Developing Multifunctional Farming Systems for Canada

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Take home message

With the right farming systems in place, agriculture in Canada can deliver greater economic returns to farmers and rural communities while helping Canada to meet environmental and clean energy goals. The continuing trend in mainstream agriculture is towards specialized and simplified farming systems. These systems are inherently unable to deliver on an increasing range of demands on agriculture, including a sustained fair return to farmers, environmental stewardship, the production of safe and abundant commodity and specialty products and the production of clean energy alternatives. Delivery on these multifunctional demands will require dedicated efforts to develop farming systems which are more biologically diverse and inherently multifunctional.

Background

Over the past 40 years the industrialization of agriculture allowed farmers to dramatically increase productivity and production efficiency by rapidly adopting and employing an evolving stream of green revolution technologies. The industrial model of farming successfully supports a productive agri-food industry which supplies safe nutritious and affordable food.

With success in industrial farming there is a now a move to look to new and emerging goals for farmers and agriculture. Although the industrial farming model was effective in delivering productivity and safe, nutritious and affordable food, it cannot fully deliver on additional goals in two key areas; farmer income and environmental stewardship. The inability of the industrial model to deliver on these broader goals is a function of trade-offs in the model where specialization facilitated by production technology (primarily pesticides and synthetic nitrogen fertilizer) is used to facilitate production scale increases. Specialization commonly results in farming systems that lack integrated biological diversity (e.g. diverse crop rotations) and key farm income and environmental stewardship goals can only be met by farming systems that are built on biological diversity.

Farming systems that are able to meet broad goals of productivity, farm income and environmental stewardship (multifunctional farming systems) must be biologically diverse. The reliability and functionality of farming systems increases when they are more biologically diverse (including livestock where possible) and even more so when the biological diversity is integrated within the systems. This diversity provides to these systems the advantage of <u>biological risk management</u>. Biologically diverse farming systems deliver a more stable yield in unpredictable weather conditions, require less external energy inputs and fewer cash inputs, they offer a more consistent and predictable farm income level, are more nutrient and water efficient and they support a more diverse range of macro and micro-organisms on the landscape. There is great potential economic and environmental value in increasing the integrated biological diversity within farming systems with the goal of building farming systems which more closely resemble robustly functional natural systems. In the context of unreliable weather and markets, these systems will be inherently better able to reliably deliver on societies increasing expectations of agriculture including: high quality food, secure product and commodity supply, food safety, food sovereignty, bio-based clean energy, a diversity of novel agricultural products, a healthy environment and clean water.

Multifunctional Farming Systems: goals, tactics to achieve goals and resulting economic and environmental benefits.

