Rotation 120 – Lethbridge, Alberta

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Summary
Rotation 120 was initiated in 1951 at the Lethbridge Research Centre to evaluate the sustainability of common and potential crop rotations for the area. The rotations range from fallow-wheat to continuous wheat, with and without inorganic fertilizer, livestock manure, legume green manure, or alfalfa hay. The crop rotation and replenishment of nitrogen (N) impacted soil quality as measured by soil organic carbon (SOC), light fraction carbon (LFC), light fraction nitrogen (LFN), and mineralizable carbon (C) and N. Rotations that replenished N with alfalfa, N fertilizer, and green or livestock manure had higher SOC and grain yield. Rotations with frequent summerfallow and those without replenishing N to the system had lower SOC and grain yield. This study has shown that over the long-term, cropping systems altered the quality and productivity of soil. Two practices that will contribute to current and future soil productivity were the replenishment of N removed by the harvested crop and limited use of summerfallow.

Introduction
The initial objective of the rotation study was to evaluate the sustainability of crop rotations that producers in southern Alberta were using and some rotations that were viewed as having potential for adoption on a broader scale. Initially the experiment, currently known as 'rotation 120', used the same rotation designations (letters A through U) originally adopted by the Dominion Department of Agriculture for crop rotation experiments across Canada.[4] The study established in 1951 included the same summerfallow-spring wheat rotations that had been implemented as 'rotation ABC' in 1910, only 'rotation 120' had a modern experimental design with replication and smaller plots to accommodate a broader range of rotations or cropping systems. In 1985, some of the rotations were replaced, to increase the understanding of how cropping systems impact soil quality and crop productivity. Rotation 'F' (fallow-winter wheat-winter wheat or barley) was discontinued because of susceptibility to winter-kill and winter annual grassy weeds, and rotation 'K' (fallow-wheat-wheat-grass-grass-grass) was discontinued because there was no N added to the system. The plots from the two discontinued rotations plus four adjacent plots to the replicates were randomly assigned to new cropping systems. The new systems were based on continuous wheat (W), fallow-wheat (FW) and fallow-wheat-wheat (FWW) systems, but incorporated a replenishment of N either with inorganic fertilizer, livestock manure or green manure annual legumes. A native grass mixture was also added.

The soil at the site is an Orthic Dark Brown Chernozem (Typic Haplustoll) developed on alluvial lacustrine parent material under native vegetation of tall and short grass species (49.705ºN, 112.775ºW). Surface soils have a loam texture (45% sand, 30% silt, 25% clay). Subsurface layers are calcareous. Plots were established on land that had been used for a mixed crop rotation with light manure applications every sixth year since being broken from native grass in about 1910.

Detailed Description of Study
This dryland crop rotation experiment was initiated in 1951. The purpose of the experiment was to evaluate the influence of cropping frequency and nutrient amendments on grain yield and sustainability. The plots for the rotations were randomly assigned (with minor exceptions), using a complete randomized block design. There were four replicates. All phases of each crop rotation were present each year (for example, a 6-yr rotation has 6 plots per replicate). Plots were 3.2 x 36.6 m. Since 1951, the study has been modified and re-named based on the number of plots. The original experiment (Rotation 96 – Table 1) was modified in 1955 (Rotation 100 – Table 2). A continuous wheat rotation was added, but seeding the wheat crop of this rotation depended on the level of soil moisture. The plot was seeded only if soil moisture was adequate. The "IF" rotation was designed to provide flexibility from a fixed rotation of either wheat or fallow-wheat. Significant changes occurred in 1985 when several rotations were eliminated and new rotations were added (Rotation 116 – Table 3). The "IF" rotation was discontinued because it was seldom

