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CASE STUDIES

A technical manual of recommended management practices

CROPLAND, GRASSLAND, INTEGRATED SYSTEMS AND FARMING APPROACHES

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43. Response of soil carbon to various combinations of management practices (annual-perennial rotation system, animal manure application, reduced tillage) in Quebec, Canada

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1. Related practices

Crop rotations, manure applications, reduced tillage.

2. Description of the case study

In Eastern Canada, most dairy farms present some form of integrated livestock and crop production. They are generally based on hay or silage production, but small cereals, maize (silage and grain), and soybeans are also produced for on-farm use or as an opportunity source of revenue. Also, as cattle are generally kept in the barn for most of the year, animal manure is accumulated in storage facilities (either in liquid or solid form) and disposed of on the farm land during the growing season and the post-harvest period before onset of winter (soil freezing). The integration of crops and livestock productions results in combining several management practices which will influence soil carbon (C) stocks. Among them, annual-perennial rotation systems usually lead to higher soil organic C stocks than annual systems (Gregorich, Drury and Baldock, 2001). Also, animal manure application generally leads to soil C increase in comparison to mineral fertilization, but studies focusing on the soil C stocks to liquid animal manure are scarce compared to the literature on solid manure (Maillard and Angers, 2014). In addition, the response of C stock to liquid manure seems to be quite variable (Maillard *et al.,* 2016). Finally, adoption of reduced tillage generally results in higher soil C stocks in surface soil layers in comparison to conventional till (Angers and Eriksen-Hamel, 2008). All these practices can interact together but relatively few long-term field studies have investigated their combined effects. In this context, soil C stocks were measured

21 years after the implementation of an experiment including a cereal-perennial forage rotation compared to a cereal monoculture in combination with two nutrient sources (liquid dairy manure application vs. mineral fertilization) and two fall primary tillage practices (moldboard vs. chisel plowing).

3. Context of the case study

The case study is located at the Normandin Research Farm of Agriculture and Agri-Food Canada (48°50'42''N, 72°32'25''W) in the province of Quebec, Canada and was initiated in the fall of 1989. The area is characterized by a cool temperate and moist climate (IPCC, 2006) with mean annual temperature of 1.1°C, and mean annual precipitation of 849 mm. The silty clay soil belongs to the Labarre Series and is classified as a Humic Gleysol (Lamontagne and Nolin, 1997; SCWG,1998). The 0-15 cm soil layer had the following characteristics at the initiation of the study: pH of 5.6, bulk density of 1.36 g/cm^3, 26.1 g/kg organic C, 49 percent clay and 8 percent sand. Prior to the implementation of the study, the site was under a barley (*Hordeum vulgare*)-alfafa (*Medicago sativa*) rotation. More details on the site, soil and experimental design of this study are presented in Bissonnette *et al.* (2001) and Maillard *et al.* (2016). The compared crop rotations were a continuous spring barley monoculture (MON) and a 3-yr cereal-perennial forage rotation (ROT) (Photo 95). From 1989 to 1999, the cereal-perennial forage rotation consisted of barley underseeded with a forage mixture of timothy (*Phleum pratense*) and red clover (*Trifolium spp.*) . Since 2000, orchard grass has replaced timothy in the forage mixture. Barley was harvested at the end of the 1st year of rotation, followed by two years of forage production. The two fall primary tillage practices consisted of chisel plow (CP) to a depth of 15 cm, and moldboard plow (MP) to a depth of 20 cm. The two crop rotations involved different tillage frequencies: yearly in the cereal monoculture, and at the end of the forage phase in the cereal-forage rotation (i.e. once every three years). The two nutrient sources were a complete mineral fertilizer (MIN) and liquid dairy manure (LDM) (Photo 96). The experiment was arranged as a split-split-plot design with crop rotation as the main plot, tillage system as the subplot, and nutrient source as the sub-subplot. Soil samples for C measurement in the surface soil layer (0-20 cm) and in the whole-soil profile (0-50 cm) were taken in 2010, 21 years after the initiation of the experiment.

