Rotation ABC – Lethbridge, Alberta

Elwin G. Smith, Benjamin H. Ellert, H. Henry Janzen and Darryl J. Nakonechny,
Agriculture and Agri-Food Canada, Lethbridge Research Centre, Lethbridge AB, T1J 4B1
Corresponding author e-Mail: Elwin.Smith@agr.gc.ca

Summary

Rotation ABC was established in 1911 at the Lethbridge Research Centre. The rotation study has been and continues to be used to evaluate the long-term impacts of cropping systems on soil quality, productivity, and the broader environment. The non-replicated study includes three wheat-based rotations, rotations that were considered feasible in western Canada. The rotations were continuous wheat (A), fallow-wheat (B), and fallow-wheat-wheat (C). In 1967 and 1972 the plots were divided to impose four fertility treatments within each plot by applying all combinations of two rates of nitrogen and phosphorus fertilizer. In 2010, six plots of Rotation T, land adjoining Rotation ABC and in a fallow-wheat rotation since the 1950's, were used to replicate Rotation ABC. Associated with the rotation are the Chemist plots. These were smaller plots with the same crop rotations and fertility treatments (fertility treatments delayed until 1992) as Rotation ABC. The Chemist plots were established for detailed soil analyses by the chemists located in Ottawa. Originally the Chemist plots also included rotations M, S and T but these three plots were allocated to other studies.

Introduction

The native prairie to the East of the fledgling town of Lethbridge was first tilled in about 1910 to establish an experiment to investigate cropping systems for producing wheat. The soils were typical of the region, and are classified as Orthic Dark Brown Chernozems (or Typic Haplustolls in the US system of soil classification) developed on lacustrine parent material under native vegetation of tall and short grass species. Surface soils have a loam texture (45% sand, 30% silt, 25% clay) and neutral pH. Subsurface layers are calcareous. The cropping history of these plots since the native prairie was first tilled is known and periodic soil samples have been collected, dried, and stored in glass jars.

The initial objective of the rotation study was to evaluate spring wheat-based crop rotations that producers in southern Alberta were using and some rotations that were viewed as having potential for adoption on a broader scale. It was part of a wider effort by the Department of Agriculture to put in place studies to better understand the long-term effects of cropping systems[9,10]. A suite of crop rotations (designated by letters A through U) were specified within the Research Branch of the Department of Agriculture for long-term crop rotation studies across Canada[3,15]. Rotations A, B and C received no livestock manure. Starting in 1967 the plots were divided into two sub-plots: with and without applied nitrogen (N). In 1972 the two nitrogen sub-plots plots were further divided to accommodate all four combinations of two rates each of N and phosphorus (P) fertilizer. Over time the objective of the rotation changed from evaluating crop rotations to understanding the impact of cropping systems on nutrient flows, soil productivity, and the stock of soil organic carbon. The objective of the study is now to determine the long-term effect of fallow frequency and fertilizer amendments on soil chemical and physical properties, crop productivity, the sustainability of the production practices, and the broader environment.

Description of Study

These dryland cropping experiments were established in 1911 as three distinct rotations or treatments (A, B and C) (49.70ºN, 112.7775ºW). The rotations comprised three sequences of 1, 2 or 3 years in which spring wheat was grown or the plot was summerfallowed. Rotation A was continuous wheat (W), Rotation B was fallow-wheat (FW), and Rotation C was fallow-wheat-wheat (FWW). Prior to 1924, rotation FWW had oats in the third year instead of wheat. These rotations were non-replicated, but were established as two sets of plots:the 'Rotation plots' were larger (0.6 ha), and had a single plot for each year of each crop sequence (six plots in all), whereas the 'Chemist plots' (49.7005ºN, 112.7693ºW) were smaller (0.2 ha, with the same width as the rotation plots) and had a single plot for each rotation (three plots in all). In 1985 Rotation B was reassigned to adjoining plots because of encroaching city road construction.

The new piece of land for rotation B was from two adjacent Rotation T plots (49.70ºN, 112.775ºW), a rotation of fallow-wheat since the 1950s. No fertilizer had been applied to Rotation ABC plots until 1967, when N fertilizer was applied to a sub-plot of the plots. Fertilizer was applied to all phases of the rotations, including fallow, from 1967 to 1985, but only to cropped phases thereafter. The N fertilizer sub-plots received either no fertilizer or a fixed rate (45 kg N ha^{-1}) broadcast as ammonium nitrate (34.5-0-0). In 1972, P fertilizer (triple superphosphate, 0-46-0) was added to plots at a rate of zero or a fixed rate of 45 kg P_2O_5 ha^{-1}, but was reduced to 22.5 kg P_2O_5 ha^{-1} in 2010. Each plot with wheat production has four fertility treatments from no fertilizer to N plus P (Figure 1). The experiment has six plots that are 22.7m (74.6 ft) wide and 212.8 to 276.0 m (700 to 908 ft) long. The main plots vary in area from 0.49 to 0.63 ha, and are separated by a 2.4 m pathway.