Key Goals	Introduction	Tactics to achieve goal	Economic benefits to farmer	Greenhouse gas emission reduction and mitigation	Energy use impacts	Influence on water quality	Other environmental benefits
Reduce N fertilizer costs	- Fertilizer N cost rose 220% over past 6 years. -Legumes fix atmospheric N reducing need for purchased N -No-till soils show greater soil N supplying power reduce purchased N needs	-Legume cash crops -Legume forage crops -Legume perennial grain crops -Legume service crops -Animal manure (see crop-livestock integration below)	-N fertilizer 30 to 40% of variable crop production cost -N fertilizer cost savings of 15% to 70% possible -Reduces cash inputs and financial risk	-Every 1 MJ fossil fuel energy use emits 0.0157 kg C/ha. Average ha of grain land emits 50 kg C due to N fertilizer manufacturing	-N fertilizer alone accounts for up to 60% of energy use in grain production -Whole farm energy savings of 8 to 40%	-N in whatever form (inorganic or organic) can reduce water quality. Soluble fertilizer N forms most dangerous in this regard	-Mixed farming systems provide the greatest biodiversity benefits
Reduce reliance on pesticides	- With simplification of cropping systems (e.g. less crop rotation) there is an increasing reliance solely on pesticides for pest control	-Legume forage (especially perennials) and service crops provide practical diversity that directly reduces dependence on pesticides - pesticide-free production and organic farming systems	- pesticides equal 15 to 20% of variable crop production costs.	-Farming systems can changes maximize C sequestration -Deep-rooted perennials sequester 20% more C in subsoil than annual crops	- Pesticides comprise up to 6% of energy input in non-diversified farming systems.	- Pesticide use reduction reduces risk of movement of pesticides to surface and groundwater	- Pesticide use reduction reduces risk of negative effects on non-target organisms
Reduce on-farm energy use (and costs)	- Sources of energy consumption on farms in order of quantity: N fertilizer>liquid fuel>machinery>P fertilizer>herbicide. -Energy costs of faming rising faster than crop value - current lack of crop livestock integration	-Crop-livestock integration - N fixing legumes -legume-based forage vs. grass only forage -Herbicides instead of tillage to reduce fuel use -(bio)diesel use -Cattle grazing instead of confined feeding -Organic crop production	-Energy cost reductions of up to 50% -Greater net return and reduced economic risks -C savings from 50% energy reduction results in $1.2 million annual revenue from sale of C credits	-Every 1 MJ fossil fuel energy use emits 0.0157 kg C/ha -A 50% reduction in fossil fuel use over 5 million ha results in a C emission reduction of 250,000 tonne /yr	-Improved diverse and integrated farming systems can significantly reduce energy use in farming	- Crop-livestock integration can be optimized to reduce energy use and protect water quality. -Less tillage and use of legumes in rotation potentially reduces water pollution	-Enhanced wildlife habitat
Sequester more carbon in agricultural soils	-Level of soil C sequestration depends on farming practices. -Source of soil C is plant matter -Soil is the world's 3rd largest C sink - There is now an international market for C credits.	-No-till farming -Deep-rooted perennials in rotation -Perennial grain crops -Cover crops	-Higher C soils have greater ability to 'hold' N, and can reduce N fertilizer costs -Increase inherent productivity of soil. -C trading at $6-7/t on Chicago Climate Exchange	-Farming systems changes can maximize C sequestration -Deep-rooted perennials sequester 20% more C in subsoil than annual crops	-Both reduced tillage and perennial legumes in rotation greatly reduce energy use in farming systems	-Perennial plants reduce nutrient leaching -Diverse rotations including perennials and service (cover) crops reduce surface runoff	-Less soil erosion due to better soil structure - Increased biodiversity in soil with higher soil C levels = greater environmental mitigation capacity

(Entz et al. 2006)

Reducing N fertilizer costs

Over the past 6 years, N fertilizer costs have increased 220% (Flaten, pers comm.). Commodity prices continue their 150 year downward trend (in current dollar terms), resulting in a large profitability gap for Manitoba grain farmers. Because N fertilizer makes up 30 to 40% of the variable costs for producing a crop in Manitoba, heavy reliance on inorganic fertilizer in Manitoba crop production will continue to make grain farming unprofitable.

Increasing the efficiency of fertilizer N

While some gains can be made in fertilizer N use efficiency, these gains are so small (<5%) that they will not solve the problem of economic risk from fertilizer N use. Manitoba farmers already apply N fertilizer at optimum times and using optimum application technology.

Table: Nitrogen benefits of different legume systems in Manitoba cropping systems.
Source of information: Various Manitoba field studies (1990 to present).

Legume option	**N savings in following year**	**N saving in year 2**	**N saving in year 3**	**Total N saving[2]**	**Other benefits**	**Source of information/Trial locations**
4 year alfalfa hay stand	80 kg/ha	30 kg/ha	10 kg/ha	[1]120 kg/ha ($116/ha)	Salinity and weed control; soil tilth	Forster (1999) Winnipeg (The point); Portage la Prairie
4 year alfalfa/grass pasture	100 kg/ha	40 kg/ha	20 kg/ha	[1]160 kg/ha ($152 kg/ha)	Salinity and weed control; soil tilth	Various sources
Sweet clover green fallow	60 kg/ha	15 kg/ha	0	75 kg/ha ($72.75/ha)	Weed control	Campbell et al. (1990) Indian Head, SK
Chickling vetch green manure	82 kg/ha	8 kg/ha	0	90 kg/ha ($86.30)	Weed control	Bullied et al. (2002) Winnipeg (The Point)
Indian Head lentil green manure	75 kg/ha	10 kg/ha	0	85 kg/ha ($82.45)	Weed control	Bullied et al. (2002) Winnipeg (The Point)
Pea green manure	[3]80 kg/ha	NA		Min. of 80 kg/ha ($77.7/ha)	Weed control	Knaggs (2002) Carman and Winnipeg
Pea grain crop	25 kg/ha	0	0	25 kg/ha ($24.25ha)		Przednowek et al. (2004) Carman and Brandon
Dry bean crop	5 kg/ha	0	0	5 kg/ha ($4.85/ha)		Przednowek et al. (2004) Carman and Brandon
Soybean grain crop	10 kg/ha	0	0	10 kg/ha ($9.72/ha)		Przednowek et al. (2004) Carman and Brandon
Late-season legume cover crop after winter wheat	[4]40 kg/ha	5 kg/ha	0	45 kg/ha ($43/ha) [4]Up to $67.80/ha	Weed control; soil dewatering	Thiessen Martens et al. (2005) Winnipeg and Carman
Tilled summerfallow	60 kg/ha	-4 kg/ha	0	56 kg/ha ($54.30)	Weed control	Bullied et al. (2002) Winnipeg (The Point)

