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Alternative Cropping Systems Study – Scott, Saskatchewan

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Summary
A long-term, cropping systems study was initiated in 1994 near Scott, Saskatchewan, to develop an enhanced understanding of the role of inputs and cropping diversity in sustaining crop production and soil quality/health as well as preserving biodiversity in the region. Each of three input strategies was applied to three levels of cropping diversity. Organic input systems were based on non-chemical pest control and nutrient management; reduced input systems used integrated long-term management of pests and nutrients utilizing chemicals and no-till practices; high input systems used pesticides and fertilizers "as required" based on accepted recommendations associated with pest thresholds and residual soil nutrient levels from soil tests. Cropping diversity comparisons compare wheat and fallow based systems with either a diverse mix of cereal, oilseed and pulse crops, or a mix of annual and perennial crops. Findings, to date, suggest soil quality/health can be improved and nutrient accumulation in the soil profile minimized by increasing cropping frequencies and reducing tillage. Furthermore, high crop yields and positive economic returns can be sustained by using appropriate combinations of inputs and crop diversification.

Introduction
The Alternative Cropping Systems (ACS) study was established in 1994 on a Dark Brown Chernozemic soil located on the transition between the semi-arid and sub-humid prairies, near Scott, Saskatchewan. The soil has a loam texture, a mean organic matter content of approximately 4%, and surface pH of about 5.5. Prior to establishing this study, the area had been maintained in a cereal–fallow or cereal–cereal–fallow rotation with limited (mainly phosphorus) fertilization.

Cropping systems in this region, and indeed on the Canadian prairies in general, are shaped by diverse and often conflicting forces. Reducing tillage intensity and eliminating summer fallow helps avoid soil degradation and improves water conservation, but increases reliance on fertilizer and pesticide inputs. The use of chemical fertilizers and pesticides can dramatically increase crop yields, but these inputs are expensive and there are concerns regarding their non-renewable nature and potential negative impacts on food and environmental quality.

Response to these and many other factors has resulted in an array of management approaches to cropping systems, which can be broadly grouped as organic, low input, or high input farming systems based on the level of cropping inputs used. They can also be grouped as low diversity farms that rely on summer fallow and cereal monoculture, those that grow a diversity of cereal and broadleaf crops with minimal use of summer fallow, and those that employ a diversity of both annual and perennial crops. Combining the three diversity levels with each of three input levels results in a matrix of nine systems, which in a general way, represent the spectrum of cropping systems found on the Canadian prairies. The long-term sustainability of these management systems has remained largely unexamined, particularly at a systems level. The objective of the Alternative Cropping Systems study was to determine and compare the long-term economic, agronomic, and environmental performance of these nine cropping systems. The experiment was laid out in a four replicate, split plot design, with main plot treatments consisting of three levels of inputs and sub-plots comprised of three levels of cropping diversity each having a six year rotation cycle[1] (Table 1).

Organic input systems (ORG) were based on non-chemical pest control and nutrient management in an attempt to mimic practices of organic growers. Reduced input systems (RED) employed no-till practices and integrated long-term management of pests and nutrients. The intent was to reduce inputs (pesticides, fertilizers, and fossil fuels) such that any yield reduction was at least offset by reduced input costs. High input systems (HI) used pesticides and fertilizers "as required" based on accepted recommendations associated with pest thresholds and residual soil nutrient levels from soil tests.

Low crop diversity systems (LOW) utilized wheat, oilseed and fallow or green manure (GM) based rotations (Table 1) reflecting cropping systems chosen by risk averse producers. Diversified annual grains systems (DAG) included a diversity of cereal, oilseed and pulse crops, while the diversified annual and perennial systems (DAP) included a mix of grain and forage crops.

Between the time of crop harvest and soil freeze up, one or more tillage operations were performed to manage crop residue and control weeds on the ORG and HI systems (Figure 1). For RED systems, tillage was done only rarely, except in RED-DAP where tillage was used to terminate alfalfa in some years. Fall application of phenoxy herbicides (2,4-D or MCPA) was typically used for fall weed control with RED. Spring pre-planting tillage was done for weed control and seed-bed preparation, typically consisting of one to two operations with a sweep type cultivator followed by harrowing or harrow-packing. Pre-planting weed control with RED was usually achieved with herbicides. Pre-planting tillage with RED was done with harrows to spread crop residues or in the case of RED-DAP, to prepare a seedbed after fall tillage to terminate alfalfa. Tillage was employed to control weeds on fallow and green manure partial-fallow phases of the ORG-LOW and the HI-LOW. The number of tillage operations required after ORG green manure fallow was about half that needed on conventionally tilled HI fallow.