under fallow and therefore comparable to the continuous wheat rotation. The rotation with winter wheat (F) and with grass (K) were discontinued because winter wheat was susceptible to winter-kill and infestation by downy brome (*Bromus tectorum*), and the rotation with grass was unproductive with the depletion of available N. The rotations that replaced these two included wheat-based rotations with added N fertilizer, rotations with green manure[7] during the year of fallow, and native grass. From 1995 to 2000 the entire plot area was seeded yearly to wheat (bioassay years) to determine the residual effect of the previous rotations on wheat yield (Table 4). Each plot was divided into two strips (strip plot design) and one of the halves received N fertilizer and the other half did not receive N fertilizer. In 2001, the rotations that were present prior to 1995, with some changes, were re-established (Rotation 120 – Table 5). One green manure rotation was replaced with an oat-pea forage plus livestock manure applied every 6th year rotation, and continuous dwarf corn seeded with the same narrow row spacing used for wheat was added to include a C4 plant in the rotation. The C4 plant will help follow changes to soil carbon because the residues have a different isotopic signature than crops such as wheat.

Management Practices

Crop management practices have evolved over time, reflecting current practices used by the farming community. Cultivars were changed every four to six years to reflect the advancements in plant breeding. Herbicide use also changed to reflect the changes in herbicide chemistry. No herbicides were used during the hay phase of the rotations. Starting in 1985 phosphorus (22.5 kg P ha^{-1}) was applied to all wheat crops, reduced to 20 kg P ha^{-1} in 1995 and further reduced to 11 kg P ha^{-1} in 2001.

The original field books, journals and other documents recorded all crop management practices such as cultivars used, seeding rates, seeding and harvest dates, tillage operations and herbicide applications. These documents have been preserved. Current documentation of field activities, input and other notes are recorded on electronic media.

Seedbed preparation in early May typically involved light tillage with a heavy-duty cultivator followed by harrowing. Nitrogen fertilizer (ammonium nitrate) was broadcast in late April – early May before tilling. A heavy-duty cultivator or wide blade cultivator was used for weed control in the fallow phase. In-crop weeds were controlled using herbicides. Hay was not harvested in the establishment year, and normally harvested once per year in the two subsequent years, except in moister years when a second cut was taken.

Soil Samples

In April, 1954 the first soil samples were taken from the 0 to 15 and 15 to 30 cm depths from all plots. Additional soil samples have been taken periodically since (Table 6). The soil samples were archived and stored in glass jars or plastic lined paper bags at room temperature.

Major findings of the study

Yield

Early findings of this study focused on the effect of crop rotations on yield and soil fertility[4, 12, 14, 15, 16]. The wheat yield after fallow was highest when livestock manure was used as an amendment (Figure 1). The highest yield for wheat after wheat was for the fallow-wheat-wheat-hay-hay-hay (FWWHHH) rotation where hay was a mixture of grass and alfalfa[15]. Perennial forages depleted soil moisture, typically taking two years to recover to the levels of annual crop rotations. The profitability of the systems was dependent on the price of wheat. At an average wheat price and without N fertilizer, the net return for the fallow-wheat systems was similar and higher than for or continuous wheat. However, at higher wheat prices the three-year rotations were more profitable than the two-year, which was more profitable than FWWHHH and continuous wheat rotations[17].

Of the five rotations that remained from 1951 through 1994, wheat yield was highest for phases of wheat after fallow compared to wheat after wheat (Figure 1). None of these rotations received inorganic N fertilizer. For wheat after fallow, rotations $F_{(M)}$WW (manure applied at the end of the fallow year) and FWWHHH had the highest yield. These two rotations received N from livestock manure and biologically fixed N by alfalfa, which increased yield for the following and the subsequent wheat crop. In dry periods it was found that hay production depleted most of the soil moisture in the FWWHHH rotation, resulting in a depression of wheat yield even though the land was fallowed the previous year. Wheat yield trended up at a similar rate for all rotations (illustrated for $F_{(M)}WW$ in Figure 1).

To compare wheat production in rotations with contrasting fallow frequency, we calculated mean rotation production as the sum of wheat produced in all phases of the rotation in a given year, divided by the total area of all phases including summerfallow, green manure, and hay. When these values of mean rotation production were accumulated to show the long-term trends, the yields were similar for rotations $F_{(M)}WW$, W, and FWW (Figure 2). The FWWHHH rotation had the lowest cumulative production because wheat was grown only twice in six years (Figure 2). The cumulative wheat production from FWWHHH was about one-half of $F_{(M)}WW$, in proportion to the frequency of wheat in the rotation. The FW rotation had less cumulative production than W, $F_{(M)}WW$, and FWW.

