



## NO-TILLAGE SYSTEMS – EFFICIENT FARMING IN SEMI-ARID AND SUB-HUMID ENVIRONMENTS

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**Introduction – A Systems Perspective**

Conservation tillage has been quietly expanding, and evolving, around the globe for the past 3-4 decades. Defined as reduced tillage systems that leave a certain percentage of crop residues on the soil surface after planting, conservation tillage, or any of the many common synonymous descriptors (zero tillage, no-till, direct seeding, reduced tillage, etc.) are being replaced by the more generic term, conservation agriculture. The United Nations' FAO describes conservation agriculture as: *Involving a process to maximize ground cover by retention of crop residues and to reduce tillage to the absolute minimum while exploiting the use of proper crop rotations and rational application of inputs (fertilizers and pesticides) to achieve a sustainable and profitable production strategy for a defined production system* (FAO, 2008). The FAO definition integrates residue management with cropping systems and production inputs and appears to best explain its successful adoption in many countries around the world. Conservation agriculture is more inclusive than conservation tillage, with zero tillage as its cornerstone. For our purposes, zero tillage and conservation agriculture will be used interchangeably in this discussion.

There are few countries where conservation agriculture is not practiced successfully by at least some farmers. Derpsch and Friedrich (2009) report that conservation agriculture is carried out on farms from 60° N latitude (e.g. Finland) to the Equator (e.g. Kenya, Uganda) to 40° S (e.g. Argentina, Chile), from sea level to 3000 m elevation (e.g. Bolivia, Colombia), and from extremely dry conditions (200 mm rain; e.g. western Australia) to extremely wet (e.g. 2000 mm in Brazil, 3000 mm in Chile). Conservation agriculture is applied on farms of all sizes, including small landholders (< 0.5 ha) and on soils that vary from 90% sand (e.g. Australia) to 80% clay (e.g. Brazil's Oxisols and Alfisols) and in all crops, including root crops. The wide ranging conditions of climates, soils, and geographic conditions where conservation agriculture has been successfully implemented will ensure further interest and development of this technology.

Zero tillage is now estimated to be practiced on over 105 million hectares (M ha) worldwide, mostly in North and South America (Derpsch and Friedrich, 2009). South America leads with 47% of the world's zero till acreage followed by 38% in North America, 12% in Australia/New Zealand, and 2% in Asia. South America will continue to be the hot spot for future development, but Asia and Eastern Europe also have great potential.

The success of no-till seeding systems around the world reflects on a great source of adaptation and innovation by agricultural producers. Adoption of no-till comes with considerable effort to "make the system work" in all the areas it has been implemented. The term "system" is used in this presentation to address the many aspects which come into play when working to have success with no-till. Use of a no-till seeder is only one aspect of making the production system work, along with crop rotation, nutrient management, crop residue management and pest management. Failure to consider all aspects of the production system

has resulted in failure in many parts of the world. However, in regions where the growing season precipitation is limited, and the timeliness in the seeding operations are critical, no-till seeding systems have been successful.

## **Key Developments in Canadian Prairie Agriculture**

The development and success of no-till seeding systems on the Canadian prairies came about as a result of a number of key developments in the region. These developments played a major role in making the system work both from an agronomic and profitable position for farmers.

- **Strong scientific evidence supporting crop residues management in erosion control and water conservation.**

In the mid to late 1930s, studies conclusively showed that maintaining crop residues on the soil surface could improve water infiltration, reduce evaporation losses, reduce surface runoff, reduce wind and water erosion and conserve more water because of the increased ability to trap and hold snow (Smika and Unger 1986). For the Canadian prairies, Mitchell et al. (1944) reported that uncultivated native prairie soils contained from 0.2 to 0.7 percent nitrogen and that by the 1940s, barely 60 years after the first plough turned over the virgin prairie sod 15 to 40 percent of it had been lost. This trend continued so that, by the 1980s, most prairie soils had lost more than 40 percent of their initial organic nitrogen content. These findings led to increased efforts to develop soil and crop management practices that could make better use of the potential offered by crop residues, especially for the arid and semi-arid areas. It was later reported that standing stubble was four times more effective at protecting the soil from wind erosion than flat lain residues allowing for adequate wind erosion protection in years of low residue production (Lyles and Allison 1981). More recent studies have confirmed how no-till significantly reduces sediment losses after heavy precipitation events (Mostaghimi et al. 1992).