Management Practices

Crop management evolved over time, reflecting accepted practices used by local farmers. Initially, field operations were by horse drawn implements and grain sheaves were hauled to a central location for threshing. Over time, field operations were mechanized, which improved the timeliness of field operations. Grain threshing (1928) with a combine retained crop residues in the field. Chemical weed control, first broadleaf weeds (1948) and later grassy weeds (1970), reduced weed competition and increased grain yield. Moving to no-till management (2000) retained surface residues and reduced wind erosion. New wheat varieties were adopted every 4 to 6 years.

A no-till press drill with disk openers was used since 2000 to directly seed hard red spring wheat (85 kg ha^{-1}) into the untilled stubble persisting from the previous crop or summerfallow year. Ammonium nitrate was broadcast on the soil surface without incorporation prior to seeding, and P fertilizer was applied with the seed. A pre-seeding "burn-off" with a non-selective herbicide, such as glyphosate or a tank mix with glyphosate, was used to control early emerging weeds. Chemical seed treatment was applied for pythium, fusarium, damping off, common bunt, loose smut and take all. In-crop weed control used herbicides appropriate for the weeds present. Fall herbicide applications controlled winter annual weeds, and glyphosate was applied post- harvest to control patches of Canada thistle. On fallow, weeds were controlled by non-selective herbicides or tank mixes with selective herbicides. Plots were monitored for pests and diseases, and if necessary appropriate treatment for control was applied. The pathways between the main plots were mowed or tilled to control weeds.

A grain sample was collected at harvest for each sub-plot. A sub-sample of grain was dried at 60 °C for 7 days to determine moisture content. Another sub-sample was sifted through screens to remove weed seeds and other foreign material to determine the clean weight of the sub-plot harvest. A grain sample was archived for future lab analyses. The clean grain weight of the sub-plot harvest was adjusted to 12.5% moisture.

Soil Samples

The first soil samples were collected in 1910, the same year when the native prairie sod was first plowed. Until 1953, all soil samples were taken from the Chemist plots; since then, samples have been taken from both the Chemist and the Rotation plots. Samples have been taken periodically for the last 100 years. Samples were last taken in the fall of 2011 for depths of 0 to 15, 15 to 30 and 30 to 45 cm for all fertility sub-plots. For Rotation ABC there were five transects, for the shorter Chemist plots there were three transects. The soil samples have been archived and stored dry at room temperature in glass jars

Major findings of the study

Yield

Spring wheat yields varied among successive years, partly due to variability in growing-season (April through July) precipitation. To smooth over this temporal variability, a 5-year running mean was plotted in Figure 2 (i.e. the value plotted at year along the horizontal axis was the mean of yield in that and the previous four years). The relatively large yields during the first few years of the study were caused by an usually high yield in 1915 (typically acknowledged as the year of the bumper crop in the annals of Canadian history) which elevated the running mean in five consecutive years. Even with these relatively high yields at the start of the experiment, there was a clear upward trend in yields, typically ascribed to assorted technological advances, during a century of spring wheat production without fertilizer or manure (Figure 2). For these unfertilized treatments, wheat yields after fallow (FW of rotation B and F(W)W of rotation C) were about double those after wheat (W of rotation A and FW(W) of rotation C). The yield trend increase was greater for wheat after fallow (16 kg ha^{-1} yr^{-1}) than for wheat after wheat (10 kg ha^{-1} yr^{-1}). However, production for the total land area, including the fallow land, increased 11.6 kg ha^{-1} yr^{-1} for W, 6.8 kg ha^{-1} yr^{-1} for FWW, and 8.2 kg ha^{-1} yr^{-1} for FW (Figure 3). The upward trend in yield since the 1950s can be attributed to better cultivars, better weed control[7], and more timely and improved field operations including weed control both on fallow and in-crop, seedbed preparation, and seeding equipment. The five-year average yields fluctuated over time due to variability in precipitation, especially during the growing season.