Crop cultivars were selected based on their suitability for production in the area, with the same cultivars used with all input and diversity systems for a full rotation cycle wherever possible. Crops were sown at recommended rates in HI and at 33% higher rates in ORG and RED to help reduce the need for weed control treatments. Fertilizer nitrogen (N) was applied in the non-organic treatments at or before sowing based on soil test recommendations. In HI the same rate was applied to all replicates of each treatment, while in RED the rate varied across replicates (landscape based) depending on soil test values for each plot. Phosphorus (P) fertilizer was applied to RED and HI with the seed at constant rates (averaging 10.8 kg ha^{-1} of P) that differed very little between treatments. Recommended chemical seed treatments were used on seed for HI and RED systems based on perceived need. With N fixing legumes as green-manure fallow, grain or forage crops, *Rhizobial* inoculants appropriate for that crop were applied to seed with all input systems. To meet some crop P requirements, a commercially available *Penicillium bilaii* formulation was applied as a seed treatment on ORG and RED crops. At the end of each six year cycle, compost was added to RED-DAP and ORG-DAP to replace the N that would be available if the forage and barley grown in these systems were fed to feeder cattle and the manure spread on the land. The compost was applied and incorporated with tillage between the last forage phase and the subsequent grain phase.

In-crop weed control in HI systems utilized recommended herbicides at recommended rates based on weed populations. For ORG systems, in-crop harrowing was typically done where cereal and field pea crops were grown. Where insect thresholds were exceeded or conditions were considered favorable for disease losses to exceed chemical control costs, recommended insecticide and fungicide treatments were applied in RED and HI systems.

Results and Discussion

Agronomic Performance

The general trend (12 year mean) in grain yield was for ORG-LOW and ORG-DAG to be lowest yielding, ORG-DAP, RED-LOW and HI-LOW to provide intermediate yield, and RED-DAG, HI-DAG, RED-DAP and HI-DAP to be the highest yielding systems[2] (Table 2). However, there were many years where yields departed somewhat from these trends. In dry years yields were poor on the DAP systems because dry conditions resulted in poor establishment of the perennial crops. In 1998, the pre-seed tillage on the HI systems (integral to this management system), dried out the soil and reduced emergence. This resulted in lower yields on HI relative to RED systems. In 1999, excellent field pea yields in the ORG-DAG systems resulted in overall mean grain yields that surpassed the other two ORG systems. During 2004, all ORG treatments yielded relatively well compared with HI and RED. Most of the improvement was associated with yields of ORG cereals (wheat and barley) that were 15 and 30% higher respectively than HI or RED cereals. During other years, RED and HI wheat and barley generally yielded 30 and 40% more than ORG, respectively. It is possible that ORG cereal crops were not damaged as extensively by a late spring frost or cold temperature injury during 2004, because ORG cereals were seeded later than HI or RED.

The overall trend (12 year mean) for crop biomass was for RED-DAG and HI-DAG to produce significantly more biomass than all other systems, and for RED-LOW, HI-LOW, RED-DAP and HI-DAP to produce intermediate crop biomass, while all ORG systems produced the least crop biomass. Similar to crop yield, there were numerous departures from these general trends in individual years. Lower biomass production with ORG likely reflected a reduced supply of available N, greater weed competition and to a lesser extent, a reduced supply of available P.

