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Management Strategies/Practices for Increasing Storage of Organic C and N in Soil in Cropping Systems in the Northern Great Plains of North America

Malhi et al.

Canada

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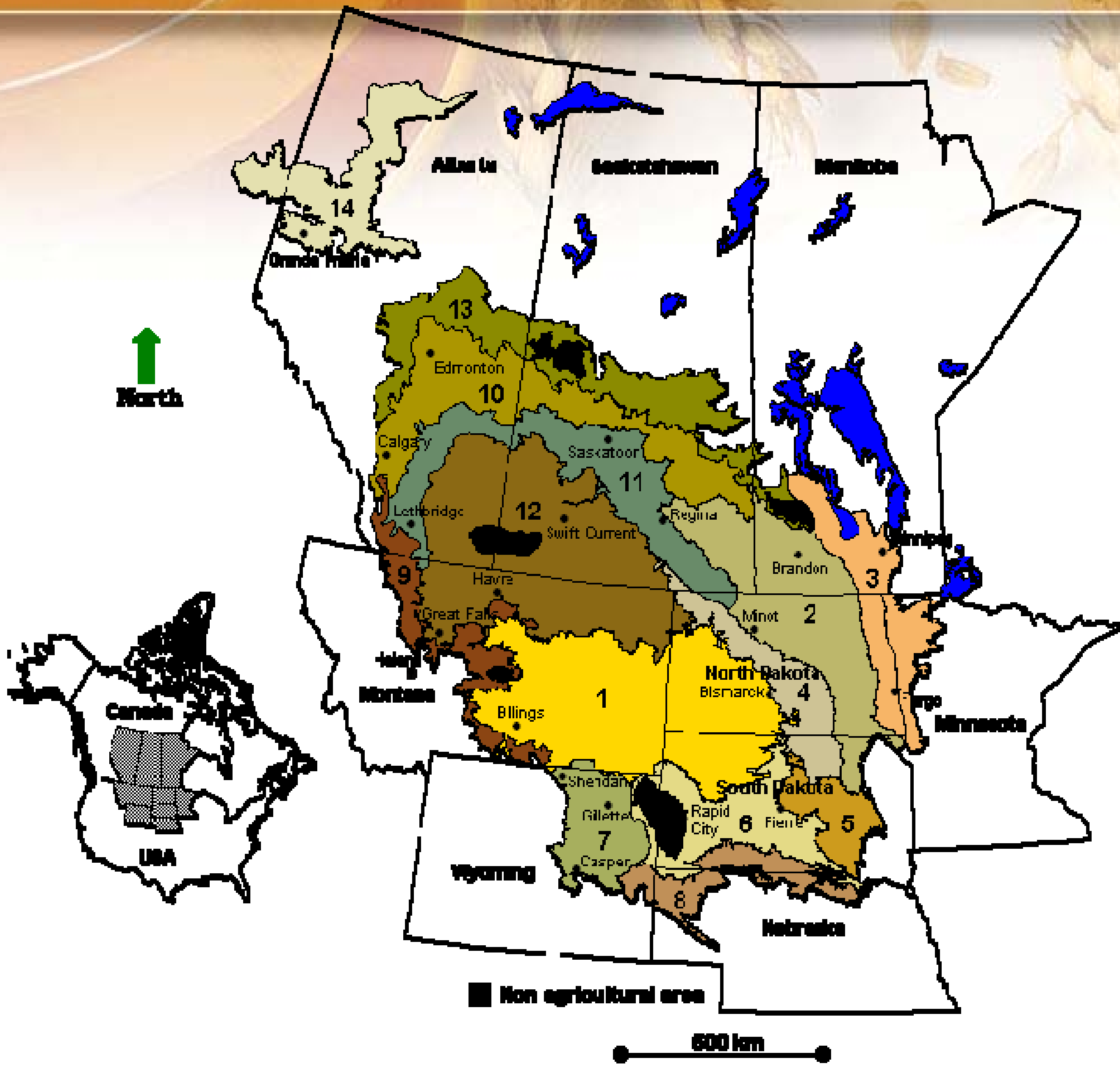

14
Saskatchewan
Manitoba
13
Edmonton
10
North
Calgary
Saskatoon
11
Lethbridge
12
Swift Current
Regina
Brandon
3
9
Havre
Great Falls
Minot
2
Montana
North Dakota
Bismarck
4
1
Billings
Canada
Minnesota
South Dakota
Sheridan
Gillette
Rapid City
6
5
7
Casper
Wyoming
USA
8
Nebraska
Non agricultural area
600 km

Background

- Soils lost substantial original organic C and N reserves in last 100 or more years.