The application of N and P fertilizer since 1972 has increased yield for all rotations (Figure 4a, 4b). For wheat after fallow, the application of N alone had no yield impact until the 1990s (Figure 4a). By the early 1990s, the N supplying ability of the fallow soil had declined and was unable to meet crop requirements. Initially the application of P alone for wheat after fallow had more yield impact than N alone because available P was more limiting than N. The yield benefit of P has remained nearly constant over the past 35 years. The application of N plus P resulted in greater yield than either nutrient alone, and the benefit of applying both of these nutrients has increased over time. For wheat after fallow, the average increase in yield with the application of N or P was 12%, and with the application of N plus P was 35%.

For wheat after wheat, the yield for the unfertilized and P only treatments has remained nearly constant over the past 35 years (Figure 4b). Without added N, P application had no yield benefit. Available N limited productivity of these soils. This was illustrated by the inability of the unfertilized and the P only treatments to utilize moisture from the mid to late 1990s when growing season precipitation was excellent (Figure 4b). The application of N alone increased yield, and the yield benefit over the unfertilized treatment increased over time. Adequate N resulted in yield responding to the good moisture conditions in the mid-late 1990s. The application of N plus P resulted in the highest wheat yield for wheat after wheat. The average yield increase over no fertilizer with the application of N was 46%, with P was -2%, and with N plus P was 85%. The yield benefit was lower in 2011 because some plot area was flooded in the spring after seeding and wild oat control was delayed. Wild oat density has been higher on the plots with N plus P.

The yield for wheat after wheat was less every year than for wheat after fallow, regardless of fertility treatment. For the past 20 years and without fertilizer, wheat after fallow yielded about two times that of wheat after wheat. When fertilized with N plus P, wheat after fallow yielded about 1.4 times that of wheat after wheat. Total wheat production from unfertilized FW and W rotations was about the same. When fertilized, average wheat production over both years of the FW rotation was 30% less than the W rotation.

Soil Organic Carbon

The concentration of soil organic carbon (SOC) in these rotations decreased since the native prairie was converted to arable land[12]. There was initially a rapid decline in SOC in the upper 15 cm of soil, but the decline reached a new equilibrium (Figure 5). The decline in SOC was slower for the continuous W rotation, than for those containing fallow. Part of the fast decline, which ended in the 1940s, can be attributed to the removal of crop residue during grain threshing. The SOC in the 15 to 30 cm zone was nearly constant for the first 40 years, but has since declined about 20%[12]. Fallowing soils in semiarid environments limits the potential to increase SOC.[13]

The concentration of SOC in the upper layer of soil was influenced by the crop rotation and fertility treatment[8,14]. The SOC was higher for the W rotation than for the FWW rotation by about 12%, which agreed with earlier analyses[6]. Fertilizer application of P had no impact on SOC, but N increased SOC by about 14%. Mineralized N was also higher for the W rotation, and for treatments with N fertilizer. From the initial level of SOC, the rotations with more fallow resulted in lower SOC. With the application of N, SOC was increased for all rotations in this study. These influences on SOC have implications for greenhouse gas emissions.

The concentration of glucose in the soil was found to be higher for the W rotation.[5] Carbohydrates are an energy source for soil microorganisms and have a role in binding soil particles into stable aggregates. The application of P though was found to reduce the uptake of Zn, Cu and Ca[4]. The amount of root colonized by

Vesicular-arbuscular mycorrhizal (VAM) fungi was found to be less for the treatments with P fertilizer. Soil microbial processes were impacted by management, though the processes are not well understood. The absence of P fertilizer resulted in the drawdown of all soil P pools (inorganic and organic), and the drawdown was greater for the W rotation[11]. The addition of P fertilizer increased all the soil P fractions, but mostly the inorganic fraction. Nitrogen balance from Rotation ABC has indicated more nitrogen has been removed in the grain than can be accounted for in soil changes. It was determined that the associative nitrogen fixation was not supplying appreciable N and that N deposition must be coming from other sources such as the atmosphere[2]. On these well-drained soils, soil EC (a measure of salinity) declined during the first 75 years of the study[1]. There was also evidence of nitrate leaching, which was greater on the FW rotation than the W rotation. Crop rotations without fallow can be profitable, but requires managing fertility requirements[16].

