three no-till pioneer farmers from Paraná State, Brazil were interviewed independently in 1997 to express their views on this problem. The interviewed farmers were Herbert Bartz (then 26 years of continuous no-tillage), Nonô Pereira (then 22 years of permanent no-tillage), and Frank Dikstra (then 22 years of continuous no-tillage), totalling 70 years of no-till experience. Their soils vary from about 80% clay to about 80% sand. The farmers were unanimous in stating, that they do not perceive compaction as a problem in permanent no-tillage (Revista Plantio Direto, 1999). They also stated that there is no need to till the soil every so often after

no-tillage has been established. Finally they said that the best way to avoid compaction in a no-tillage system is to produce maximum amounts of soil cover, use green manure cover crops and good crop rotations, so that roots and biological activity as well as earthworms and insects, etc., loosen the soil, resulting in biological soil preparation. Good soil cover is also essential to maintain higher moisture content on the soil surface and this will result in better penetration of cutting elements of the seeding equipment, as well as of roots. At present, 10 years later, these farmers continue practicing permanent no-tillage and their views about compaction have not changed. Controlled traffic should be aimed for in this system and no heavy trucks allowed indiscriminately in the fields, especially at harvest.

**6. Produce the highest amount of mulch cover possible**

*Almost all advantages of the no-tillage system come from the permanent cover of the soil and only a few from not tilling the soil.* No-tillage with low amounts of crop residues will not give us the full benefits of the system. Farmers should aim at maximizing biomass production in a no-tillage system. This can be achieved by choosing crop varieties and/or crop species with higher biomass than others (e.g. using tall instead of short straw wheat varieties), or choosing crops like maize and other high biomass producing crops instead of crops that produce low amounts of biomass like beans, lentils or soybeans. If climatic conditions allow, when farmers commence no-till they should aim at producing more than 6 t $ha^{-1}$ and later, if possible more than 10 t $ha^{-1}$ of dry biomass per year. This can be achieved by using adequate crop rotations that also include green manure cover crops. *Crop residues should never be burned!* In some countries or regions of the world (e.g. in Chile), farmers think that they always have a good reason for burning, arguing it is the only way to allow economic production. More than reasons, these are excuses of farmers that practice no-tillage with conventional thinking and have not yet understood the basic principles of a sound no-tillage system. *Also green manures should never be plowed under but left on the soil surface, being incorporated biologically into the soil as they decompose.*

Of course in semi arid climates the large biomass amounts mentioned above cannot be achieved, but the goal is still to maximize biomass production. Initially it is always difficult to obtain maximum amounts of plant residues. With additional years of no-tillage, soil fertility management and improved management capabilities, higher amount of residues will be obtained, as can be observed on the farm of Rick Bieber in northern South Dakota (Bieber, 2000) and others throughout the drier areas of the U.S. and Australia.

The benefits of large amounts of mulch on the soil surface are: a) good weed suppression (savings in herbicides); b) positive effects on soil moisture (especially important in drier areas); and c) favorable effects on soil temperature. All this results in improved chemical, physical and biological soil conditions improving soil fertility and yields. We should not only look at the amount of mulch but on the distribution of it as well. Harvesting machines should have a well designed device to spread the straw and chaff evenly over the entire cutting width. Machine manufacturers often do not understand this requirement of no-tillage, the result being an uneven distribution of plant residues, with excessive residue in the center (plus chaff) and too little or none at the edges. This results in poor performance of herbicides and seeding equipment. Adequate straw and chaff spreaders should replace straw choppers if they do not perform adequately. When buying a new combine harvester many farmers in Paraguay have taken off the straw chopper/spreader and replaced it with straw and chaff distributor, which needs less power and does a better job of even distribution of residues.

**7. Buy a no-till seeding machine**

Only after having met all previous requirements mentioned above should a farmer buy a no-till planter or seeding machine. All too often it is observed that some farmers hear about the no-tillage technique, get exited about it and before long they go to the shop, buy a special no-till machine and start no-tillage without considering the previous six steps to no-till adoption. This leads to a failure of the system. The farmer then blames the failure on the no-tillage

technique, not admitting that it is his lack of knowledge of the basics of this system that has caused this failure. Farmers that fail in making no-tillage work are the best advocates of discrediting the system.