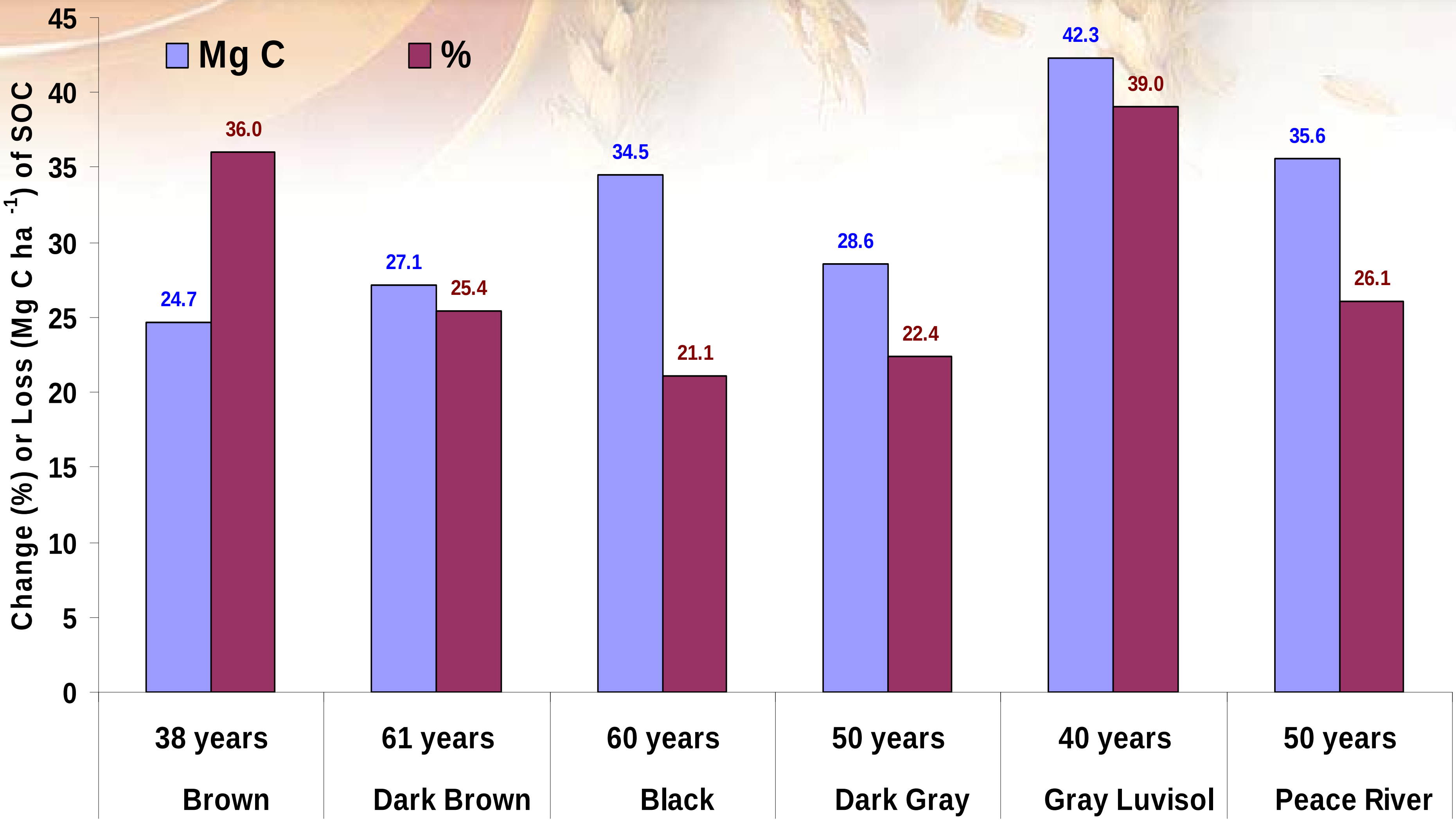
- Range from 16.2 to 62.1%, or 4.2 to 51.4 Mg C ha^{-1}, or 0.105 to 0.734 Mg C ha^{-1} yr^{-1}.