Economic Performance

Using 2007 input costs and product prices, average net returns and 12-year net present values were higher for organic than for non-organic treatments, with the ORG-LOW system being the most profitable[7] (net returns = \$234 ha^{-1} yr^{-1} and net present value = \$1953 ha^{-1}) (Table 3). Net returns averaged about 10% less for ORG-DAG compared to the most profitable system, and about 22% less for HI-DAG and RED-DAG (the best non-organic systems). The DAP treatments that included forage were not economically competitive with the other treatments, often producing economic losses. The relative profitability of the ORG treatments was highly dependent on the existence of organic price premiums. When price premiums for organic crops were reduced to less than 70% of the 2007 levels, the ORG treatments were less profitable than the comparable non-organic treatments. The ORG treatments also experienced significantly lower (and often negative) net returns compared to the non-organic treatments during completion of the 3-year organic certification period. We estimated that it required 5 to 7 years after completion of certification for the ORG treatments to break even with the comparable nonorganic treatments. Thereafter the ORG treatments produced consistently higher net earnings. Production costs averaged 16% lower with ORG compared to HI, but there was little difference in total costs between the respective HI and RED treatments. The organic treatments also displayed lower income variability than the non-organic treatments.

Non-Renewable Energy Use and Efficiency

Input and diversity affected energy input requirements. HI and RED systems required more than double the energy inputs compared to ORG , largely due to the high energy costs of fertilizers, particularly N[6] (Table 3). Compared to the HI systems, RED input systems realized some energy savings for fuel, oil and machinery, but this was offset by greater energy inputs for seed and pesticides. Energy requirements were highest for the HI-DAG and RED-DAG due to their greater reliance on inorganic fertilizers.

Despite higher energy inputs, HI and RED systems produced more net energy (Energy Output – Energy Input) compared to the ORG systems. In general, net energy production reflected the overall yield of the system, thus net energy production was lowest for the LOW diversity systems because one-third of the rotation area was in fallow or green manure (no marketable yield) each year. The ORG-DAG system had very low net energy production compared to the corresponding HI and RED input systems, because yields were generally lower and green manures were grown on one third of the rotation area each year.

When the energy use efficiency, as measured by the ratio of energy output per unit of energy input, is used as the measure to compare the systems, a somewhat different picture emerges. ORG-DAP was the most energy efficient, with a ratio of 11.7, while ORG-LOW and ORG-DAG systems had ratios that were slightly greater (7.4 to 7.5) than the corresponding HI or RED input systems (6.4 to 6.9). HI and RED DAP systems were slightly more energy efficient than the corresponding LOW and DAG systems. Improved energy use efficiency appears linked to reduced energy requirements.

Soil Fertility and Nutrient Balance

Sustainable nutrient management aims to optimize productivity while protecting the environment. A simple nutrient balance can be calculated by estimating amounts of each nutrient added as fertilizer, compost or by N fixation minus the amounts removed in harvested crops[4]. The ORG-DAP and ORG-LOW systems had small N deficits, while the ORG-DAG system had a small surplus (Table 4). The surplus with DAG likely reflected the fact that one-third of the land was attributed to legume green manure, while another one-sixth was devoted to an N fixing pea crop. The HI-LOW system was nearly balanced, but all other systems had large surpluses.

Surpluses of nitrate-N may enhance soil fertility but can also lead to gaseous losses of N from the soil surface, or leaching into the subsoil. Residual available soil N in the 0-90 cm depth at the end of the growing season was greater with HI compared to ORG and RED input systems in most years[3,4]. Thus, despite the large surpluses calculated for the RED systems, the N appears to have stabilized in organic form, likely reflecting the much lower tillage intensities on the RED compare to the other two systems. Residual soil nitrate-N (0-90 cm depth) amongst the diversity levels ranked in the order of LOW > DAG > DAP, mainly reflecting the impact of fallow and green manure in mineralizing N, and a longer period of N uptake by forage in the DAP systems.

Nitrate-N below the rooting zone represents a loss of a valuable plant nutrient, and is an indicator of potential contamination of subsoil water. The amounts of nitrate-N in the 90-240 cm depth in fall 2006 (after 12 growing seasons) were much greater with the HI compared to the ORG and RED systems, with the highest amounts of soil residual nitrate-N in the HI-LOW treatment[4] (Table 4). From 2000 to 2006, the HI-LOW system gained 196 kg N ha^{-1} of nitrate-N below the rooting zone, the ORG-LOW gained 113 kg N ha^{-1}, while the other systems experienced only small gains or losses. The use of tillage-based summer fallow/green-manure mineralizes N from soil organic matter and stores soil moisture leading to an increased risk of nitrate leaching. The RED-LOW system with one legume green manure and judicious use of fertilizer appears to use N and water more effectively thus avoiding large nitrate leaching losses. In the continuously cropped DAG and DAP systems, water use by crops each year likely restricted the potential for N to leach below the rooting zone.