- **Introduction of selective and non-selective herbicides.**

The introduction of the selective broadleaf herbicides 2,4-D in 1947 and MCPA in 1953 represented a huge leap forward. This was followed with the introduction of the selective wild oat herbicides diallate and later triallate in the early 1960s (Timmons 2005; Appleby 2005). These introductions allowed for more continuous cropping, especially in the moister areas of the prairies. In 1962 and 1966, diquat and paraquat were registered as fast-acting, non-selective, non-translocated, non-residual herbicides (Timmons 2005). The introduction of these herbicides allowed for more investigations into the concept of no-till production systems. The first studies looking at the potential for chemical summer fallow were conducted from 1949 to 1955 in Havre, Montana (Baker and Krall 1956). Their results represent some of the first documented evidence showing that tillage was not necessary to grow a crop. The introduction of the non-selective herbicide glyphosate in 1971 represented a key technology for the detailed investigation of no-till or conservation agriculture production systems worldwide (Appleby 2005). However, it wasn't until the early to mid 1980s that glyphosate became associated with no-till systems. Unlike diquat and paraquat, glyphosate translocated readily into the plant providing very good perennial weed control and overall good annual weed control when applied prior to seeding or after seeding prior to crop emergence.

- **Development of high clearance seeding equipment for no-till.**

The paramount role of farmers in the development of machinery for the agricultural community in Canada cannot be overstated. Farmers have been responsible for all of the seeding equipment innovations found in the region. The most significant was the air seeder, which played a major role in achieving positive seed-to-soil placement under

high residue field conditions. This cultivator based implement has also been used extensively for fertilizer placement using in-soil bands, a major contribution to increased fertilizer use efficiency, and reduced nutrient loss by volatilization and immobilization. The wide array of no-till seeding implements available now speaks to the importance of this technology to agriculture in this region of North America.

- **Development of in-soil banding of N while seeding.**

With the advent of inorganic fertilizers came the issue of placement, timing, form and rate. Other than limited amounts of urea placed with the seed, the majority of it was broadcast on the soil surface either in the fall or in the spring prior to seeding. This placement method quickly exposed volatilization problems that had not been observed with ammonium nitrate. This led the WESTCO fertilizer company in the mid-70s to investigate ways to circumvent this problem (Harapiak 1990; Harapiak et al. 1993). They discovered that if the urea fertilizer was placed in the soil as bands, these limitations could be prevented. This propelled the air seeding industry forward with new designs such that by the early 1980s, the precision in terms of depth control and seed metering were as good or better as the conventional drills of the day (Memory and Atkins 1990). One can therefore argue that the concept of in-soil fertilizer bands paved the way for further improvements in air seeding technology leading to the development of the concept of the one-pass seeding and fertilizing system involving placement of the fertilizer to the side and below the seed row or else mid-row banded between every second seed row.

- **Introduction of winter wheat as a new crop in the region.**

The finding that winter wheat could over-winter and avoid winter kill when seeded into standing stubble because of the insulating effect of the snow trapped by the standing stubble provided new cropping opportunities and some important agronomic benefits (Fowler et al. 1983). Winter wheat could take advantage of early season moisture conditions, grow during a cooler part of the growing season and mature earlier than other crops. This provided new opportunities to continuous cropping, especially in the drier areas of the Canadian prairies. The other important aspect to winter wheat was the requirement to seed into standing stubble. Any producer seeding winter wheat needed to use no-till production or “stubbled-in” practices thereby initiating them to no-till production concepts. In 1985, approximately 203,000 ha of winter wheat were planted in Western Canada, essentially all under no-till.