In 1985 fertilized versions of the W, FW, and FWW rotations were included by adding 80 kg N ha^{-1}. The plots of the previous K and L rotations (Table 2) were randomly assigned to these new fertilized rotations. From 1986 through 1994, cumulative wheat production was lowest for FW, and for most of the period equal to FW+N (Figure 3). Over the first eight years, the application of N had little impact on production (Figure 3). Cumulative production by 1994 was higher for the rotations with less frequent fallow and for those receiving N. The addition of N fertilizer to these three crop rotations did not increase yield until about 1991, which could be an indication that soils became depleted of the ability to supply N for crop production and now require external sources of N[5].

Soil Properties

Soil organic carbon (SOC) and light fraction carbon (LFC) are indicators of soil quality. For the three wheat only rotations without fertilizer or manure addition, SOC declined from the start of the study (about 19 g C kg^{-1} soil) until about 1985 (Figure 4)[9]. The decline in SOC has halted, and from 1985 to 1992 there was a small increase. Some of the increase could be attributable to higher yield and residue returned to the soil with the addition of P fertilizer since 1985, however, crop yield from 1985 to 1992 was not above average (Figure 1) so additional residue would have had a limited impact. Improved management practices would have also contributed to the increased SOC. The W rotation had higher SOC (10% to 13%) than either of the rotations with fallow. SOC was lowest for the FW rotation. The lower SOC associated with fallow occurred because there was no crop production during the fallow year to add organic material to the soil, and decomposition of SOC was higher during fallow. The LFC showed a similar pattern to SOC for these three rotations. Since the mid-1970s, LFC increased, primarily for the W rotation. Mineralizable carbon was highly correlated with SOC and LFC, for the five rotations measured (Table 7).

Over all the rotations in this study, SOC was highest for rotations with added livestock manure or perennial hay in the rotation, and lowest with frequent fallow in the rotation and without replenishment of nitrogen[2]. Livestock manure was an external input of organic carbon that would be associated with feeding a greater quantity of plant material to livestock than could be produced within the rotation. SOC was lower with higher frequency of fallow and without N replenishment (Table 7). A similar pattern existed for light fraction C and N. The soils with lower SOC and LFC had lower crop yield. LFC was the most recent carbon added to the soil and the carbon most likely to be decomposed or mineralized in the soil. LFC was highest after the addition of livestock manure and for the native grass, and lowest after fallow and without replenishment of N to the system[2,3]. The lack of nutrient replenishment either in the form of fertilizer, livestock manure, or biologically fixed N from perennial hay and green manure restricted plant production and sustenance of SOC[2,3,6,8,10,11,12]. The only exception to this was the continuous grass which was not harvested, so nitrogen exports were minimal, unlike all other rotations.

Crop rotations have differing water demands, and this provided an opportunity to evaluate rotation impacts on the distribution of soil salinity (EC), sodium absorption ratio (SAR), nitrate-N and extractable-P[1,13]. Within the 90- to 150-cm depth, most salt (EC level) leaching had taken place under the FW rotation and least under the W rotation. The SAR increased with depth for all rotations. Nitrate-N concentration by soil depth was measured for the W, FW and

FWW rotations[1]. In the 0 to 90 cm depth, NO_3-N was significantly higher for the W rotation, but at lower depths was higher for the FW rotation. The FW rotation had greater volumes of water moving down through the soil, carrying soluble nutrients below the rooting depth of cereals. Extractable-P movement was limited to the 0 to 30 cm depth[1].