4. Possibility of scaling up

About 80 percent of Canada's dairy farms are located in the provinces of Quebec and Ontario (Dairy farmers of Canada, 2016), and dairy production is the most important agricultural sector in these two provinces. These dairy farms can be defined as "integrated crop-livestock operations" and typically include the management practices described in this case study. However, in the last years, the surface area under perennial forages in Eastern Canada has decreased and has partly been replaced by annual crops, including silage maize, leading to a decline in soil C stocks (McConkey *et al.*, 2017). For example, in the province of Quebec, the surface area under hay decreased from 842 000 ha to 658 500 ha between 2007 and 2016, whereas the area under silage maize increased from 47 000 to 66 400 ha (MAPAQ, 2018). The case study described above clearly demonstrates the benefits of recycling dairy manure on soil health and fertility, especially when combined with perennial forage-based rotations. These beneficial management practices should be maintained and encouraged to maintain or increase soil C. This specific case-study could be applied to any regions exposed to a cold, humid climate. Other studies might be necessary to validate the results under warmer and drier conditions.

5. Impact on soil organic carbon stocks

It is first noteworthy that the effects of the different practices varied according to the soil depth considered. Indeed, as we see in Table 178, among the beneficial management practices, the cereal-perennial forage rotation was the practice showing the greatest impact on soil C stocks both in the surface soil layer (0-20 cm) and the soil profile (0-50 cm). Both liquid dairy manure application (compared to mineral fertilizer) and chisel plowing (compared to moldboard plowing) significantly increased soil C stocks in comparison to their respective reference practices (mineral fertilization and moldboard plow) when considering the 0-20 cm soil layer. However, the effects of those practices were not significant when the 0-50 cm soil profile was considered. Combining the three beneficial management practices together (ROT-CP-LDM) resulted in the greatest soil C storage potential both in the surface layer and the soil profile.

Table 178. Soil Organic Carbon stocks changes observed in the study site over a 21-year period

Baseline C stock (tC/ha)	Additional C storage (tC/ha/yr)	Depth (cm)	More information	Reference
80.2	0.74 (ROT)	0-50	The baseline stock corresponds to the cereal monoculture (MON). The increase is statistically significant.	Maillard *et al.* (2016)
85.3	0.26 (LDM)		The baseline stock corresponds to mineral fertilization (MIN). The increase is not statistically significant.	
71.0	-0.06 (CP)		The baseline stock corresponds to moldboard plow (MP). The change is not statistically significant.	
85.8	0.81 (ROT-CP-LDM)		The baseline stock corresponds to the cereal monoculture combined with moldboard plow and mineral fertilization (MON-MP-MIN). The change is statistically significant.	Maillard *et al.* (2016); Unpublished
50.8	0.63 (ROT)	0-20	The baseline stock corresponds to MON. The increase is statistically significant.	Maillard *et al.* (2016)
53.9	0.33 (LDM)		The baseline stock corresponds to MIN. The increase is statistically significant.	
54.2	0.30 (CP)		The baseline stock corresponds to MP. The increase is statistically significant.	

Baseline C stock (tC/ha)	Additional C storage (tC/ha/yr)	Depth (cm)	More information	Reference
48.7	1.23 (ROT-CP-LDM)		The baseline stock corresponds to MON-MP-MIN. The change is statistically significant.	Maillard *et al.* (2016); Unpublished

Climate is cool temperate moist, soil type is Humic Gleysol

6. Other benefits of the practice

6.1. Improvement of soil properties

With the increase of soil C observed in the 0-20 cm soil layer under the beneficial management practices (perennials, chisel plowing, manure application), it is expected to observe other benefits on soil quality in general. Indeed, as the main component of organic matter, soil C provides a range of other benefits, (e.g. improvement of soil aggregation, water infiltration, source of nutrients for crops). This was confirmed by the work of Bissonnette *et al.* (2001) who measured selected surface (0-7.5 cm) soil properties during the first seven years of this case study (Bissonnette *et al.*, 2001). Overall, liquid dairy manure application increased water-stable aggregation over mineral fertilization. On average, tillage methods had little effect on aggregation in the monoculture, whereas chisel plow resulted in better soil aggregation than moldboard plow in the rotation. Overall, the microbial biomass C content and the alkaline phosphatase activity were positively affected by liquid dairy manure application both in the cereal monoculture and in the rotation. In addition, similarly to soil C, soil N stocks were higher under the beneficial management practices (D'Amours, 2018).