- **Strong farmer organizations linking farmers and coordinating information distribution.**

The development and active participation of farmer managed organizations in the demonstration of technology and information distribution played a major role in the development of no-till seeding. This “farmer-to-farmer” concept of technology delivery was new to this part of North America, but has proven its effectiveness as an extension process. Conferences and trade shows held by the farm groups have drawn crowds exceeding 1,000 farmers in search of information and new technologies. This role of farmer directed technology development and delivery is believed by most to be one of the most important factors impacting on the rapid adoption of this technology.

## **Challenges to Development of No-Till**

A large number of concerns were raised about the development of no-till seeding technology and many reasons were given as to why it would fail. As it turns out, these concerns turned out to be myths and one by one, these myths were dispelled and proven unfounded over time through sound scientific field research, the collective experience, and the test of time. An attempt is made to identify these major myths and show how they were dispelled.

- **Long-term Health of Prairie Soils.**

It was a myth to think that we could keep on managing our soils the way we had in the past without losses in productivity. We were blind to the devastating effects of wind and water erosion and the degradation from many of the production practices in use (Shutt 1905 in Janzen 2001; Mitchell et al. 1944). In order to sustain the Canadian prairie soil resource, a combination of no-till or conservation agriculture with proper nutrient management, continuous cropping and crop diversification is required. The good news is that these practices can actually improve the overall productivity of prairie soils (McConkey et al. 2003; Lafond et al. 2008).

- **Impact of No-Till on Soil Temperature.**

One of the first concerns expressed by producers with respect to no-till was the potential effects of lower soil temperatures on germination and emergence when residues are left on the soil surface. The sensitivity of germination and emergence to low temperatures, especially the temperatures observed in early spring have been well documented (Lafond and Fowler 1989a,b). It was hypothesized that crop emergence would be delayed more with no-till relative than conventional tillage. Some of the first documented research on this problem in Western Canada did indeed show that surface soil temperatures were lower under no-till (Gauer et al. 1982). However, another study found that if crop residues were pushed away from the seed row barley and canola emergence was improved relative to conventional tillage (Arshad and Azooz 2003). The extensive use of hoe openers, which in essence pushes the crop residues away from area above the seed rows, may have indirectly contributed to avoiding these negative effects. This may also explain why no-till seeders with hoe-openers are by far the dominant seeding technology used on the Canadian Prairies even though many types of no-till disc seeders are available to producers.

- **Crop Residue Decomposition and Residue Accumulations under No-Till.**

Another common concern expressed by producers in the early adoption phases of no-till continuous cropping production systems was the potential for residue accumulation at the soil surface. The belief was that crop residues at the soil surface would decompose very slowly resulting in a rapid build-up leading to difficulties with seeding and more problems with cool surface soil temperatures hence the need for tillage. These concerns were addressed by two studies. The first study showed that residue decomposition was determined almost exclusively by the nutrient content of the crop residues rather than by their biochemical composition (Janzen and Kucey 1988). Their research showed that when wheat, lentil, and canola crop residues had similar nitrogen concentrations, their rate of decomposition were the same. The second study showed that the initial nitrogen content of the crop residues, the accumulated heat units and their placement (buried vs surface) after a minimum amount of precipitation had been received were the determining factors in explaining the rate of residue decomposition (Douglas and Rickman 1992). Experience has also shown that when no-till is combined with diversified crop rotations, the concerns about crop residue accumulation at the soil surface have not materialized and the start of seeding has not been compromised. Grain legume crop residues have higher nitrogen contents resulting in faster decomposition than wheat residues and the residues tend to be cut finely after going through the harvesting operation greatly reducing any potential problems with plugging.

- **Nitrogen Fertilizer Management under No-till –One Pass Seeding and Fertilizing System.**