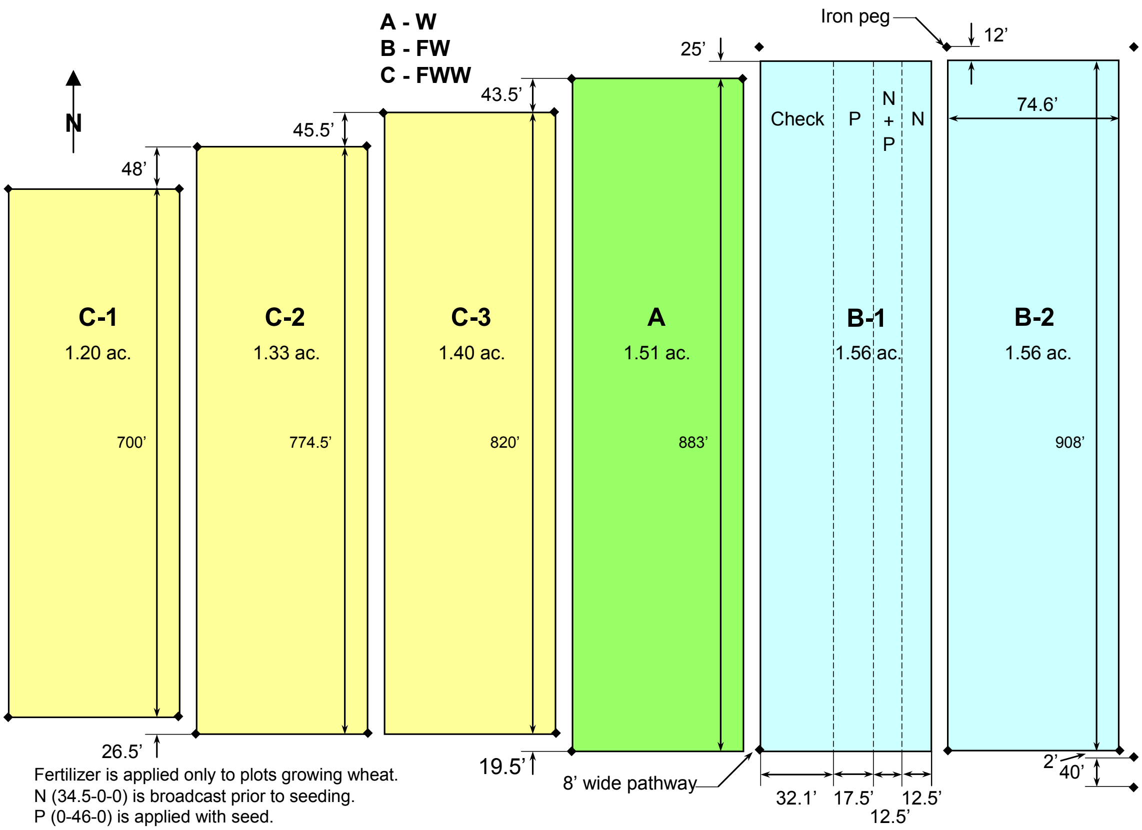

Figure 1. Plot plan for Rotation ABC

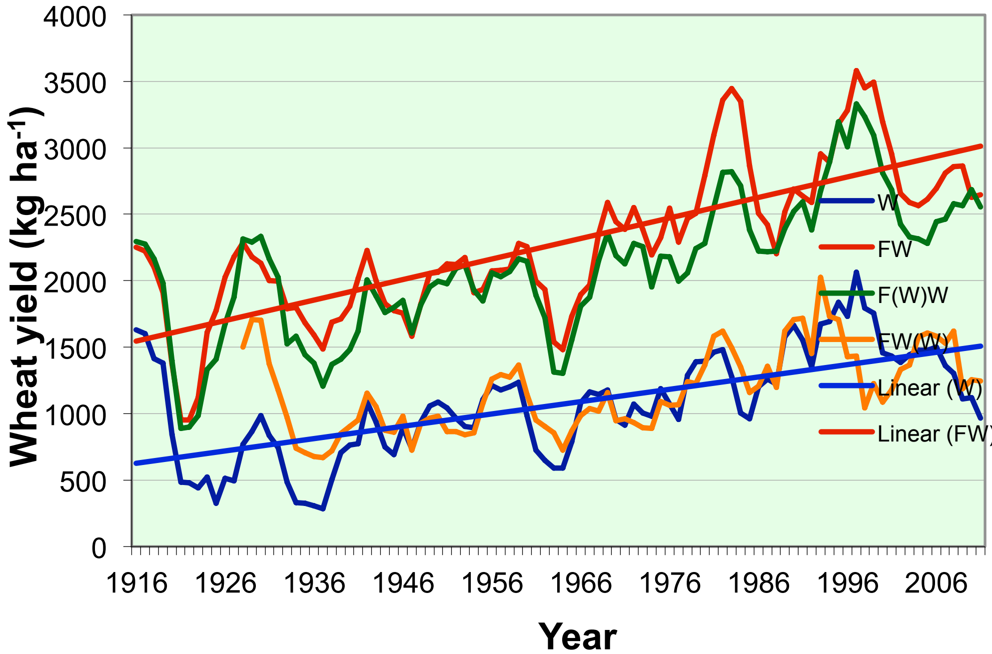

Figure 2. Five-year average crop yield and trend for unfertilized rotations for wheat after wheat (W