[1]Small N benefits will occur up to 10 years after forage crop termination
[2]N fertilizer at $0.97/kg
[3]Based on soil nitrate N in spring the year following a pea green manure crop compared with a previous flax seed crop.

[4]Based on a red clover/alfalfa cover crop mixture. Recent Manitoba research (Pridham, MSc student, Department of Plant Science) showed that hairy vetch had a fertilizer N replacement value of 65 kg/ha in the year after cover crop growth.

Legumes and animal manures

The two best hopes for reducing inorganic N fertilizer use are legumes in rotation and animal manures. Legumes hold more promise than animal manure because: 1) applying animal manures in an environmentally-responsible manner (i.e., basing manure application rates on manure P concentration and not manure N concentration) will limit the amount of manure N applied per acre; and 2) legumes are adapted to all areas of Manitoba. Legume options include: 1) perennial forage crops (e.g., alfalfa, birdsfoot trefoil, etc.); 2) green fallow (e.g., sweet clover, annual red clover, vetches, lentil); 3) legume cash crops (e.g., peas, soybean, beans); and 4) legume service crops (e.g., red clover with winter wheat).

Perennial forages and environmental quality

The effects of perennial forages on environmental quality have been examined in several Manitoba studies. In an extensive farm survey, it was found that forage phases in the rotation reduced the need for herbicides in following crops (Entz et al., 1995; Ominski et al., 1999).

The role of perennial forages in reducing deep-leaching of nitrates was documented in a field survey conducted by Manitoba Agriculture Food and Rural Initiatives. Entz et al. (2001a) found that a 4 year alfalfa stand extracted deep-leached nitrates to a 240 cm soil depth.

Perennial forages in rotation increase nesting habitat for migrating waterfowl (Gross, Ducks Unlimited, pers comm.). Perennial forages in rotation reduce soil erosion risk by increasing the stability of soil aggregates (Nelson, 2005).

Service crops also increase biodiversity in other ways. For example, Galvez et al. (1995) documented that an overwintering cover crop increases innoculum of VAM fungi. Drinkwater et al. (1998) have documented the positive effects of green manures on soil biological function and improved overall N cycling.

Farm experiences with legumes in rotation

Manitoba farmers have made tremendous progress in the use of legumes in rotation. The following examples (Table 2) show how Manitoba farmers have used pulse crops, perennial alfalfa and green fallow crops in their crop rotations. A common theme in all the examples is that farmers have learned how to manage legumes to benefit the entire farming system.

Table: Examples of Manitoba farmers using legumes in their crop rotations.

Legume system	**Location**	**Read about it…**
Peas in a no-till rotation	Kenton, MB	http://umanitoba.ca/outreach/naturalagriculture/profiles/peas/peas.html
Perennial alfalfa in rotation	Clanwilliam, MB	http://umanitoba.ca/outreach/naturalagriculture/profiles/short/short.html
Green fallow in conventional system	Argyle, MB	http://umanitoba.ca/outreach/naturalagriculture/profiles/grown/grown.html
Green fallow in organic system	Kenton, MB	http://umanitoba.ca/outreach/naturalagriculture/profiles/transn/transn.html

Improving soil – increasing the soil organic N pool

Soil organic matter holds the largest reserve of N in soils. Certain management practices, such as crop rotation with legumes and no-till, build up the soil organic N reserves. Figure 1 shows three soils with different management history. Agriculture and AgriFood researchers have established that the 20 year no-till soil (centre photo) has a much higher N supplying power than the conventionally managed soil (left). The research is showing that the centre soil now requires significantly less N fertilizer than the conventionally managed soil and the reason is higher N supply within the organic matter of the “restored” soil.