Appropriate no-tillage machines are not available in every country so they have to be imported. When the pioneer no-till farmer of Latin America, Herbert Bartz, started no-tilling on his farm in 1972 he had to import an Allis Chalmers no-till planter from the United States. The first machines for no-tillage were not built in Brazil until 1975. The first Brazilian machines were based on the rotary hoe (Howard Rotacaster) and were slow and disturbed the soil too much, so farmers were very happy when the faster triple disc machines (that do little soil disturbance) appeared on the local market in 1976. Production in other countries of Latin America (Argentina, Mexico) started much later. Today about 15 industries in Brazil and about the same amount in Argentina are building recognized no-tillage equipment for local and export markets. The list of manufacturers can be seen at the website www.rolf-derpsch.com. Worldwide there are about a hundred manufacturers of no-till equipment.

When choosing a no-till seeding machine or planter, a farmer should make sure that the machine he is buying is adequate for his soil conditions. Also he has to consider what crops he is going to seed, wide row crops, narrow row crops, or both, and select his equipment accordingly. Multipurpose machines are available that do both wide and narrow row crops, but often it takes a lot of labor to change settings from one row distance to the other. Farmers should be careful to choose low disturbance equipment that cuts easily through thick amounts of residues. This can only be achieved with discs and traveling at reasonable speeds. Machines that use shanks or tines move too much soil and cannot meet this requirement.

As no-tillage starts in a country, in order to reduce costs, it is advisable that old seeding equipment is modified into a no-till seeding machine. This was often done at the beginning in Latin America when adequate machines were not on the market and also later to save costs. A modified machine, for which only the units in contact with the soil are bought new, may cost only 40% to 60% of the value of a new machine. All the other required modifications can be done in local shops.

## 8. Start on 10 percent of your farm

No-tillage is a completely new production system. Tillage is not done any more, the weed types become different, spraying is different and has to be done much more accurately; seeding is different, diseases and pest control are different, crop rotations are different, management is different, etc. When changing from conventional to no-tillage the whole system has to be changed. It does not help to change the different components one by one because then it will take years before the complete system is adopted. With so many changes taking place at once this is a challenge for everyone, even for excellent farmers and researchers, for people with many years of farming experience and good management skills. Therefore the recommendation is to start small and not to change the system on the whole area of the farm at once.

Before starting, a farmer should gather the necessary knowledge about the system from peer farmers that are already practicing no-tillage, from extensionists, from experienced researchers, from specialized books and magazines, etc. The important thing is not to start before acquiring enough basic knowledge about the system. To start on about 10% of the farm in the first year is a reasonable goal in order to gain experience and avoid failures. Depending on the confidence a farmer gets from this first experience he could then expand the area to 30 to 50% in the second year and only after mastering the system should a farmer go for 100% of the area of his farm under no-tillage. To start on the whole farm area in the first year is a very risky venture which may result in poor crop establishment, failure in adequate weed and pest control, etc. and finally in significant financial losses.

Completely new no-till seeding equipment pose a challenge to farmers with no experience with these machines in terms of adjusting them to seed through the mulch cover at

even depth, without disturbing the soil excessively. It also takes time to find out which is the most appropriate moisture content of the soil for seeding with a specific machine.

Weeds may change substantially when moving from conventional to no-tillage. Weeds that were easily controlled in conventional tillage systems may suddenly become a problem in no-tillage. New weeds that never were a problem before may appear on the farm and be difficult to control, or herbicides may not be readily available to control specific new weeds. Further observations made when describing step one of the adoption process should be taken into consideration.

In relation to pests it has been observed that there may be a major shift. Pests that were never a problem in conventional tillage may appear in the no-tillage system. Others that were a problem in conventional may disappear with no-tillage. Aphids for instance do not like the light reflection from straw in no-tillage and will prefer to go to a conventional till field with no residue cover. A cutworm, *Elasmopalpus lignocellus,* will cause a lot of damage in conventional fields where the soil moisture disappears quickly and may cause no or little damage in an adjacent no-till field where the soil maintains moisture under the mulch. Other pests such as thrips may increase in no-tillage systems. The infestation depends on the year, the location, on climatic conditions, etc. Research has shown that under no-tillage, some pests increase while others decrease or remain the same. In general it cannot be said that with no-tillage one would expect more pest problems, but as said before, some specific pests may increase under certain climatic conditions (Derpsch et al., 1991).

Diseases may become a major problem in no-tillage systems. As residues from previous crops are not buried, diseases like stem rust (*Puccinia* sp.) in cereals may transfer (with drops of rain) from the partially decomposed residues to the germinating new crop. To avoid this, crop rotation has to be practiced and the recurrence of the same crop in the same field has to be determined by the complete decomposition of residues, when disease spores from necrothrophic parasites die (e.g. rust), because their food has disappeared. Some other diseases may also increase in the no-tillage system like *Roselina* sp. and *Sclerotina sclerotiorum* in soybeans, or *Fusarium* sp. and *Helmithosporium* sp. in Maize (Derpsch et al., 1991). *In general it can be said that diseases are a greater problem in no-tillage systems than in conventional tillage systems.* This, however, should not justify burning or burying crop residues with the plow. Instead good crop rotations should be developed which can solve this problem.

