An Agronomic Systems Approach to Innovation:

The Conservation Tillage Example

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Agriculture on the Canadian Prairies has initially based on exploiting the native fertility of our soils. From the late 1800's till about 1920, most of the land suited to annual cropping was tilled and cropped. For most of this era, nutrient supplies far exceeded crop needs and little attention was paid to replacing nutrients removed by the crops we grew. This was appropriate since it would have been impossible to maintain these levels of fertility without causing serious environmental damage. This mining of nutrients was accelerated by the harvest systems of the day which removed both grain and straw from the land. The result was that nitrogen began to limit crop yield.

Summer-fallow was developed as a strategy to mitigate drought, but also addressed declining nitrogen supplying capacity. Summerfallow stored moisture, but also released nitrogen into the soil in forms that crops could readily use. The droughts of the 1930's revealed a darker side to this practice: The dust storm. With less organic matter to hold soil particles together and little protective residue cover, vast areas began to drift. The resulting dust clouds carried soil far beyond the prairies where it originated. Clearly change was needed.

The most fragile and highly damaged land was abandoned and most was re-vegetated to grasses, and much remains in grass to the present. Time. The rescue of less fragile fields came from an unexpected source; the swather and combine. This new more efficient harvest system that replaced the binder and threshing machine could leave all the straw in the field. These residues held the key to halting wind erosion if only they could be retained on the soil surface. Tillage equipment at the time consisted of plow and disc implements that inverted and mixed surface residues into the tilled layer of soil. Equipment that severed weeds below the surface and left most residues on the surface was developed, evaluated and refined. The resulting wide blades, rod weeders and cultivators proved very effective at killing weeds yet leaving more crop residues on the soil surface, where they reduced wind speeds, and reduced of erosion. These implements proved easier to pull, and could be build to till a wider path and their adoption started the era of stubble mulch tillage. Opponents, and there were many, were convinced that 'plowless' tillage would create soil structural or fertility problems that would be the demise of stubble mulching.

Improved efficiency [lower cost and more acres per hour] likely drove rapid adoption of stubble mulch tillage. By the mid 1950's this was the typical practice, and it seemed that declining soil quality was solved. However hints that this practice had it's limitations soon became apparent. Stubble mulch tillage usually provided adequate protection where land was re-cropped. Summer-fallow land however was often vulnerable because repeated tillage and natural decomposition did not always leave enough reside to prevent erosion by the end of the fallow period. This was particularly evident in drought cycles when crop residue production was low. By 1970 there were numerous indicators that soil degradation was not being adequately addressed, and that new innovation was needed. However it was not apparent at the time what would be needed to address the problem.

By 1983 soil degradation caught the attention of government, and the senate standing committee on Agriculture, Fisheries and Forestry were authorized to 'examine the subject matter of soil and water conservation throughout Canada'. Their report [H.O.Sparrow 1984] summarized the problem as follows:

'Canada is facing the most serious agricultural crisis in it's history and unless action is taken quickly, this country will lose a major proportion of it's agricultural capability.'

The report clearly identified intensive tillage and summer-fallow as the primary causes of soil degradation in the prairie region. Tillage because it hastened the decomposition of soil organic matter and buried crop residues that were so essential for protecting the soil from wind and water erosion. Summer-fallow shared the same downside as tillage, but also did not contribute any fresh organic matter, while leaching nutrients from the root zone when moisture was excessive. Leaching ultimately resulted in salts being deposited near the surface at lower elevations and was a major cause of salinity. Other factors identified were lower rates of return of organic carbon to soil with annual crops compared with native grasses and use of large equipment, but clearly tillage and summer-fallow were the major factors.

So if tillage and fallow were causing problems, replacing tillage with herbicides and summer-fallow with 'king' wheat would surely correct the problem. By the late 1970's there was ample evidence that herbicides could replace tillage for control of weeds, and there were numerous studies evaluating continuous wheat. We simply needed to enhance moisture use efficiency slightly to offset the moisture storing benefits of summer-fallow and we would have a solution. It appeared that improved moisture storage could be achieved by trapping more snow, and that evaporation losses could be minimized by reducing or eliminating tillage.