- Mainly due to tilled summer fallow.

Alberta - Loss in SOC due to cultivation

soil profile

Reinl 1984

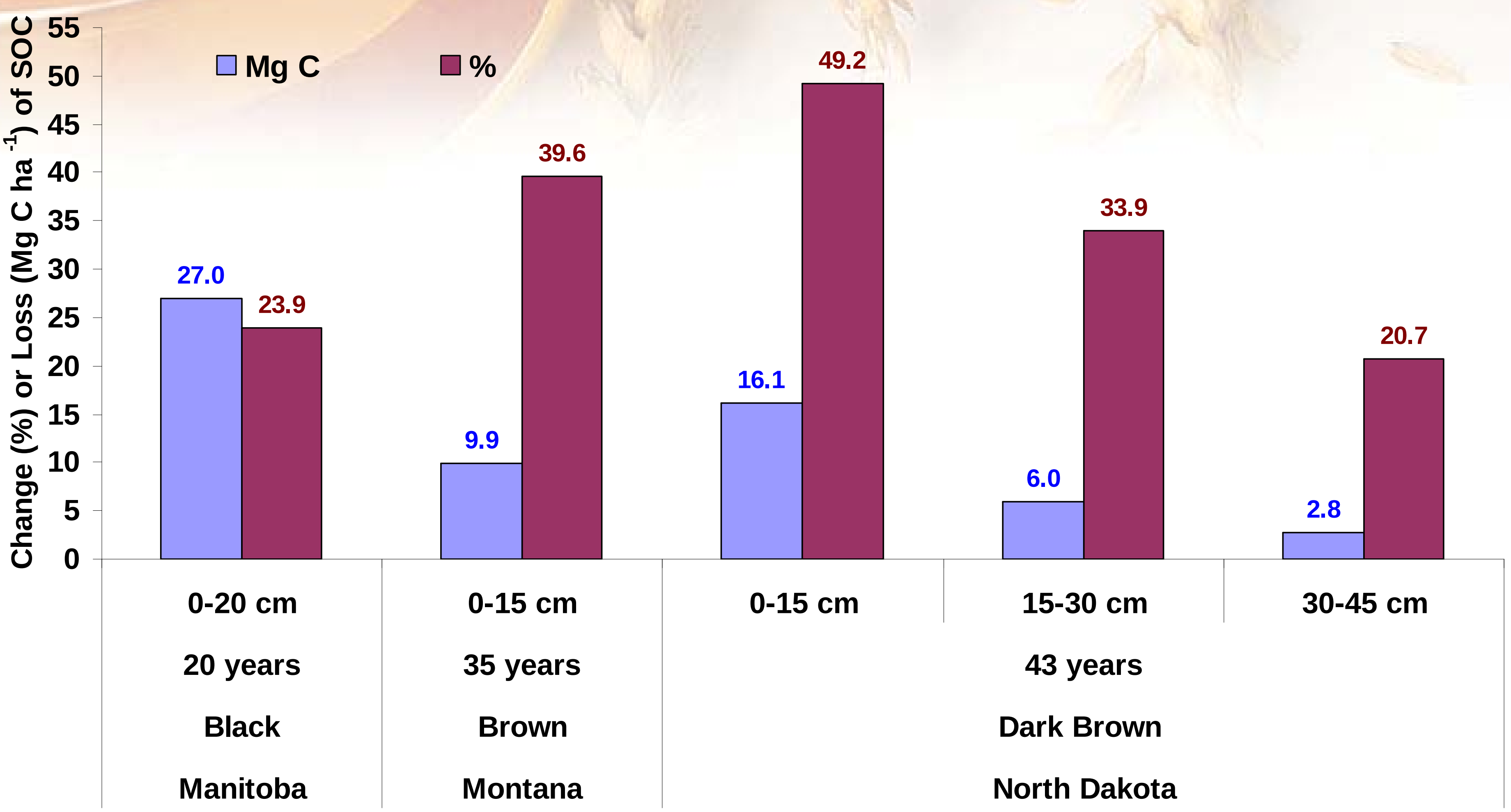


From Table 1

Loss in SOC due to cultivation

Manitoba, Montana and North Dakota

Manitoba (Shutt 1925)
USA sites (Haas et al.)