Removal of soil P in the RED and HI input systems was lower than expected due to drier than normal conditions leading to large P surpluses (Table 4). Despite additions exceeding removals, there was no evidence of downward movement of P below the 30 cm soil depth. No acceptable and effective means to replace P removed by crops in the ORG systems has been found, thus they show large P deficits (Table 4). There was generally no effect of cropping diversity on the distribution of extractable P. Extractable P was low in the 0-30 cm layer and extremely low in the 30-90 cm soil layer, thus there is little potential to bring P from deeper soil layers to the surface by using deep taproot crops.

Overall, there was no consistent effect of crop diversity on soil pH, although there was slight reduction in soil pH from consecutive applications of N and P fertilizers in the HI and RED compared to the ORG systems. Soil acidification from fertilizer application does not appear to be a concern at this site, at least in the foreseeable future.

Soil Quality and Health

Aggregate size and stability can affect soil erodability and its suitability for crop production, with larger, more stable aggregates preferred. Aggregate size as measured by mean weight diameter (MWD) was highest for the RED systems, but an interaction between inputs and cropping diversity was observed[4]. With the HI input systems, LOW had smaller aggregates than DAG or DAP, while with RED systems, DAP had the smallest aggregates and DAG the largest. Diversity had little effect on aggregates within ORG input systems. These results suggest the better soil structure was related to reduced tillage intensity, particularly when combined with the use of diversified annual grains. Wet aggregate stability was also higher on RED compared with HI or ORG input systems, but diversity had little effect.

There was no apparent effect of input level or crop diversity on total organic C and total organic N in the 0-15 cm soil[4] (Table 5). RED systems had greater light fraction organic C and N, which are thought to be more sensitive indicators of cropping system effects on soil quality, compared to the HI input systems, and the ORG input systems had the least. The DAP systems had the highest light fraction organic C and N, followed by DAG and then LOW diversity systems.

This supports the notion that systems with little or no tillage combined with perennial forages promote improved soil quality, as well as the nutrient supplying power of the soil.

Conserving adequate crop residue cover is critical to protect the soil against erosion. The ORG and HI systems were heavily reliant on tillage for weed control and these systems frequently had inadequate cover to protect against erosion. The RED systems, with very little tillage, were effective in minimizing risk of erosion, although even these systems had some land that was at risk. It should be borne in mind that 3 of the 6 years when these data were collected were much drier than normal greatly reducing the amount of crop residue returned to the soil.

Soil arthropods are considered good indicators of soil health, and soil mites {*Acarii* spp) seem to be particularly useful for this purpose. Mites inhabit near-surface soil and feed on plant debri, thereby affecting nutrient cycling[5]. It appears tillage is a major factor affecting mites because numbers were much higher in the RED compared to the HI or ORG systems (figure 2). The RED systems also had more suborders of mites than the ORG or HI input systems. This would suggest that elimination of tillage could also play an important role in preserving biodiversity. However, species richness in RED input systems was still much lower than those recorded in a nearby native prairie reference area.

The Future

Each of the nine cropping systems has a six year rotation cycle, and the study was initially conceptualized to run for three full cycles (3 x 6 = 18 years). A major sampling campaign and thorough analysis of the data set is scheduled at the completion of each of the six year cycles. The next, and possibly final, field sampling campaign and data analysis is scheduled following the 2012 cropping season. While the true value of this long-term study is just now coming to fruition, finding the resources (landbase, manpower, funding) to maintain a study of this size and complexity is an ongoing challenge. It is most likely that only a scaled down version will continue on into the future. Some questions that could be addressed in the near future include:

- Verifying that P has become a limiting factor on the ORG treatments.
- Modify the management of the RED and HI input systems in an attempt to balance N and P additions and removals.
- Test and adapt or develop a wider suite of indicators (but on fewer treatments) to monitor and predict the trajectory of soil and environmental health and soil biodiversity.
- Innovative approaches to analyzing and assessing the tremendous amount of data that has already been collected.
- Utilizing the long-term data set to test or develop crop and soil simulation models.