Future

Current plans are to utilize this study to follow future changes in productivity and soil quality. The next decade will be particularly interesting because the unfertilized soils now seem to have become depleted of available nitrogen, perhaps creating further divergence in the sustainability of the various treatments. Operational changes will include merging the two fertilizer N strips applied in 1995 for the bioassay study, once there is ample evidence there are no longer yield effects resulting from the differential N applied from 1995 through 2000. The soils will be sampled in the near future as samples were last taken in 2000. There are no plans to alter the study, but unforeseen circumstances could result in changes, such as in 1995 when resource limitations lead to the bioassay study years. In the near future, there will be increased emphasis on the impact of production practices on the cycling of nutrients.

Acknowledgements

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Table 1. Crop rotations 1951 to 1954 (Rotation 96)

Letter	Designation	Sequence of crops
A	W	Continuous wheat
B	FW	Fallow-Wheat
C	FWW	Fallow-Wheat-Wheat
D	F_MWW	Fallow (+ manure[a])-Wheat-Wheat
F	FW_WW_W	Fallow-Winter wheat-Winter wheat
H	FWWHHH	Fallow-Wheat-Wheat-Hay[b]-Hay-Hay
K	FWWGGG	Fallow-Wheat-Wheat-Grass[c]-Grass-Grass

[a] Manure was applied at 11.2 Mg ha^{-1} (wet) in the fall of the fallow year.
[b] Hay was a mixture of crested wheatgrass and alfalfa.
[c] Grass was crested wheatgrass.

Table 2. Crop rotations 1954 to 1984 (Rotation 100)

Letter	Designation	Sequence of crops
A	W	Continuous wheat
B	FW	Fallow-Wheat
C	FWW	Fallow-Wheat-Wheat
D	F_MWW	Fallow (+ manure[a])-Wheat-Wheat
F	FW_WW_W[b]	Fallow-Winter wheat-Winter wheat
H	FWWHHH	Fallow-Wheat-Wheat-Hay[c]-Hay-Hay
K	FWWGGG	Fallow-Wheat-Wheat-Grass[d]-Grass-Grass
IF	W_C (+N)	Wheat (conditional on spring moisture[e]) (+ N[f])

[a] Manure was applied at 11.2 Mg ha^{-1} (wet) in the fall of the fallow year.
[b] Winter wheat was barley from 1971 to 1984.
[c] Hay was a mixture of crested wheat grass and alfalfa.
[d] Grass was crested wheat grass.
[e] Wheat was seeded if the depth of moist soil at the surface was ≥45 cm at seeding time.
[f] Ammonium nitrate was broadcast (80 kg N ha^{-1}) prior to pre-seeding tillage.

Table 3. Crop rotations 1985 to 1994 (Rotation 116)

Letter	Designation	Sequence of crops
1	W	Continuous wheat
2	FW	Fallow-Wheat
3	FWW	Fallow-Wheat-Wheat
4	W (+N)	Continuous wheat (+N[a])
5	FW (+N)	Fallow-Wheat (+N)
6	FWW (+N)	Fallow-Wheat-Wheat (+N)
7	LW	Lentil[b] (green manure)-Wheat
8	LWW	Lentil[b] (green manure)-Wheat-Wheat
9	F_MWW	Fallow (+ manure[c])-Wheat-Wheat
10	FWWHHH	Fallow-Wheat-Wheat-Hay[d]-Hay-Hay
11	W_C	Wheat (conditional on spring moisture[e])
12	W_C (+N)	Wheat (conditional on spring moisture[e]) (+ N)
13	G	Native grass[f]

[a] Ammonium nitrate was broadcast (80 kg N ha^{-1}) prior to pre-seeding tillage.
[b] Grain lentil from 1985 to 1988.
[c] Manure was applied at 11.2 Mg ha^{-1} (wet) in the fall of the fallow year.
[d] Hay was a mixture of crested wheat grass and alfalfa.
[e] Wheat was seeded if the depth of moist soil at the surface was ≥45 cm at seeding time.
[f] Native grass was a mixture of selected Agropyron spp. Not harvested.
Triple superphosphate was applied with the wheat in the seed row at 22.5 kg P ha^{-1}.