However, as we began to evaluate this approach it became apparent that there were major short-comings that needed to be addressed. Seeding equipment sometimes did not penetrate the soil sufficiently to place seed uniformly at desired depth; sometimes it plugged with residues; sometimes straw was forced into the seed row [a condition called hair-pinning] and interfered with seed placement while hastening drying of the seedbed; and sometimes coverage of soil over the seed-row was inadequate.

Fertilizer placement presented another challenge. Broadcasting without incorporation risked serious losses of fertilizer N while incorporating negated any benefits from reducing or eliminating tillage. Pre seed banding was efficient but still involved additional soil disturbance, and in-crop top dressing was also quite risky. Only limited amounts of nutrients could be safely seed placed, so some low disturbance way to apply large quantities of fertilizer during seeding was essential.

While herbicides controlled weeds effectively on summer-fallow, costs were typically much higher than the tillage operations they replaced. Crop residues along with improved moisture combined to reduce soil temperatures in the seedbed, a change that was often implicated in poor crop establishment in cooler regions and caused concern where the growing season was already quite short. Without tillage, mineralization of nitrogen during fallow was reduced which could affect fertilizer needs. Continuous wheat itself was a problem because leaf diseases were increased, and problems with grassy weeds began to emerge. With cereal monoculture, the prospect of herbicide resistant wild oat and other grassy weeds became a reality.

There were a number of other perceived problems with a change to conservation tillage. Because tillage loosened the soil, soil compaction would surely become much more serious. Many diseases survived on crop residues and tillage was perceived as an effective control measure, so surely leaving them on the surface would be disastrous. Pesticides were poisons that were damaging to the environment so any practice that relied more heavily on them must by definition be much more damaging than the practices that they replaced. Crop cultivars were developed in tillage and fallow based systems, therefore they would be less than ideal under this radically changed cropping system. And finally, summer-fallow was seen as a period of 'rest' for the land, and continuous cropping would place too much stress on the land so such practices were certain to fail.

Clearly the solution was far more complicated than just reducing or eliminating tillage and summer-fallow. Further, the fact that these issues came to light when we began to change the cropping 'system' suggested that we could no longer try to address issues in isolation, but rather to look at them from a systems perspective. The systems approach went beyond just dealing with agronomy, but also included equipment and how new information was communicated. What evolved was a group of farmers, equipment manufacturers, extension specialists and research scientists who shared a common belief that only by working together could they identify and resolve the key issues that prevented widespread adoption of conservation tillage. What bound this group together was the knowledge that failure to address soil degradation would ultimately deplete the soil resource to the point where large areas would no longer be suitable for crop production.

Development of straw choppers and chaff spreaders quickly alleviated some of the problems associated with plugging of seeding equipment and some of the concerns about nutrient and possible phytotoxic effects of uneven spreading of crop residues. With uniformly spread residues, equipment manufacturers could design seeding equipment with adequate residue clearance to minimize risk of plugging with straw. Major improvements in seed placement occurred as a result, and with recognition that improved seedbed moisture would allow shallower seeding another limitation was soon overcome. Shallower seed placement meant the seed was placed into warmer soil, effectively overcoming much of the detrimental effect of cooler soils in the absence of tillage. An added benefit was that seedlings were less susceptible to some seedling diseases, and direct seeded crops were often more vigorous because they exhausted less of their energy reserves emerging from the soil than deeper seeded conventionally tilled crops.

Initial attempts to side band fertilizer suffered from either inadequate separation of seed and fertilizer or excessive soil disturbance, and sometimes both. Regardless of the cause, crop establishment was the victim. However designs that actively placed soil over fertilizer or banded it mid way between rows largely overcame these limitations. An added benefit of such fertilizer placement was that crops had preferential access to the nutrients, improving vigor and competitiveness with weeds.

