Engineering Breakthroughs in Conservation Tillage/Direct Seeding Technology

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Summary

Conventional tillage is no longer conventional on the Canadian prairies. In fact, more than 70 percent of Canada's cropland is under some form of conservation tillage with direct seeding (no-till) the most popular or predominant production system on the prairies.[1] Engineering breakthroughs in crop residue management, chemical weed control, seed and fertilizer placement have played a key role in this transformation of prairie landscapes. Driven by the need to develop more sustainable land management practices, innovative farmers and producer groups encouraged researchers, engineers and manufacturers to develop more effective equipment. Canadian manufactures were the leaders in this development and today there are more than a dozen companies including several multinationals that manufacture specialized harvesting, spraying and seeding equipment for the growing domestic and international markets for direct seeding technology.

Introduction and Early History

Various types of reduced or conservation tillage have been practiced on the southern prairies of Canada for nearly 70 years. Alerted to the dangers of wind erosion during the dirty thirties (1930's), farmers practiced strip farming and plowless tillage with one-way discers and cultivators that buried only 40-50 percent of the crop residue. Although these practices reduced erosion substantially, it was not until the development of the wide-blade cultivator in 1936 did we begin to recognize the potential benefits of Atrash-cover farming.@ Trash cover farming with the wide-blade ANoble@ cultivator did more to stabilize and improve dryland farming than any other previous innovation. The ravages from wind erosion and resulting soil degradation could finally be minimized or halted.

But the trend toward larger farms and wider equipment in the 50's and 60's made strip farming (30-60m wide) inconvenient or impractical. As a consequence, the fields became larger and wider. Most farmers used more intensive tillage equipment (cultivators and discs) because weed control with the wide-blade cultivator was not particularly good under wet soil conditions or outside the Brown soil zone. Also, the additional crop residue left on the surface by the blade cultivator made seeding more difficult because of trash clearance and plugging problems. Furthermore, with the advent of soil incorporated herbicides and increasing popularity of inorganic fertilizers, more intensive tillage operations seemed necessary. This more intensive tillage coupled with the drier conditions and lower yields in the sixties left the prairie soils more susceptible to wind and water erosion. These factors plus the general lack of awareness by a new generation of farmers resulted in severe soil erosion problems in the late sixties and early seventies.

Early Focus on Chemical Summerfallow

In the 1960's, herbicides like paraquat and atrazine made it possible to study the effects of reducing or even eliminating tillage. Although it was known that repeated applications of these herbicides for summerfallow were not economical, early research on the prairies demonstrated that little, if any, tillage was necessary to maintain yields.[2,3] Hence, most of the early research with minimum or zero tillage was targeted toward chemical summerfallow in an effort to increase crop residue conservation and provide greater erosion protection. Seeding equipment of the day was adequate because crop residues were not excessive under chemical fallow and there was little need or emphasis on fertilizer placement. Research with chemical fallow clearly demonstrated increased erosion protection, greater moisture conservation and equivalent or higher yields compared to conventionally cultivated fallows.[4]

The greatest potential application for zero tillage and chemical fallow seemed to be in the Brown soil zone where the risk of soil erosion was greatest and the benefits of increased moisture conservation could result in higher yields. But the high cost of repeated applications of herbicides and the risks associated with residual-type herbicides were too high in relation to the potential benefits of chemical summerfallow. Economic evaluation of various minimum tillage practices indicated that a significant yield advantage was necessary to offset herbicide costs and it was difficult to demonstrate the economic value of soil conservation.[5] But as a consequence of this early work and experience many producers began questioning the value of fall tillage and repeated summerfallow tillage and began substituting herbicides for tillage for winter-annual weed control or pre-seeding weed control. It became clear that zero tillage could reduce the need for summerfallow and that research and development efforts should be targeted to more intensive recropping systems and crop rotations that included little or no fallow.