Table 4. Crop Rotations - 1995 to 2000 (Rotation 116, bioassay years)

All plots were direct seeded to wheat each year. Triple superphosphate was applied with the seed in the seed row at 20 kg P ha^{-1}. The replicates were divided into two strips (strip plot design) across their width and one strip received ammonium nitrate broadcast prior to seeding (56 kg N ha^{-1}) and the other strip did not receive N.

Table 5. Crop rotations 2001 to Present (Rotation 120)

Letter	Designation	Sequence of crops
1	W	Continuous wheat
2	FW	Fallow-Wheat
3	FWW	Fallow-Wheat-Wheat
4	W (+N)	Continuous wheat (+N[a])
5	FW (+N)	Fallow-Wheat (+N)
6	FWW (+N)	Fallow-Wheat-Wheat (+N)
7	O_{PM}WW	Oat + field pea (forage) (+ manure[b]) -Wheat-Wheat
8	LWW	Lentil (green manure)-Wheat-Wheat
9	F_MWW	Fallow (+ manure[c])-Wheat-Wheat
10	FWWHHH	Fallow-Wheat-Wheat-Hay[d]-Hay-Hay
11	M (+N)	Corn (maize)[e] (+N)
12	H	Hay[d]
13	G	Native grass[f]

[a] Ammonium nitrate (45 kg N ha^{-1}) is broadcast prior to pre-seeding tillage.
[b] Manure is applied at 11.2 Mg ha^{-1} (wet) in the fall in every second cycle (6^{th} yr) of the rotation..
[c] Manure is applied at 11.2 Mg ha^{-1} (wet) in the fall of the fallow year.
[d] Hay is a mixture of crested wheat grass and alfalfa.
[e] Grain corn.
[f] Native grass is a mixture of needle-and thread, blue grama, June grass, green needle grass and western wheat grass. Not harvested. The plots are periodically burned in the spring to remove accumulated plant litter.
Triple superphosphate is applied with the wheat and corn in the seed row at 11 kg P ha^{-1}.
Triple superphosphate is broadcast prior to seeding crested wheat grass and alfalfa (hay) at 22.5 kg P ha^{-1}.
Triple superphosphate is broadcast in the spring on the continuous crested wheat grass and alfalfa (hay) at 22.5 kg P ha^{-1} every third year after the establishment year.

Table 6. Soil samples taken on Rotation 120

Year (season)	Depth increments	Plots
1954 (Spring)	0 to 15 and 15 to 30 cm	All plots
1967 (Spring)	0 to 15, 15 to 30, 30 to 60 and 60 to 120 cm	All plots
1974 (Spring)	0 to 15, 15 to 30, 30 to 60 and 60 to 120 cm	All plots
1985 (Fall)	0 to 15 and 15 to 30 cm	All plots
1992 (Fall)	0 to 7.5, 7.5 to 15 and 15 to 30 cm	All plots
1995 (Spring)	0 to 7.5, 7.5 to 15 and 15 to 30 cm	All plots
2000 (Fall) [a]	0 to 7.5, 7.5 to 15 and 15 to 30 cm	All plots including the strips[b]

[a] Plot 30 on all reps was sampled in the spring of 2001.
[b] With the plots split into two strips since 1995 there have been 240 plots.

Table 7. Organic C, light fraction and mineralizable C, 1992[a]

	Organic C		Light fraction[b]		Mineralizable[bc]	
	0-7.5 cm	75.-15 cm	C	N	C	N
Rotation	g kg^{-1}					
W[d]	18.7	16.1	3.27	0.23	0.94	0.052
FW	15.9	14.1	1.60	0.10	0.62	0.034
FWW	17.0	14.3	2.15	0.14	0.80	0.034
W (+N)	18.5	15.0	2.67	0.19	0.96	0.055
FW (+N)	16.6	14.4	1.77	0.11	0.73	0.033
FWW (+N)	16.4	14.2	1.92	0.13	0.74	0.040
F_MWW	21.7	15.7	3.56	0.27	0.98	0.035
FWWHHH	18.6	16.8	2.78	0.20	0.98	0.046
NG	19.9	17.1	4.75	0.31	1.45	0.043

[a] All values are adapted from Bremer et al, 1994[2].
[b] Averaged across all phases of the rotation, 0-7.5 cm depth.
[c] Mineralized (CO_2) for the 0-7.5 cm depth for a moist soil, 70 days at 25 °C
[d] The rotation abbreviations are in Table 5.