To summarize, the rule is to start small and increase the area under no-tillage as a farmer masters the system and is able to solve the new issues that appear. Farmers will succeed with no-tillage as they are able to solve the problems they encounter and will fail if they do not show this ability, or react when the problems first appear with the argument “it does not work” and abandon the new technology.

**9. Use crop rotations and green manure cover crops (GMCC)**

Black fallow or bare soil fallow is the worst that can happen to a soil. Living plants and roots, if possible all year round, are important to change from soil degrading production systems to new systems that improve soil fertility, like no-tillage.

After previous steps have been met, farmers should aim to establish an optimum rotation from the point of view of yields, weed suppression, amount of residues left on the soil surface, economics and risk management. When this stage is reached, farmers can sell their tillage equipment.

In a no-till system the use of crop rotations is much more important than in conventional tillage systems and a diverse rotation should always be a goal when applying no-tillage techniques. The greater the biodiversity the better no-tillage works. Of course we have to apply a sensible diversification, we cannot use dozens of different crops. Diversification has to be economic and can be best achieved with the use of crop rotations and green manure cover crops (GMCC). Cover crops are the missing element in the no-tillage system in most parts of

the world. There are a lot of prejudices against cover crops. Some people still think that they have to be plowed under, and this is certainly an out of date concept.

Cover crops need to be integrated into the agricultural system of each farm and show their beneficial effects. Cover crops, in combination with no-tillage and sensible crop rotations ensure the sustainability of agricultural production. “But, rotation isn’t just a helter-skelter array of crops” (Bieber, 2000). Without the knowledge of positive or negative residual effects of one species on the succeeding crop, any attempt of organizing a crop rotation is merely a theoretical model. One of the biggest challenges is to fit green manure cover crops into a farmer’s current crop rotation, or to develop new rotations that take full advantage of their benefits. Each farmer has to find the “window or niche” where a specific cover crop will fit to accomplish specific purposes. It has to be kept in mind that in general, cover crops function in the “off season” of crops but they may also be intercropped with cash crops or over sown in standing cash crops.

While in some regions of the world farmers concentrate on avoiding tillage, Latin American farmers have understood that adequate production and management of crop residues are key issues in the no-tillage system. Cover crops do not cost but will pay. When practiced in monoculture or even in double cropping, i.e. when the same crop or crops are repeated on the same land each year, no-tillage is an imperfect and incomplete system, in which diseases, weeds and pests tend to increase and profits tend to decrease. Disease, pest and weed outbreaks will oblige farmers at a certain point to abandon monoculture and practice crop rotation. Adaptive research in this area is the most important factor to make no-tillage work, that is, take advantage of all the benefits of the system, reduce weed pressure and increase economic returns!

In order to properly design rotations we need knowledge about green and dry matter production and profitability of green manure cover crops, how to fit them into different crop rotations and what residual fertilizer effect we can expect of each GMCC planted before the main cash crop. A number of publications have contributed in filling this knowledge gap in Latin America (Sorrenson and Montoya, 1984; Monegat, 1991; Derpsch et al., 1991; Derpsch and Calegari, 1992; Calegari et al., 1992; Vallejos et al., 2001; Florentín, et al., 2001). Several publications on the use of cover crops have appeared in the US in the last decade (e.g. *Cover Crops for Clean Water,* W.L. Hargrove, ed. 1991; *Managing Cover Crops Profitably,* SAN-SARE, 1998, www.sare.org). There is increasing information on cover crops also in websites (see www.rolf-derpsch.com under cover crops).

When looking at the experiences in the Americas we of course cannot “copy” what is done there. *Farming is always site specific, but the principles of using cover crops and crop rotation are valid all over the world.* The experiences with these practices from Latin America are especially interesting for no-till farmers, because they have played a key role in further developing and perfecting the no-tillage system. We should be aware that some cover crop species adapt to a very wide range of climatic and soil conditions. Several cover crop species used in South America are well adapted to the conditions of northern United States, Canada and countries of Central Asia and Europe. As a matter of fact, most cover crops used in South America were brought there from Europe. Farmers should be aware that *“no matter where you farm, there are cover crop species that meet your need”* (USDA-ARS, 2002).