The evolution of nitrogen fertilizer management from broadcast and seed placement to in-soil bands while seeding is largely a contribution from the machinery industry. The limits of seed row placement, and losses with surface applied urea, made both of these options unacceptable for most farmers. It wasn't till the late 70s and early 80s that the technology for in-soil banding became possible allowing ammonium based fertilizers like urea and anhydrous ammonia to be used effectively (Harapiak 1990). Research

conclusively showed that losses from volatilization with urea could be almost eliminated if it was placed in the soil and covered properly (Harapiak et al. 1993; Malhi et al. 2001). Research showed that it was possible to apply urea and anhydrous ammonia as a side-banded treatment in a one-pass seeding and fertilizing no-till system with a side-banding opener (Johnston et al. 1997). This concept was also verified with other third-party bolt-on openers capable of side-banding using urea during the seeding operation (Johnston et al. 2001). The one-pass seeding and fertilizing no-till system is now regarded as a highly efficient way of managing nitrogen fertilizers for achieving high nitrogen use efficiencies (Malhi et al. 2001; Grant et al. 2002) and also recognized as a best management practice for minimizing the potential for nitrous oxide emissions and other nitrogen losses such as from leaching and denitrification (Lemke and Farrell 2008).

- **No-Till and the Long-Term Impact on Weed Numbers and Weed Community Shifts.**

A legitimate concern expressed with early adopters of no-till was the long-term impact of no-till on weed densities and the potential for major shifts in weed community composition towards more perennial type species and from selection pressure resulting from the continued use of particular herbicides (Lafond and Derksen 1996; Derksen et al. 2002). More recently, the no-till producers have expressed concern over the increase in weeds becoming resistant to herbicides. To date, the large anticipated shift in weed communities with no-till has not yet materialized. There are a number of documented reasons as to why these shifts have not occurred. One has to do with crop diversification which allows for a broader range of herbicide chemistries with more diverse crop types and growth habits (spring or winter crops) which provides for varied selection pressure (Derksen et al. 2002). Another has to do with the precise placement fertilizers with the one-pass seeding and fertilizing system which increases the competitive ability of crops against weeds (O'Donovan et al. 1997). A third one is the large differences in weed communities on the same plot from year to year due to temporal variability in climatic conditions (A.G. Thomas, personal communication). A fourth one is the combined impact of planting rates, crop rotations, crops, planting dates and herbicides in lowering weed seed recruitment in the soil seed bank thereby reducing densities in future years. (Harker and Clayton 2003). No-till producers have not had to resort to tillage to stay on top of their weed problems, even after 30 years in some fields. In general, lower weed populations were reported by farmers that practice no-till in western Canada, which is indicative of lower weed seed banks (Blackshaw et al. 2008). The long-term weed management strategy for no-till producers on the Prairies is to employ a diversity of weed management tools and to ensure that no one tool gets a disproportionate amount of use lest its effectiveness be greatly diminished (Harker and Clayton 2003).

- **No-till and the Long-Term Impact on Plant Diseases.**

Another frequent concern about no-till systems was the potential for increased leaf and root diseases because of the residues left at the soil surface. However, the effects of tillage systems on the incidence and severity of plant disease were found to be small relative to the effects of environment and crop rotation (Bailey et al. 2001; Turkington et al. 2006). Nonetheless, no-till was shown to reduce the severity of common root rot in cereals (Bailey et al. 2001). No-till reduces many crop diseases because of their direct and beneficial effects on soil biology (Krupinski et al. 2002). A healthy soil with diverse and balanced populations of soil micro-organisms will provide substantial competition against root pathogens as these often use the same organic carbon substrate. Attention also needs to be given to other disease control methods such as providing disease-resistant cultivars, disease-free seed with high vigour, use of seed treatments or foliar fungicides if warranted, balanced soil fertility, control of weeds and volunteer crops to break pathogen cycles, and careful record keeping of disease incidence (Krupinski et al. 2002).

## Pillars of Successful No-Till Production Systems

As part of the promotion of no-till seeding the farmer based conservation agriculture organizations focused in on practical steps required to successfully adopt a no-till seeding system at the farm level. In particular, the Saskatchewan Soil Conservation Association (SSCA) developed a set of five “pillars to no-till success” which were promoted to those starting out in no-till.

- **Crop residue management.**

On the Canadian prairies very little crop residue is removed from production fields. As a result, how this residue is managed during harvest is critical to the unimpaired operation of no-till seeding equipment the following spring. The priority issue here has been promotion of straw choppers and spreaders which distribute the majority of the straw and chaff back over the area from which it came. The second innovation which has been very popular has been the use of heavy harrows, a long tine harrow which is used in the field as soon as it is harvested. This harrowing does some spreading of the straw and also is quite effective in breaking up the long pieces of straw if the material is dry and brittle. Unfortunately, delaying harrowing often limits residue movement and has little beneficial effect.