Soil P was also studied in the experiment. After 10 years, the perennial-based rotation resulted in greater labile Pi and Po pools than the monoculture in the 30- to 60-cm layer. When applied in the rotation system, LDM resulted in the largest total labile P pool, whereas the LDM resulted in about 20 percent higher degree of soil P saturation as expressed by the Pox/(Feox +Alox) molar ratio than the MIN in the 0- to 30-cm layer. Our observations stressed that the impacts of crop sequences and nutrient sources on soil labile P extended deeper into the profile than the disturbance caused by primary tillage (Zheng, MacLeod and Lafond, 2004).

6.2 Minimization of threats to soil functions

Table 179. Soil threats

Soil threats	
Soil erosion	Increase of soil C stock and improvement of aggregation can prevent soil erosion and soil losses.
Nutrient imbalance and cycles	The soil C content is linked to soil fertility. The soil N and P contents were generally improved under the beneficial management practices.

6.3 Increases in production (e.g. food/fuel/feed/timber)

The effects of the beneficial management practices on forage and barley grain production were assessed during the first 21 years of the experiment (Lafond *et al.,* 2017). Barley grain yields were 14 percent higher with the moldboard than with chisel plowing during the first 10 year of the experiment only. In the perennial-based rotation, grain yields were comparable between the two fertilizer sources, but in the cereal monoculture, liquid dairy manure resulted in lower yields compared with mineral fertilization. In contrast, forage yields were 11 percent higher under liquid dairy manure application than under mineral fertilization. In the long term, perennial forages and barley can be sustainably produced in rotation without productivity loss using liquid dairy manure and either moldboard plow or chisel plow. Residual N effects and non-N benefits from manure and rotation are identified as important factors contributing to cereal and forage productivity.

6.4 Mitigation of and adaptation to climate change

N_2O emissions from soils were measured for two consecutive years in this case study in 2011 and 2012, but only on all phases of the cereal perennial-forage rotation receiving mineral fertilization or dairy cattle manure in combination with moldboard plowing (Chantigny, 2013). The objective was to establish emission factors for the entire rotation under moldboard plowing with animal manure in comparison to mineral fertilization. The average amount of N_2O-N emitted for the entire rotation was:

- For mineral fertilization: 0.718 kg N/ha for barley + 1.223 for first year of forage + 2.455 for second year of forage = 4.396 kg N/ha;
- For manure fertilization: 2.304 kg N/ha for barley + 0.709 for first year of forage + 0.846 for second year of forage = 3.859 kg N/ha;

N_2O emissions for the second year of forage were related to the moldboard plowing of the forage stand in the fall. Despite N_2O emissions tending to be larger with LDM than MIN in the barley phase of the rotation, the opposite trend was found during the forage phase of rotation. From these emission values, we can hypothesize that the values for three years of cereal monoculture would be 2.154 kg N/ha for MIN and 6.912 kg N/ha for LDM. Consequently, the emissions would be higher with LDM than with MIN for the cereal monoculture, whereas they are lower with LDM than with MIN for the rotation under moldboard plowing.

7. Possible increases in greenhouse gas emissions

The variability in N_2O emissions, which varied with crop rotation and nitrogen source under moldboard plowing (see 6.4), illustrate the importance of their measurement when calculating the net GHG balance of dairy farm soils, as N_2O-N emission may counterbalance the gain in SOC accumulation.

8. Recommendations before implementing the practice

The impacts of implementing these practices may vary according to climate and soil. However, we believe based on this and other studies (Angers, 1992; Poirier *et al.*, 2009; Samson *et al.*, 2020), that similar trends would apply to heavy-textured soils in similar climatic conditions.

9. Potential barriers for adoption

In general, in dairy farms of this area, crops and livestock productions are generally already well integrated. Crops are generally used on farm as feed and manures are valorized on farm.

Photos

Photo 95. Barley and forage experimental plots located at the Normandin Research Farm of Agriculture and Agri-Food Canada

Photo 96. Liquid dairy manure application on forage plots located at the Normandin Research Farm of Agriculture and Agri-Food Canada

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