Managing cover crops in no-tillage is completely different than in a conventional tillage system. A knife roller to flatten and kill green manure cover crops and leave the plant residues on the soil surface is an essential tool for cover crop management. This implement is not very expensive and in many cases can be made locally or by the farmer himself. The implement can be pulled by medium sized tractors and has contributed a lot in reducing herbicide rates in the no-tillage system. (See pictures and dimension at www.rolf-derpsch.com). The knife roller has become an essential tool for managing GMCC in many countries of South America. Alternatively steel bars can be welded on top of the discs of an old disc harrow and the implement used for the same purpose. The use of machines that chop cover crops like a rotary

mover is not recommended in warmer climates because residues decompose too rapidly and generally these rotary mowers do not distribute the chopped material evenly.

**10. Be prepared to learn constantly and stay up to date with new developments**

We should remember that the adoption of no-tillage is a continuous learning process and that even after many years of practicing the system there is always something new to learn. The no-tillage technology is so new, that even "old" no-tillers with 20 or 30 years experience find that they can learn from others that have improved some aspects of the system. Until now, after more than 40 years of research and practical experience, nobody can claim that he knows everything about no-tillage. *The best advisor to teach you the no-till know-how is a successful no-till farmer in a similar environment as yours, even if he comes from abroad. Don't be afraid and don't be too proud to ask your peer farmer what he has done to be able to practice no-tillage successfully.* More than telling you his success story, he should tell you the problems he encountered, because in general one learns more from failures than from success stories.

Even today, with many millions of hectares of no-tillage being practiced by farmers worldwide, it can be said with considerable confidence, that knowledge is one of the main constraints to expanded no-till adoption. Despite the fact that knowledge has been generated, this knowledge is not reaching the farmer. Sometimes the problem is that general knowledge is there, but site specific knowledge is lacking. Research stations have generated valuable general knowledge, but at a certain stage, researchers and extensionists have to go out to the farms and conduct site specific on-farm research and technology development with farmers in a systems approach and extend the technology to the farmers. Also, in many countries extension agents do not know enough about the no-till system and consequently are not able to transmit adequate knowledge to the farmer.

Another problem is that all too often knowledge is published in scientific papers and publications and not transformed into a language that is more practical and more accessible to extensionists and farmers. One part of the problem is the reward system of the scientific community. Scientists in general are rewarded for the number and quality of their publications, but the reward system seldom takes into consideration the adoption of an innovation by farmers. Although a thorough knowledge about the erosion process was already generated in the USA back in the 1940s (when the first pictures of the raindrop impact on a bare soil surface were made by the Naval Research Laboratory together with USDA Soil Conservation Service), it is surprising that even today many farmers, extensionists and even researchers in the USA and elsewhere do not understand this process adequately. Many people still think that one has to loosen the soil by intensive tillage to create big pores and increase water infiltration. Knowledge is useless if it is only on paper and not in the minds of people. One problem of course is, that the literature generated even in the recent decades, is using outdated information about the alleged benefits of traditional tillage which in general have been shown to be wrong. The most consistent proof of this is the fact that today many millions of hectares are being successfully planted in no-tillage systems worldwide (see www.rolf-derpsch.com) and the area is growing constantly. An important step is to ensure incorporation of the knowledge accumulated of no-till systems into university and college curricula. For this, lecturers need to be trained and new teaching material has to be developed, a task that could well be accomplished by researchers. Today in Brazil for instance, there are a number of universities offering no-till studies at the graduate level and many have incorporated no-till at the undergraduate level (Landers et al., 2001). Brazil also offers no-tillage in post graduate courses, one of them via internet (www.abeas.com.br).

## Final remarks

No-till innovators should consider that “There is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new order of things. Whenever his enemies have occasion to attack the innovator they do so with the passion of partisans, while the others defend him sluggishly so that the innovator and his party are vulnerable.” (Rogers, 1983, quoting Niccolo Machiavelli (1513), *The Prince*). No-till pioneers all over the world have experienced the sad truth of this statement.

When new technologies are being extended to farmers, the conditions for the utilization of technology have to be met. It should be taken into consideration that **if farmers are to adopt innovations, they must want to, they must know how to and, they must be able to follow recommendations**. If no-tillage machines or appropriate herbicides are not available, farmers will not be able to follow the recommendation.

Strategies for the implementation of no-tillage should carefully consider, that “the results of various diffusion investigations show that most individuals do not evaluate an innovation on the basis of scientific studies of its consequences, although such objective evaluations are not entirely irrelevant, especially to the very first individuals who adopt. Instead most people depend mainly upon a subjective evaluation of an innovation that is conveyed to them from other individuals like themselves who have previously adopted the innovation. This dependence on the communicated experience of near-peers suggests that the heart of the diffusion process is the modeling and imitation by potential adopters of their network partners who have adopted previously” (Rogers, 1983).

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