In addition, a well designed and maintained study such as this will no doubt provide answers to any number of unanticipated questions.

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Table 1. Description of cropping systems maintained in the Alternative Cropping Systems study at Scott[a].

Diversity level[b]	Input level[c]	Crop sequence[d]
LOW	ORG	GM-Wheat-Wheat-GM-Mustard-Wheat
	RED	GM-Wheat-Wheat-Chem Fallow-Canola–Wheat
	HI	Fallow-Wheat-Wheat-Fallow-Canola-Wheat
DAG	ORG	GM-Wheat-Pea-Barley-GM-Mustard
	RED	Canola-Soft White Wheat-Pea-Barley-Flax–Wheat
	HI	Canola-Soft White Wheat-Pea-Barley-Flax–Wheat
DAP	ORG	Mustard-Wheat-Barley-Alfalfa-Alfalfa-Alfalfa
	RED	Canola-Wheat-Barley-Alfalfa-Alfalfa-Alfalfa
	HI	Canola-Wheat-Barley-Alfalfa-Alfalfa-Alfalfa

[a] Source: Brandt[1]
[b] LOW = low; DAG = diversified annual grain; DAP = diversified annual perennial.
[c] ORG = non-chemical pest control and nutrient management; RED = integrated long-term management of pests and nutrients utilizing chemicals and no-till practices; HI = pesticides and fertilizers "as required" based on conventional recommendations associated with pest thresholds and soil tests
[d] GM = green manure (Indian Head Lentil) partial fallow; Chem fallow = summer fallow with weeds controlled by herbicides; fallow = summer fallow with weeds controlled by tillage.

Table 2. Influence of input level and cropping diversity on mean yield and in-crop weed biomass over 12 years (1996-2007) in the Alternative Cropping Systems study at Scott[a]

Input level[b]	Diversity level[c]	Crop yield[d]	Weed biomass[d]
		- - - - - - - - kg ha^{-1}	- - - - - - - -
HI	LOW	1243	47
	DAG	1605	143
	DAP	1567	93
	Mean	1472 a	94 b
RED	LOW	1179	46
	DAG	1552	89
	DAP	1527	83
	Mean	1419 a	73 b
ORG	LOW	806	210
	DAG	811	340
	DAP	1204	232
	Mean	940 b	261 a
Mean	LOW	1076 b	101 b
	DAG	1322 a	191 a
	DAP	1433 a	136 ab

[a] Source: Brandt[2]
[b] ORG = non-chemical pest control and nutrient management; RED = integrated long-term management of pests and nutrients utilizing chemicals and no-till practices; HI = pesticides and fertilizers "as required" based on conventional recommendations associated with pest thresholds and soil tests
[c] LOW = low; DAG = diversified annual grain; DAP = diversified annual perennial.
[d] Input level or diversity means followed by a different letter are statistically different at $P < 0.05$.

Table 3. Input costs, net returns, energy input, energy output, Energy Input/Output ratio and energy use efficiency under three input levels and three crop diversity levels during 1996-2007 with 100% Organic premiums applied in the Alternative Cropping Systems study at Scott[a]

Input level	Crop diversity			
	LOW	DAG	DAP	Mean
Input costs ($ ha^{-1})				
HI	270	342	322	311
RED	269	333	327	310
ORG	254	258	276	262
Mean	264	311	308	
Net returns ($ ha^{-1})				
HI	176	190	-4	121
RED	156	182	-24	104
ORG	234	211	76	173
Mean	189	194	15	
Energy input (MJ ha^{-1})				
HI	3466	4487	3484	3812
RED	3459	4331	3408	3733
ORG	1963	1898	1806	1889
Mean	2963	3572	2899	
Enegy output ((MJ ha^{-1})				
HI	23386	28761	27482	26541
RED	22268	27734	26773	25592
ORG	14597	14435	20768	16600
Mean	20084	23643	25008	
EO/EI ratio				
HI	6.95	6.71	7.97	7.21
RED	6.46	6.43	7.91	6.93
ORG	7.20	7.39	11.73	8.77
Mean	6.87	6.84	9.20	
EUE – kg yield of grain plus forage per unit of EI (kg produce yield J^{-1})				
HI	369	378	454	400
RED	342	360	451	384
ORG	397	416	678	497
Mean	369	384	528	