From Table 1

Background

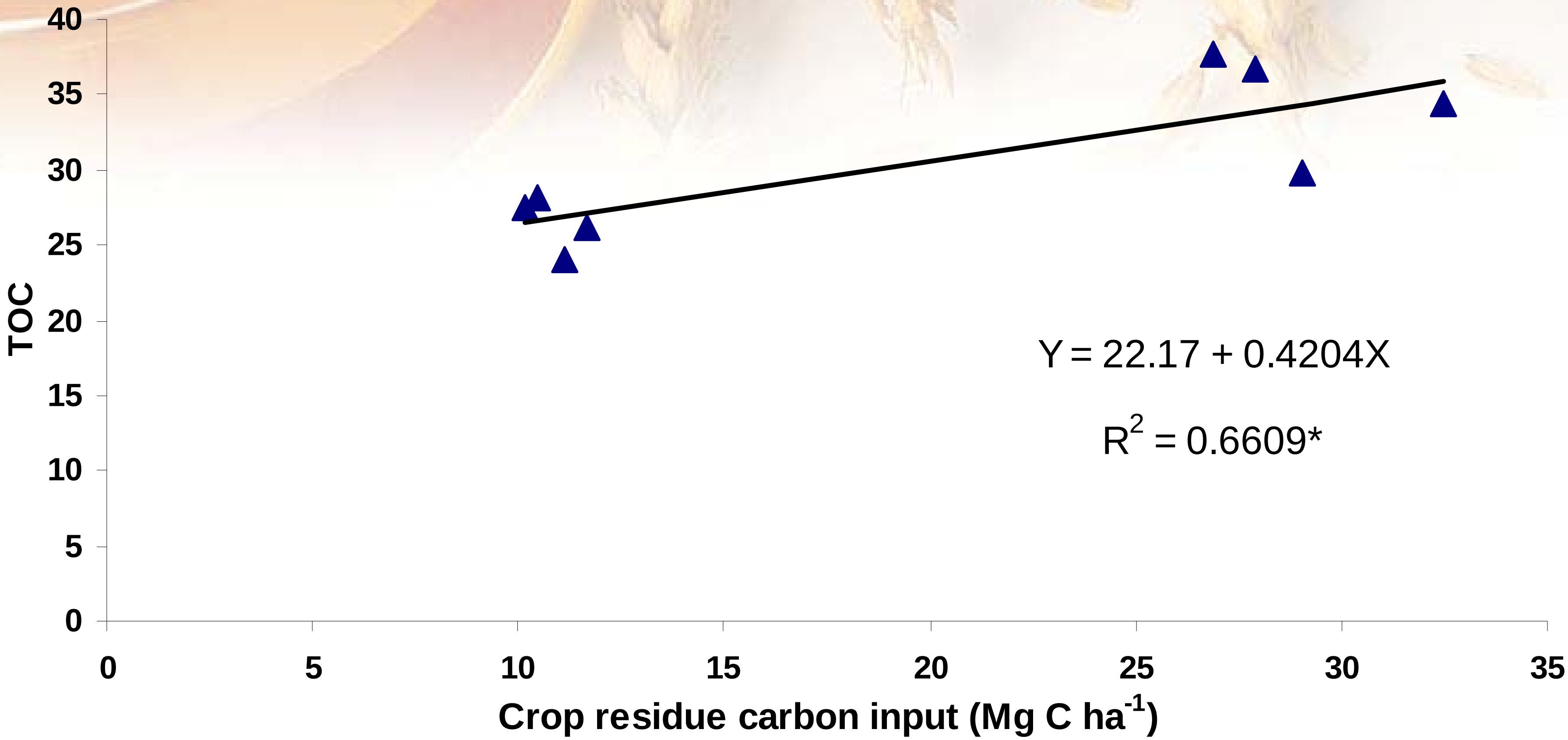
- Currently, many soils represent a potential sink for atmospheric CO_2.

- In this report, we summarized research information on the impacts of tillage, crop residue management, balanced fertilization, manure, crop rotation/diversity and frequency of summer fallow on cultivated cropland, and conversion of cultivated land to perennial grassland on storage of organic C and N in soil.