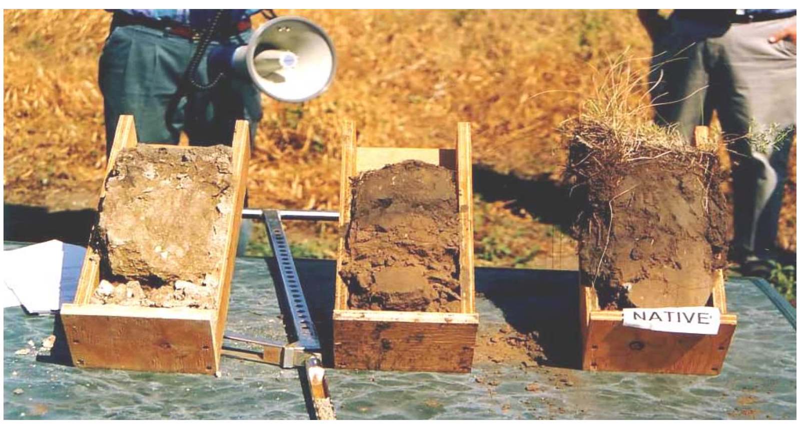

Figure: Three soils from long-term management at Indian Head, SK. Left soil: conventionally managed with tilled summerfallow; middle soil: 20 years of no-till farming and continuous cropping; right soil: native prairie soil. Photo credit: Bill Crabtree, Western Australia.

Tilled summerfallow – an efficient, yet damaging way to extract soil N

Some farmers have resorted to tilled summerfallow as a means of sustaining their farms economically (see: http://umanitoba.ca/outreach/naturalagriculture/profiles/fallow/fallow.html). Tilled summerfallow is not recommended, however it does provide short-term economic benefits. Long-term summerfallowing reduces soil organic matter (i.e., reduces natural capital of land). However, when legume crops are added to the fallow year, the practice is very positive (see http://umanitoba.ca/outreach/naturalagriculture/profiles/grown/grown.html).

Organic farming

Organic farming relies exclusively on legumes for N supply. A survey of 14 organic farms in Manitoba and eastern Saskatchewan showed that soil N supplies ranged from adequate to very high (Entz et al., 2001b). Organic farmers use two main legume systems, perennial forage crops in rotation and green fallow. We are now working on organic/low till systems.

Reducing Pesticide Use

Numerous tactics exist to use herbicides more efficiently and herbicides can sometimes be replaced by non-chemical weed control methods. Many of these tactics and methods have been investigated and demonstrated for use on field crops in Canada (Nazarko et al. 2005). However, herbicide use reduction is fundamentally dependent upon preventative strategies designed to create robust cropping systems that maintain low weed densities. Diverse crop rotation forms the basis of preventative strategies as it inherently varies cropping system conditions to avoid weed adaptation. There is evidence that residual weed densities resulting from herbicide use reduction are manageable within competitive cropping systems. A great deal of research has been done on herbicide use reduction on field crops in Canada, and most projects report definite possibilities for herbicide use reduction in field crop production in Canada. Synthesizing and extending this information, and customizing it for use on individual farms remain challenges. Collaboration between researchers and farmers can help to build successful strategies for herbicide use reduction which reflect the context of modern farming, the will of farmers and the culture of technology adoption among farmers.

Continuum of Reduced Herbicide Use Approaches

“Get Lucky”	**“Make Your Luck”**	**“No Herbicide Required”**
Assess herbicide need at time of spraying	Create opportunity for reduced herbicide use	Organic techniques and attitudes

Increasing Crop and Management Diversity

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Decreasing Importance of Herbicide for Weed Control

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Reduce on-farm energy use

Manitoba grain farmers use approximately 6,000 MJ of fossil fuel energy/ha each year (Table 3). While these farms still produce more energy than they consume (approximately 7 units of energy for every unit of energy invested in fuel, fertilizer, machinery and pesticides, Hoeppner et al., 2005), there is scope to increase energy use efficiency on Manitoba farms.

Table: Comparison of energy use and carbon emissions in zero-till and conventional-till systems. Both are 1,600 acre farms in Manitoba. Conventional farm located in Red River Valley; zero-till farm located near Kenton, MB.

	Energy Use (MJ/ha/year)		Carbon Emissions (C/ha/year)		Zero-till expressed as % of Conventional till	
	Conv Till	Zero Till	Conv Till	Zero Till	NRG Use	C Emission
Machinery	551.47	370.09	10.55	7.08	67.11	67.12
Fuel	1197.09	762.86	22.56	14.57	63.73	64.58
N-Fertilizer	3886.79	3530.91	54.90	51.53	90.84	93.87
P-Fertilizer	382.90	365.09	7.70	7.34	95.35	95.34
Herbicide	312.36	427.55	4.52	5.87	136.87	129.82
Total	6330.62	5456.49	100.23	86.39	86.19	86.20

[1]Source: Gulden and Entz (1999) ttp://umanitoba.ca/outreach/naturalagriculture/articles/energy.html

<u>Reduce N fertilizer use</u>

Because N fertilizer is the largest energy user on Manitoba farms, reducing reliance on inorganic N sources will yield the greatest improvement in overall on-farm energy use. Strategies to reduce N fertilizer use on Manitoba farms have been discussed above.