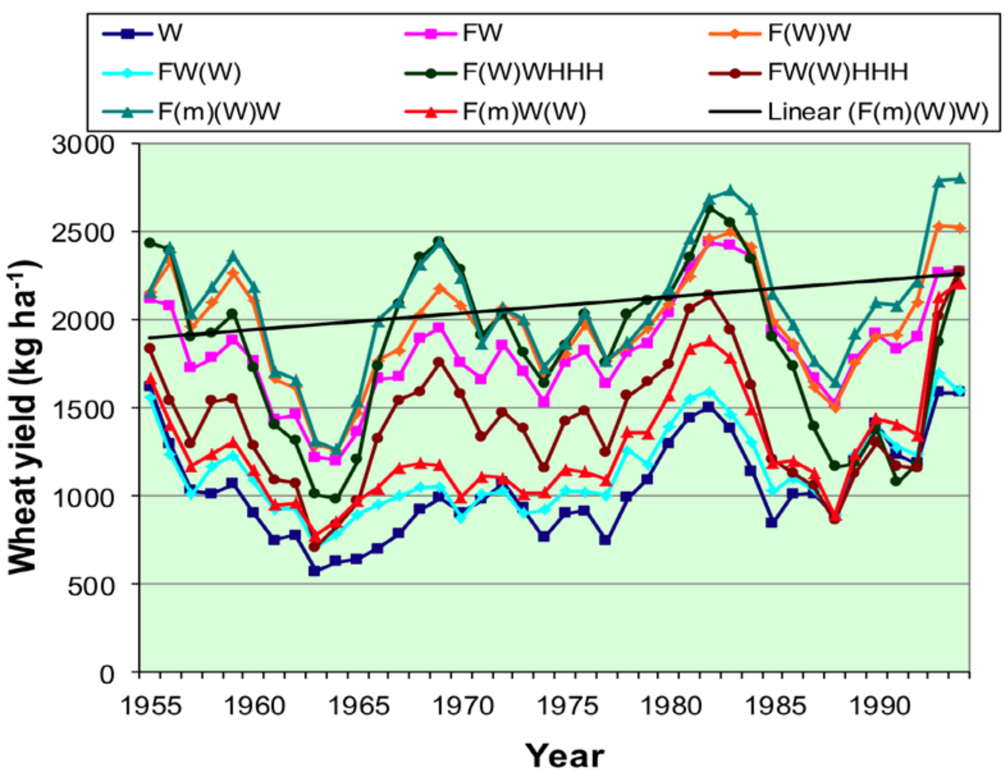

Figure 1. Five-year average wheat yield for selected rotations and rotation phase, 1951-1994