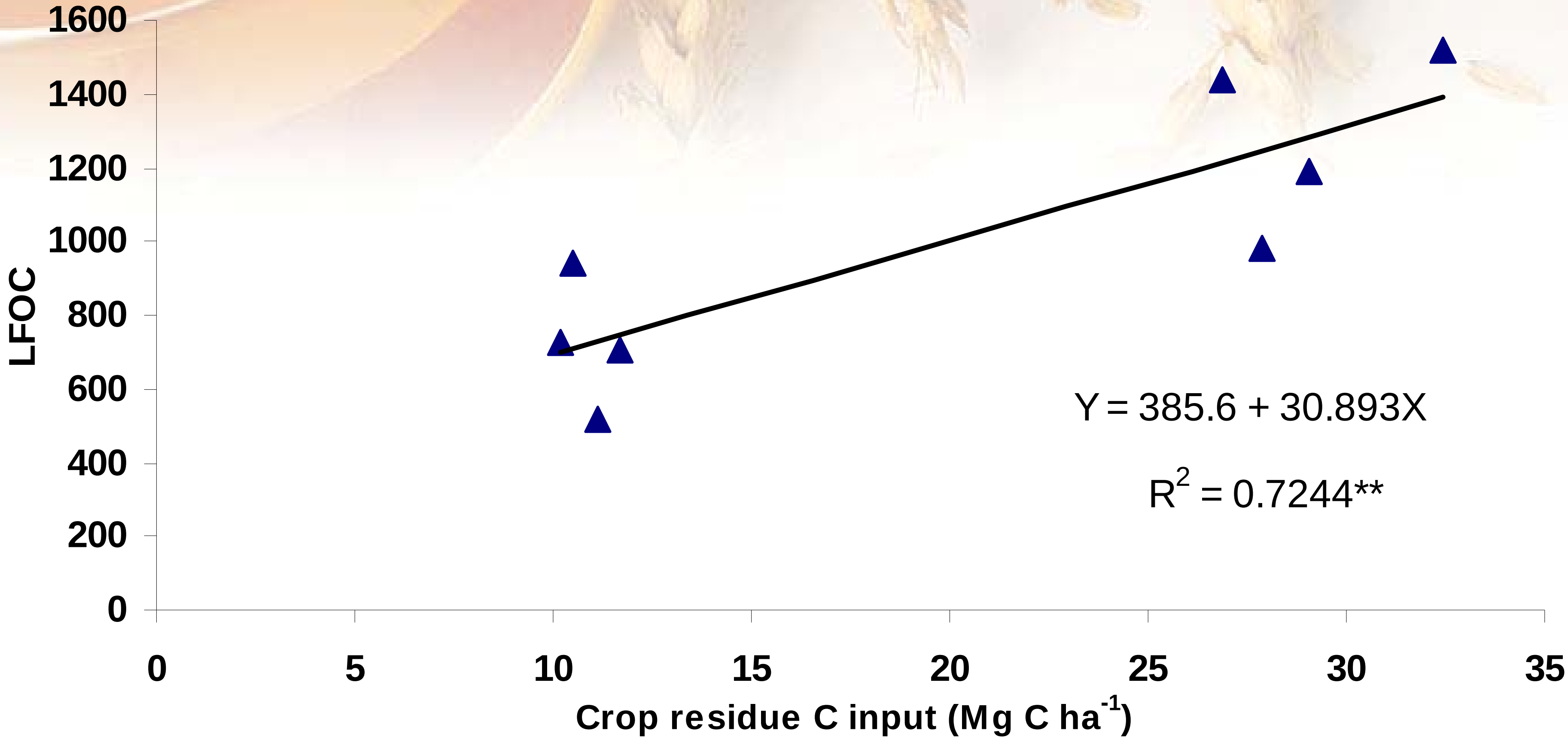
Effects of Management Practices on C and N Storage in Soil

- Crop Residue Management and Tillage
- Fertilizer Rate and Balanced Crop Nutrition
    - Annual Crops
    - Grassland for Hay
- Manure Applications
- Integrated Use of Fertilizers and Manure
- Crop Rotation/Diversity, Cropping Frequency and Fallow
    - Summer Fallow Frequency
    - Cropping Systems
- Conversion of Cultivated Land to Perennial Grassland

Relationship of soil organic C (SOC), soil organic N (SON), light fraction organic matter (LFOM), light fraction organic C (LFOC), mineralizable C (C_{min}), mineralizable N (N_{min}) or water stable aggregates (WSA), with input of crop residue, residue C, residue N, LFOC or clay content