With better seed placement, it became feasible to grow small seeded oilseed crops like canola and flax in rotation with cereals. Consequently, rotations became more diverse with oilseeds alternating with cereals. Major benefits of such changes were that pest losses were reduced and in many cases financial returns from oilseeds were higher. Improved moisture conservation also allowed for production of oilseeds in regions previously considered too dry. The next major rotational change occurred with introduction of well adapted lentil, pea and later chickpea cultivars. These pulse crops further reduced losses due to pests and reduced reliance on cereal and oilseed markets providing greater economic stability. Because they used moisture efficiently and were quite drought tolerant, pulses in rotation were instrumental in replacing summer-fallow throughout much of the drier Brown and Dark Brown soil zones. However their greatest benefit was due to their ability to fix nitrogen from the air. It reduced fertilizer nitrogen requirements in both the current and succeeding crop. Because pulses used less soil nitrogen while returning more to the soil, they increased the capacity of the soil to supply nitrogen. This overcame a limitation in conservation tillage systems where minimal soil disturbance slowed cycling or release of nitrogen from crop residues.

Numerous developments improved the effectiveness and reduced the cost of weed control, both before seeding and in-crop. Improved understanding of how climate, spray and water quality affected herbicides like glyphosate allowed for reduced rates to be used, and largely eliminated the need for repeat applications. At the same time, the manufacturer reduced the cost of glyphosate to encourage more rapid adoption of conservation tillage. Diversified rotations initially presented weed control challenges because herbicide treatments for pulse and oilseed crops were generally less effective than for cereals. However, from a systems perspective it soon became apparent that weeds were manageable in such systems, and that over time reliance on herbicides could be reduced by taking advantage of improved crop competition due to improved crop vigor and better fertilizer placement with conservation tillage.

Dealing with some of the perceived deficiencies with conservation tillage was simpler, as in most cases, problems simply did not arise. Soil compaction is not problematic. Disease problems associated with leaving crop residues have not decimated crops, pesticide use has tended to decline after adoption, cultivars requirements do not differ substantially in conservation tillage systems, and soil needs to support vegetation every year to remain productive rather than needing periodic ‘rest’ associated with summer-fallow.

What evolved was a new and much improved **system** of producing crops that enhanced yield and productivity while protecting the soil resource and environment. The system involved uniform spreading of crop residues, effective preseed weed control with herbicides, more uniform shallower seed placement, fertilizer banded at seeding and diverse rotations of cereal oilseed and pulse crops in addition to elimination of tillage and summer-fallow. Without a systems approach it is unlikely that a suitable solution could have been developed, and it’s adoption would most certainly have been much slower. Rapid adoption also reflects that farmers, extension personnel and industry agronomists played a very active role in promoting the technology and in supporting efforts to develop improvements to the system.

Lessons learned about the system approach to improved agronomic practices have not been wasted but are actively being used today in developing improved stems. An example is a recently completed study in Alberta examining the effect of timing of herbicide application combined with seed rate and hybrid vs open pollinated cultivars of canola Figure 1. In the study earlier weed removal, higher seed rates and hybrid cultivars all increased yield, but the combination of all three yield enhancing practices was most beneficial.