and FW(W)) and wheat after fallow (FW and F(W)W)

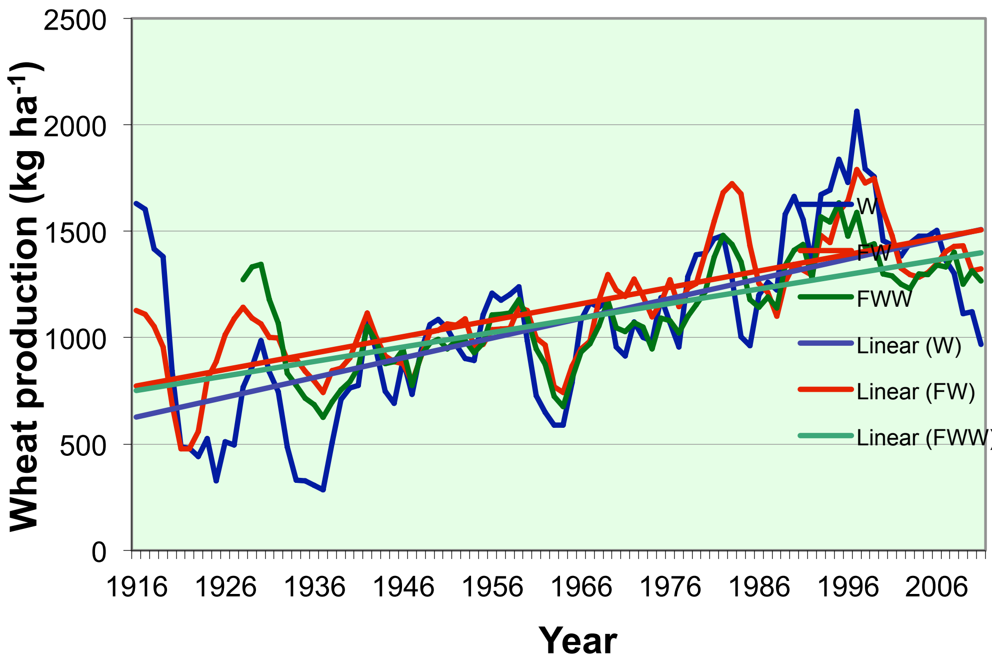

Figure 3. Five-year average crop production ha^{-1} and trend for unfertilized rotations for rotations A (W), B (FW), and C (FWW).