- **Crop rotation.**

As we are all aware, crop rotations which include a mix of cereal, oilseed and grain legumes help in the management of pests within fields, and in regions where grain market supports do not exist, also helps to improve the economics of crop production (Zentner et al., 2002). Crop rotations also help with residue management, by alternating high and low residue crops in rotation. On the Canadian prairies some of the more common rotations amongst no-till farmers are a) cereal – oilseed – cereal – grain legume, b) cereal – oilseed – grain legume or c) cereal – grain legume. Seldom is an oilseed crop grown more than once every three years, but exceptions do exist. Continuous cereal production is negatively affected by leaf and root diseases, so is not considered a good option by most farmers.

- **Weed management.**

Weed control can best be described as an obsession with Canadian prairie farmers. Wild oat (*avena fatua*) is a very common, and abundant, weed in the region, as well as a number of broadleaf annual and perennial weeds. In the absence of tillage, weed control becomes a major management issue in using the proper balance of herbicide products. By alternating grassy and broadleaf crops in the rotation the spectrum of herbicide options is broadened, allowing a focus on different weed types each season. The wide spread use of glyphosate for non-selective weed control has proven successful to date, with few problem weeds developing any form of resistance. Herbicide tolerant canola (*Brassica napus*) occupies approximately 85% of the oilseed crop area, indicating the success of this technology with farmers in achieving both improved weed control and high yields. Herbicide resistance of specific weed species is a serious concern of farmers, and one which receives considerable attention at winter extension events.

- **Soil fertility.**

As mentioned earlier, the in-soil banding of nitrogen is the dominant method of fertilizer placement in the Canadian prairie region. The efficiency and reduced losses associated with the application method have had a major impact on the success of nutrients in these no-till farming systems. Broadcast application was shown to not be successful in the absence of incorporation with early research (Malhi and Nyborg, 1992). It is important to note here that side band, or mid-row band, placement of nutrients has also helped to increase crop yields on many farms by minimizing the

nutrient loss and immobilization so common with broadcast application. Given that fertilization practices in this region are based largely on meeting crop deficiency needs, with no attempt to build soil P and K levels, rates of application are limited.

- **Crop establishment.**

As outlined earlier the issue of soil temperatures has not been a major impediment to the adoption of no-till seeding on the Canadian prairies. In fact, crop establishment (germination and emergence) is considered to be better in no-till, especially for small seeded oilseed crops. In addition, shallow seeding is more of an option when you have good surface moisture conditions, which in turn promotes more tillering on cereals, further increasing yield potential. Tall stubble is actually the desired approach for most farmers in semi-arid regions now, helping to reduce soil water loss by evaporation during the early months of the growing season (Cutforth and McConkey, 1997; Cutforth et al., 2006). Ultimately it is finding a suitable seeding implement which provides good seed-to-soil contact on the particular soil found on a farm, and then adjusting it to place the seed shallow into moisture.

### **Long-Term Implications of No-Till Adoption**

The adoption of no-till on the Canadian prairies can best be described as one of the most significant technology and management changes in farming over the past 100 years in this region. However, this part of the world is not alone in this move to no-till seeding systems. Many parts of south America have actually a higher adoption rate than Canada (Derpsch and Friedrich, 2009). In fact, it is conservation tillage in general which is the management system of choice for all farmers who have access to land and capital in all parts of the world at this time. It is also a management system which brings significant efficiency to a farming operation, including reduced labor requirements, reduced fuel and machinery costs, improved timeliness of operations (due to reduced time in doing tillage), improved efficiency in applying fertilizer nutrients, soil conservation at a level which has only been dreamed about in the past, and increased efficiency in the use of limited supplies of water in semi-arid environments. The no-till seeding system also introduces significant changes to the management of fertilizer nutrients, with in-soil band placement of nutrients having a major impact on both nutrient recovery, but reduced losses to the environment. The conclusion by most is that no-till is the critical step in the development of future farming systems around the world.

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