Early Successes with Winter Wheat and No-till Recropping

By the late seventies, there was already considerable interest and some adoption of zero tillage systems for recropping in Manitoba[6] and in the more moist areas of the Dark Brown soil zone in Saskatchewan and Alberta. Much of the interest in Saskatchewan was as a consequence of the renewed interest in winter wheat production between 1977 and 1984 and the importance of direct seeding into standing stubble to help winter survival of the crop.[7] Winter wheat yields on untilled stubble were often equal to spring wheat yields on fallow because of the crop=s improved water use efficiency and compatibility with microclimate associated with zero tillage. The most effective seed drills of the day were high clearance semi-deep furrow hoe drills like the Noble DK-5 or similar machines from Edwards. Early research identified relative benefits and limitations of conventional equipment.[8,9] A few innovative farmers had success with modifying IH or John Deere hoe drills with disc coulters or low disturbance furrow openers. The need for more effective straw choppers and chaff spreaders was addressed by some excellent engineering innovations from engineers at the U of S and rapid adoption by the industry.

There were many concerns about the impact of zero tillage on weed control, diseases, pests, soil fertility, soil physical properties, soil micro-organisms, and a growing concern about the residual effect of repeated or long-term herbicide use. Fortunately, most of these potential concerns did not materialize but they did slow the adoption of the technology until research or experience demonstrated that these issues were manageable. Producers were concerned about the lack of suitable seeding equipment and the high cost of herbicides for pre-seeding weed control. By the late seventies there was already good awareness about the potential benefits of zero tillage in terms of soil and water conservation but adoption was limited because of the apparent lack of no-till seeding equipment (at a reasonable cost) and the high cost of suitable non-residual herbicides. Specialized triple-disc drills (Melroe/Bettinson) from the U.K. and no-till drills from other countries met with limited success on the Prairies because of problems with seed placement or ineffective packing.

In an effort to minimize soil disturbance to conserve moisture and avoid stimulating weed germination, early engineering efforts focused on narrow offset double-disc seeders or narrow hoe openers. This work by Ben Dyck at Swift Current stimulated the development of commercial no-till drills by Versatile-Noble, Haybuster and other manufacturers. In addition, specialized plot seeders developed by Ben Dyck and other engineers at Swift made it possible to evaluate the relative merits of different row spacing and fertilizer placement under controlled conditions which helped advance the knowledge and understanding in this important domain.

Key Role of Producer Groups and the Sparrow Report

By the early eighties there was already considerable information available, but more importantly, thanks to support from groups like the Alberta Conservation Tillage Society, the Manitoba-North Dakota Zero Tillage Farmers Association and SSCA, governments began to provide more support for the growing conservation movement. This culminated with Senator Sparrow's "Soil at Risk" report in 1984 and the formation of the Soil Conservation Council of Canada that were important milestones that helped stimulate conservation programming and R&D efforts.

But equipment developments were slow because there was limited incentive (because of the existing small market) for major American or Canadian manufacturers to develop specialized seeding equipment for zero tillage. But given the concerns and potential opportunities associated with fertilizer placement, considerable research helped determine the relative benefits of fertilizer banding and timing of fertilizer application for various crops. The availability of liquid fertilizers stimulate interest in novel techniques like high pressure and point injection with spoke wheel applicators.[10,11]

Several important engineering and development contracts with involving industry (Versatile-Noble) and engineers from AAFC Research Centres, PAMI and Universities helped establish many of the important design criteria required for effective soil penetration, crop residue clearance and packing.[12,13] For hoe type drills it was clear that for effective trash clearance the minimum vertical and horizontal dimension was 50 cm (20 inches) between openers under most Prairie conditions. When crop residue levels exceeded 5000 $kgha^{-1}$ (typically a rare situation) it was sometimes necessary to remove a portion of the loose straw or chaff to achieve effective seed placement with any seeding equipment. It should be noted that 1200-1500 $kgha^{-1}$ of crop residue cover will eliminate the risk of wind and water erosion and 3000-4000 $kgha^{-1}$ provides near optimum soil moisture conservation. For disc machines it was determined that narrow angled (8 degree) offset double-discs were equal or more effective than the more costly triple-disc designs provided vertical loads were sufficient for soil penetration and in-row packing.

The other primary constraint at this time was the cost of the most suitable herbicides [Sweep (paraquat) and RoundUp (glyphosate)]. Although the price of these herbicides was becoming more attractive, the costs were still high in relation to mechanical weed control. Given the anticipated expiry of the glyphosate patent and potential competition, Monsanto reduced the price and developed formulations for no-till systems. Important developments in shielded sprayers, markers and nozzle technology helped reduce the risk of failure with chemical weed control.