<u>Substitute herbicides for tillage</u>

Fuel represents the second largest energy consumer after fertilizer N (Table 3). The example shown in Table 3 indicates that shifting from an intensive tillage to a no-till or reduced tillage system reduced fuel energy use by approximately 35%. Herbicide energy costs increased by 30% with no-till system; however, this only represented an increase of 115 MJ/ha.

<u>More fuel efficient machines</u>

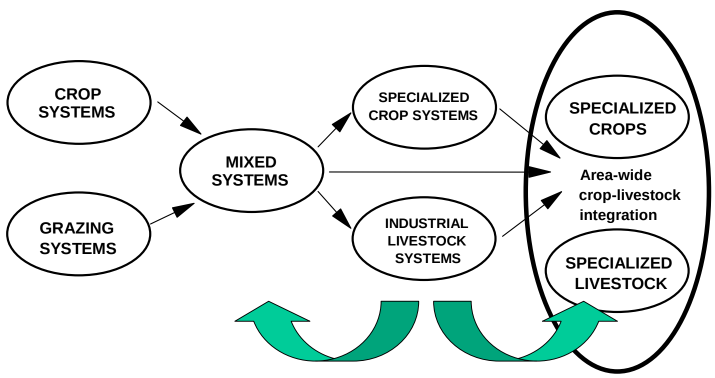
Nagy (1999) has highlighted a number of ways to increase fuel efficiency by substituting low fuel efficient systems with high fuel efficient systems. For example, shifting from single axle 3 and 4 tonne gasoline trucks to diesel tandem and semi trucks reduces fuel and use from 11 MJ/ha to 5 MJ/ha. Even when the higher energy cost of machinery is consider (i.e., it takes more steel to make a semi-truck than a smaller truck), the total energy requirement of the semi-truck is lower than for single axle gas trucks (10 vs. 15 MJ/ha).

<u>Crop-livestock integration</u>

Integrating crops and livestock provides the greatest potential to reduce energy costs in primary production. Approximately 50% of Manitoba farms have both beef cattle and grain enterprises. Improving the integration of crops and livestock on these farms can reduce energy use by 50%. The basis for less energy use in integrated systems is: 1) needing less N fertilizer due to legumes in rotation; 2) no-till technologies now available to establish and remove forage and pasture crops; and 3) using the livestock and not machines to harvest forage. In the words of Iowa sustainable farmer Tom Frantzen “cows like to walk and plants like to stand still”.

Point #3 (using livestock instead of machines to harvest forage) involves improved pasture management and novel winter feeding strategies such as stockpile and swath grazing. The novel winter feeding strategies and improved pasture management required to reduce energy use have been thoroughly investigated by Agriculture and AgriFood Canada scientists at Brandon, MB and Lacombe, AB. These approaches also result in significant economic benefits. For example, traditional winter feeding system costs account for 50 to 70% of annual input cost per cow in cow-calf production. Novel winter feeding systems alone reduce these costs by 50% (McCartney et al. 2004).

Crop-livestock integration can be practiced on both a local (on-farm) and a regional level (area wide integration) (Figure 2). Currently, one major driver for integration over specialization is manure management. Intensive livestock operations have manure disposal problems that require a plan involving cropland. While both on-farm and area-wide integration can solve the manure problem, on-farm integration offers more opportunities for energy savings than area-wide integration (Entz et al., 2005).



Schematic diagram showing different levels of crop/livestock integration. Large arrows show two ways to re-integrate crops and livestock. Left arrow shows shift from specialized crop and livestock production to on-farm integration. Right arrow shows shift from specialized crop and livestock production to area-wide integration.

On Farm Fuel Production

Manitoba farmers spend an average of $11.50 per acre for fuel for crop production. Calculated over 11.65M acres of cropped land that is a total cost of $134M on fuel purchases, all of which currently come from fossil fuel sources. At a value of $1 per litre that is 134M litres used annually in crop production. If farmers produced 13.4M litres of vegetable oil to be used in a 10% diesel fuel blend (B10), a reduction in fossil fuel use of 10% could be achieved. This would require 38,000 acres of canola production. In 2003 Manitoba grew 2.5M acres, so a 10% blend would require 1.5% of Manitoba's canola production.