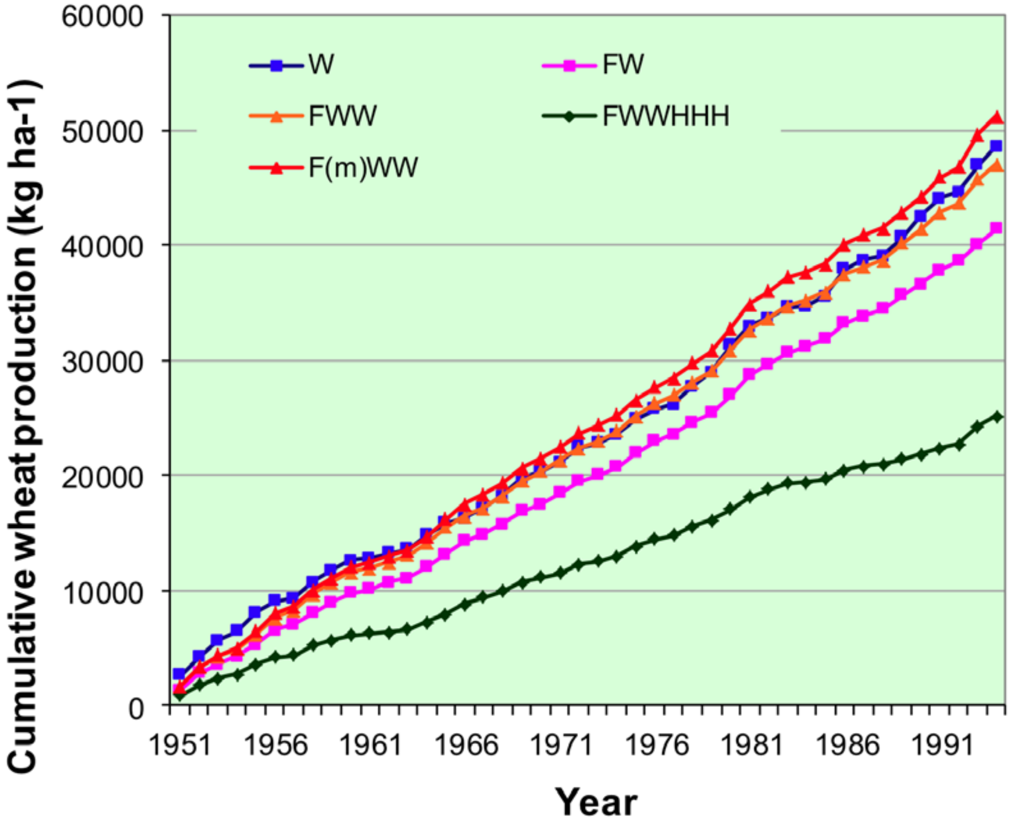

Figure 2. Cumulative wheat production for five selected rotations, 1951-1994.

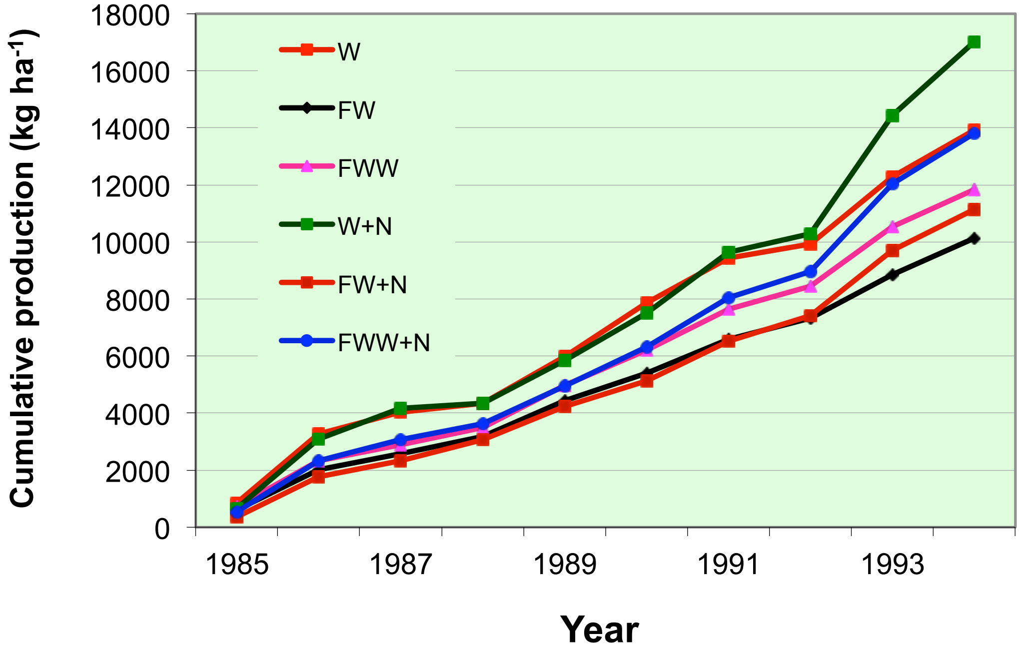

Figure 3. Cumulative production from three wheat rotations, with (+N) and without N application, 1985 to 1994.

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