[a] Source: Zentner[1,2]

[b] ORG = non-chemical pest control and nutrient management; RED = integrated long-term pest and nutrient management utilizing chemicals and no-till practices; HI = pesticides and fertilizers “as required” based on conventional recommendations associated with pest thresholds and soil tests

[c] LOW = low; DAG = diversified annual grain; DAP = diversified annual perennial.

Table 4. Influence of input level and cropping diversity on mean residual soil nitrate-N in the 90-240 cm depth and extractable P in the 0-90 cm depth in late fall 2006, and N and P balance in soil-plant systems over 12 years (1995-2006).[a]

Input level[b]	Diversity level[c]	Residual soil N	Residual soil P	N balance [d]	P balance [d]
		- - - - - - - - - - - - - - - - kg ha^{-1}	- - - - -	- - - - -	- - - - - - - - - - - - - - - -
HI	LOW	404	27	0	168
	DAG	238	22	261	255
	DAP	228	29	349	232
	MEAN	290	26	203	218
RED	LOW	289	28	124	166
	DAG	116	28	234	250
	DAP	102	30	372	249
	MEAN	169	29	243	222
ORG	LOW	164	19	-55	-40
	DAG	180	18	37	-41
	DAP	103	21	-15	-22
	MEAN	149	20	-11	-34
Mean	LOW	286	25	69	98
	DAG	178	23	177	155
	DAP	144	27	235	153

[a] Source: Malhi[3]
[b] ORG = non-chemical pest control and nutrient management; RED = integrated long-term pest and nutrient management utilizing chemicals and no-till practices; HI = pesticides and fertilizers "as required" based on conventional recommendations associated with pest thresholds and soil tests
[c] LOW = low; DAG = diversified annual grain; DAP = diversified annual perennial.
[d] Positive value implies nutrient surplus, whereas a negative value implies a nutrient deficit.

Table 5. Influence of input level and cropping diversity on mean mass of total organic C (TOC), total organic N (TON), light fraction organic C (LFOC and light fraction organic N (LFON) in the 0-15 cm soil in fall 2006 at Scott[a]

Input level[b]	Diversity level[c]	TOC (Mg C ha^{-1})	TON (Mg N ha^{-1})	LFOC (kg C ha^{-1})	LFON (kg N ha^{-1})
HI	LOW	43.07	4.131	2587	170
	DAG	42.86	4.079	3660	239
	DAP	41.04	4.111	3387	232
	MEAN	42.32	4.107	3211	214
RED	LOW	42.26	3.952	3577	236
	DAG	44.46	4.376	3733	249
	DAP	43.17	4.145	5015	338
	MEAN	43.30	4.157	4108	274
ORG	LOW	42.40	4.143	3049	195
	DAG	42.42	4.284	2965	189
	DAP	42.07	4.120	3257	207
	MEAN	42.30	4.182	3090	197
Mean	LOW	42.58	4.075	3071	200
	DAG	43.25	4.246	3453	226
	DAP	42.09	4.125	3886	259

[a] Source: Malhi[3]
[b] ORG = non-chemical pest control and nutrient management; RED = integrated long-term pest and nutrient management utilizing chemicals and no-till practices; HI = pesticides and fertilizers "as required" based on conventional recommendations associated with pest thresholds and soil tests
[c] LOW = low; DAG = diversified annual grain; DAP = diversified annual perennial.