Carbon sequestration

Two main ingredients: Vegetation (C) and a source of N

Typically, the more crop biomass left on the land, the greater the chance to increase soil C content. However N is required to "move" this C into the soil organic matter pool (i.e., sequestration). A C:N ratio of 24 or less is required to make N available for soil processes yet wheat straw, for example, has a C:N ratio of more than 80. All this C from wheat immobilizes soil N, ultimately resulting in soil C loss via respiration (due to death of soil microbes). It is for this reason that many grain farmers find themselves unable to raise their soil C levels despite producing high biomass crops. The N limitation to C sequestration is known by scientists as the "progressive N limitation theory", and there are concerns that C sequestration in agricultural soils will ultimately be limited by N (Gill et al., 2006).

How to get the needed N into the soil system? Using inorganic fertilizers is not a durable solution since manufacture of fertilizer emits its own C. The only durable solution is to increase the organic N content of soils through use of superior crop rotations with an emphasis on legume crops.

No-till increases soil C

No-till farming is an effective way to increase soil C in the surface soil layers. The best Canadian studies now estimate that adoption of no-till farming will increase soil C by 18 million tones of CO_2 per year (Anon., 1999). Another question regards the stability of stored C should no-till land be tilled periodically. Field trials at Agriculture and AgriFood (Brandon) have shown that high-intensity or low-intensity tillage after a long period in no-till did not significantly reduce soil organic C; however long-term high intensity tillage would result in release of C sequestered by no-tillage farming (Moulin and Irvine, 2005).

Composted manure increases soil C

Adding composted manure is a very powerful way to increase soil C. One reason is that the C:N ratio of composted manure is within the optimum range for C storage. Long-term studies in Switzerland show that adding composted manure not only increases soil C, but it increases the fraction of soil C made up of living microbes (Mader et al., 2002). Higher soil microbial activity further increases the ability of soils to sequester C.

Deep soil C storage using perennial plants

Carbon is best stored deep within the soil profile, since deep C is more stable over time. Few North American studies have been conducted on deep soil C sequestration. University of Manitoba research in Uruguay has shown that after 38 years, a crop rotation consisting of 4years forage then 4 years of grain crops sequestered 20% more C between 20 and 60 cm soil depth than a rotation with only grain crops (Gentile et al., 2005). The grain-forage rotation had a subsoil C content of 71 Mg C /ha vs. 54 for the grain system. Assuming a similar value for Manitoba, 1 million ha of perennial forages would sequester 17,000 t C over a similar time period.

Earthworm activity is another way to move C below the 20 cm soil depth. Earthworm populations are highest in no-till forage and pasture fields.

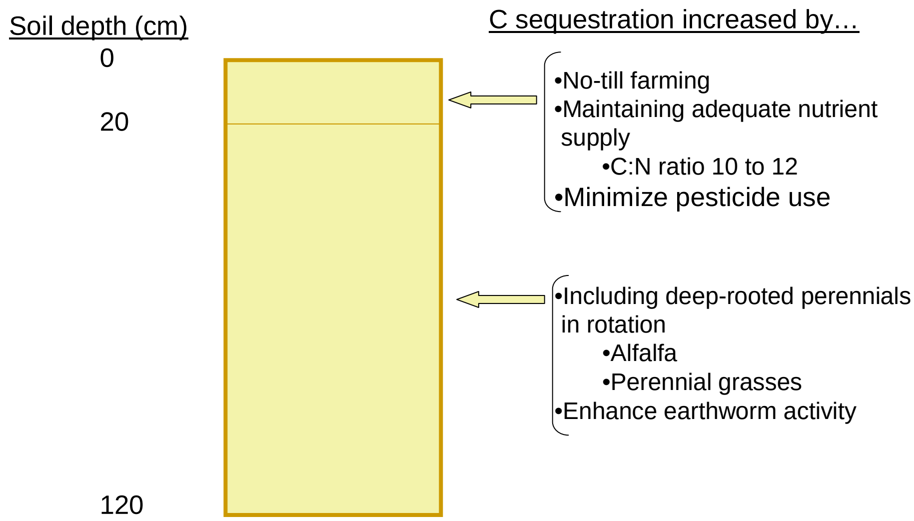


Figure: Management steps to increase soil C within a 120 cm soil profile.

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