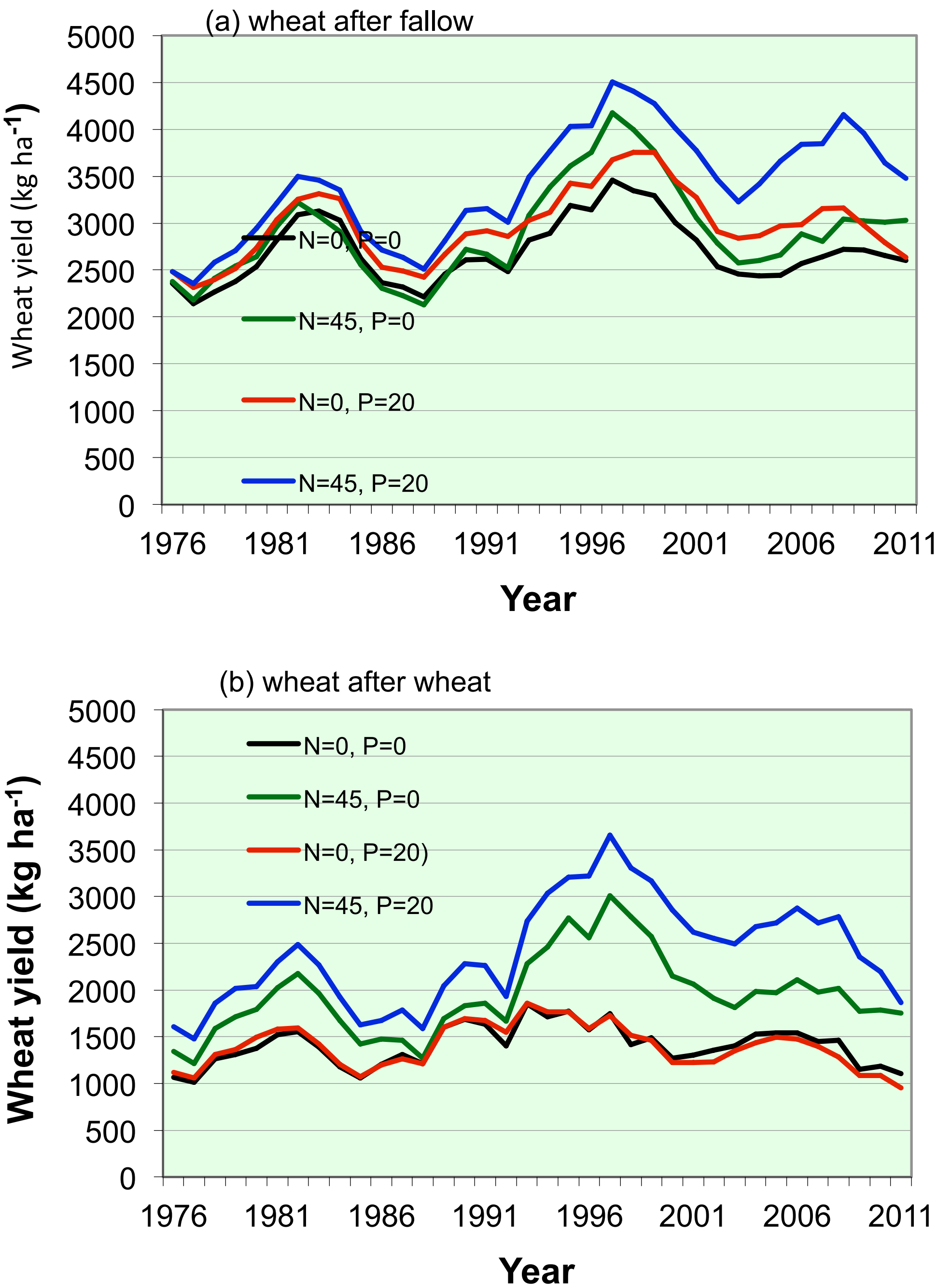

Figure 4. Five-year average wheat yield for fertility treatments with nitrogen and phosphorus: (a) wheat after fallow (F-W and F(W)W) and (b) wheat after wheat (W and FW(W))

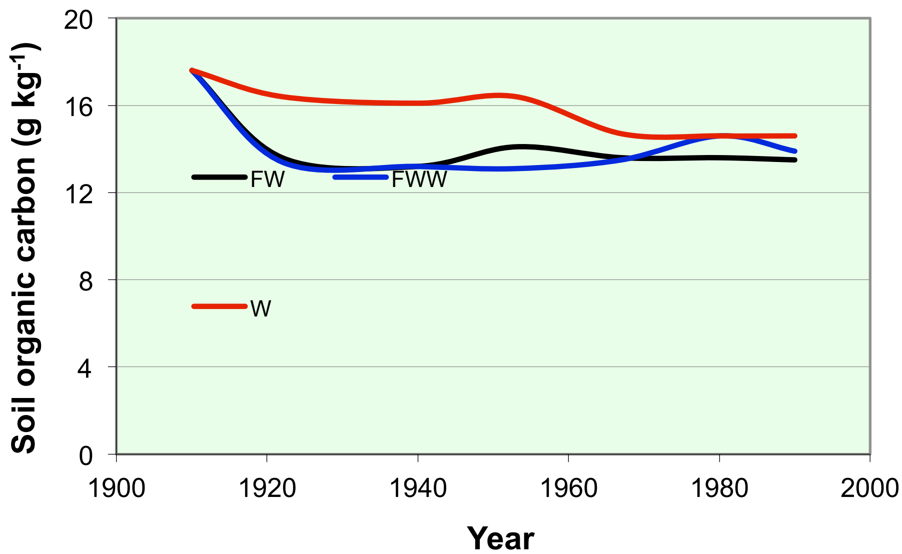

Figure 5. Soil organic carbon concentration (0-15 cm) by crop rotation (adapted from Monreal and Janzen, 1993[22]).

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