The severe drought in the early eighties helped emphasize the importance and need for more effective land management practices and clearly demonstrated the benefits of no-till. The Prairies experienced some of the worst soil erosion and dust storms since the thirties, including millions of acres in the Black soil zone. Probably one of the biggest surprises, in terms of adaptability of zero tillage or direct seeding is the fact that direct seeding has been successfully adopted in wetter areas of the Dark Brown soil and in the Black Soil Zone and Parkland regions of the Prairies. Part of the reason for this success with direct seeding in these regions was that recropping or extended crop rotations with significant fertilizer inputs were already quite common in these areas. Also, most of the direct seeding practiced today involves more soil disturbance than originally advocated to qualify as zero tillage (less than 20 percent soil disturbance). Some soil disturbance can be quite beneficial to increase soil temperature and improve germination and early growth and minimize concerns about nitrogen immobilization or denitrification. It is difficult to argue with success and one of the main reasons farmers have successfully adopted direct seeding is because of developments in the Canadian air-seeder industry.

Air-Seeder Revolution

There has been a revolution in equipment development for conservation tillage and direct seeding in the last 10 years. Air-seeders now dominate the market and there are a countless number of furrow opener and fertilizer placement options available to producers. Low disturbance (knife-type) openers are available that minimize stubble knockdown, but most producers are using medium or high disturbance openers that are effective in providing some control of weeds as well as providing effective seed and fertilizer placement in one pass. The greatest improvement in air-seeders over the last several years has been in their ability to provide more uniform depth control and effective packing over the seed row. Most air-seeders can now provide as uniform and effective seed placement as the best high clear hoe drills or no-till disc drills; but the air-seeders generally have greater trash clearance capabilities than most hoe or specialized disc drills. There continues to be some healthy debate about row spacing and the trade-offs between trash clearance, weed competition and water use efficiency. The bottom line for producers is still economics and that will usually dictate their selection for the most suitable seeding machine for their situation.

The best seeding system or row spacing often depends on soil type and predominant moisture conditions. Large quantities of crop residues coupled with moist soil conditions at seeding time enabled producers in the Parkland region to have great success with direct seeding by taking advantage of the residue clearance benefits of a narrow 7cm (<3") seed spread on a 30cm (12") row spacing. Compelling testimonials from leading producers and related research by Lafond and others have demonstrated that there are no significant yield differences among row spacings up to 30cm (12") wide.[14]

Concluding Comments

In spite of the significant benefits of conservation tillage and no-till that were well documented more than 30 years ago, development of appropriate seeding equipment was slow because the large, main-line equipment manufacturers had a vested interest in conventional tillage equipment and saw limited market potential for no-till systems. Innovative producers and a few short line equipment manufacturers working with government and university researchers were the early pioneers in equipment development. Although there were some early and important success stories in the 1970's and 80's with high clearance hoe drills and some more specialized no-till disc drills, widespread adoption of direct seeding was made possible in the 1990's with the development of air-seeders that could provide effective seed and fertilizer placement under a wide range of soil and crop residue situations.

The principles of soil and water conservation are universal. The successful adoption of conservation tillage systems in North America and particularly in western Canada has taken more than 35 years. During this period there has been a 75 percent reduction in summerfallow on the Prairies. Today more than 70 percent of Canadian farmland is under some form of conservation tillage, including 46 percent adoption of the direct seeding (no-till) culture. Successful technology transfer of conservation tillage (particularly direct seeding) required significant commitments by both the private and public sector but were it not for the leadership and dedication of conservation producer groups the state of land resources and environmental would be much different. There have been many technological innovations in harvesting and crop residue management, seeding equipment, weed control and fertilizer placement that have contributed to the successful adoption of conservation tillage and transformation of Prairie landscapes. This technology has been successfully transferred to many developing countries, particularly those countries with similar challenges related to soil and water conservation and adaptation to climate change. The future looks exciting with continued innovations in remote sensing, GIS and associated engineering applications for precision farming and automated controls to reduce energy input.

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