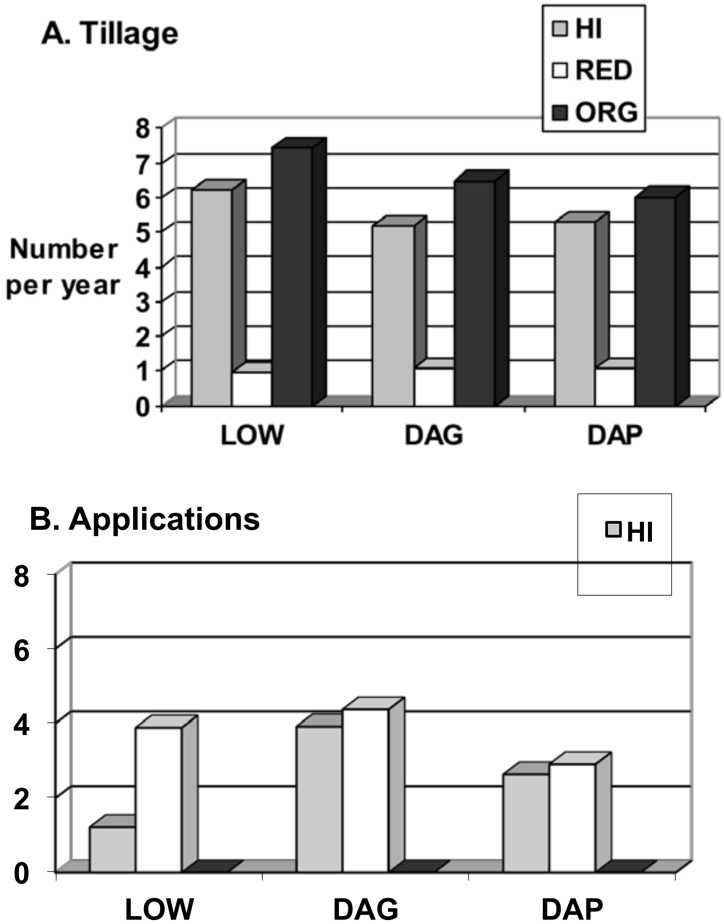

Figure 1. Intensities [number per year] of (A) tillage and (B) application of fertilizers and pesticides in High, Reduced and Organic production systems [1995-2000 means].
Source: Brandt[2]

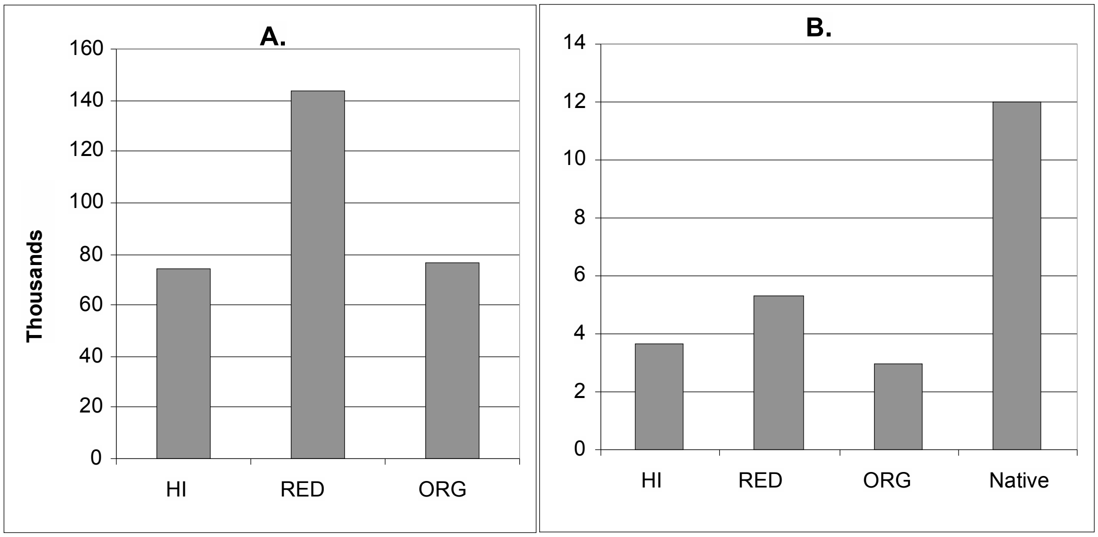

Figure 2. Mean numbers of A) mites per square meter, and B) numbers of mite suborders present in soil with High, Reduced and Organic inputs during 1996-2007 (values reflect three levels of cropping diversity and include data from a nearby native prairie area for numbers of suborders).
Source: Brandt[2]

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