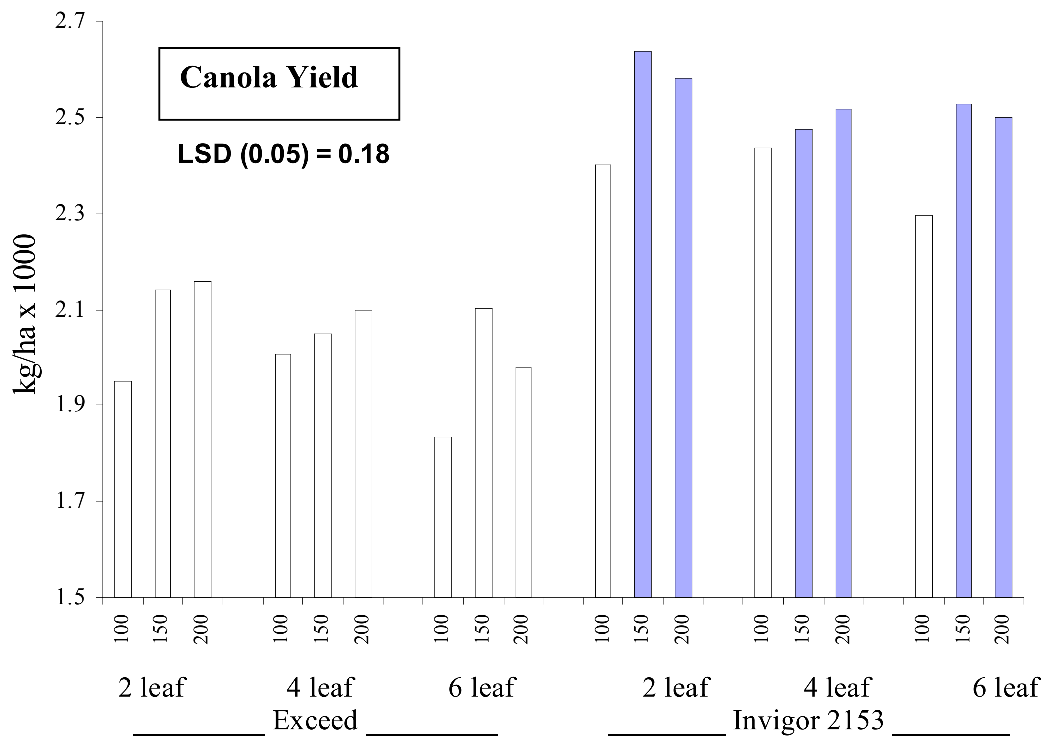

Figure 1. Canola yield with an open pollinated cultivar [Exceed] and a hybrid [Invigor 2153], weed removal at 2, 4 or 6 leaf stage and seed rates of 100, 150 and 200 seeds per square meter; alone and combined in the same system.

Source: Harker et al. 2003. Can. J. Plant Science 83: 433-440.

Another example comes from research on inputs for canola and barley. In this multi year, multi location study inputs of improved genetics, higher seed rates, fertilizer and herbicides all increased yield [Table 1]. When they were combined at near optimal levels, the combined effect was much greater than the sum of individual responses; a benefit that we are calling a stacked benefit.

Table 1. Effect of improved genetics, higher seed rates, fertilizer and herbicides on yields of canola and barley averaged over 20 location years in SK and AB.

Factor	Yield increase [bushels per acre	
	Canola	Barley
Genetics	3	2
Seed rate	2	5
Fertilizer	4	8
Herbicide	13	22
TOTAL	22	36
COMBINED EFFECT	32	42
STACKED BENEFIT	10	6

Source: Adapted from Brandt et al. Proceedings of the 2009 Saskatchewan Soil Conservation Association annual meeting.

Summary

What is clear is that tillage based agriculture is not sustainable and never has been. Tillage and summer-fallow are tools we use to mine the soil of nutrients.

Conservation tillage has addressed many of the shortcomings of tillage based agriculture. However the lessons of the past surely tell us that even this improved system will require innovation to address new shortcomings as they arise. As we move to address these issues we would be well advised to consider building on the agronomic systems approach that served us so well in developing conservation tillage. That systems approach will likely include biologists, environmentalists and other non agriculturalists who could view the land from very different perspectives. It too may rely heavily on systems modeling as a means of understanding and extending knowledge collected to date. Systems models may have their greatest value in understanding the complex interactions of systems.

Innovation in agriculture is far more likely to be driven by producers of food AND consumers of food. For most of the past decade food consumption has exceeded production. This shortfall reflects in part a lack of innovation in agriculture because food has been abundant and farmers have been more concerned with cost cutting than with increased production. However, cost cutting often means mining the soil of it's productive capacity. Far too often this occurs on the most vulnerable land. Here it is in the dry prairie where summer-fallow has depleted soil productivity to the point where more than half the nitrogen required to grow an economic durum wheat crop must come from fertilizer. That is less than what is typically needed to optimize yield on continuously cropped land. In fact it appears that most land that has been in a conservation tillage system requires less fertilizer than in the past while fallowed land has ever increasing needs. The shortfall was met by stored food in exporting countries. The price rallies, food shortages and food riots of 2008 were a wake up call. One that says we cannot afford to take food for granted.

Conclusion

Conservation tillage presented a unique challenge because the solutions were much more complex than what we had dealt with in the past. In the past, innovators like scientists and engineers recognized a need and developed a technology to address the issue. This simplistic approach was a root cause of the soil degradation problem so a different approach was used. It was based on devising a new system of cropping and was developed by many different players. The result; conservation tillage has proven highly effective with much improved sustainability. It sets the basis for improved systems of the future.