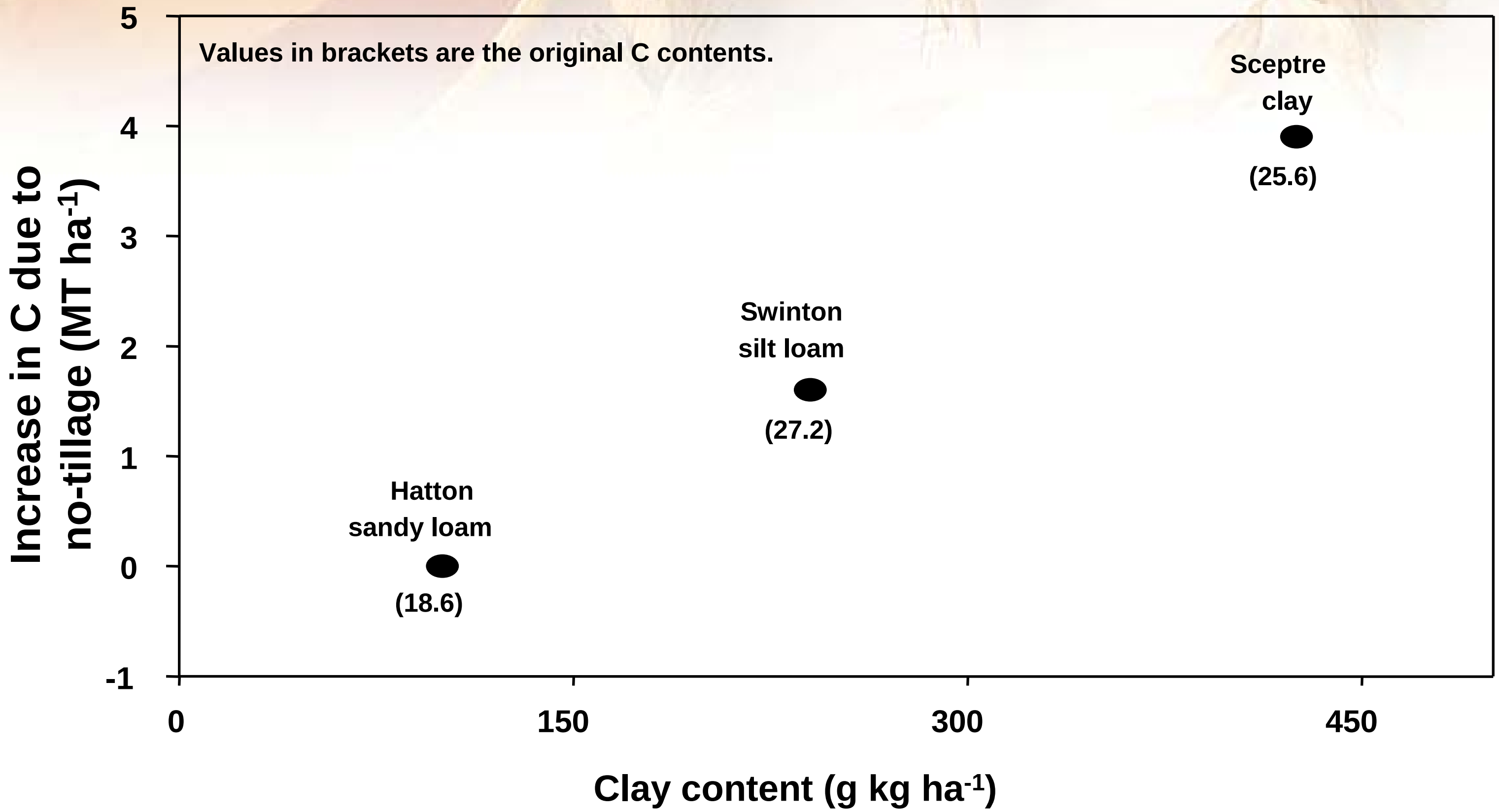


Linear regression for relationship between crop residue C input and soil TOC stored in soil from 1980 to 1998, sampled in autumn 1998 at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn, 1979).



Linear regression for relationship between crop residue C input and soil LFOC stored in soil from 1980 to 1998, sampled in autumn 1998 at Breton, Alberta, Canada (Gray Luvisol soil, experiment established in autumn, 1979).

Soil - Texture

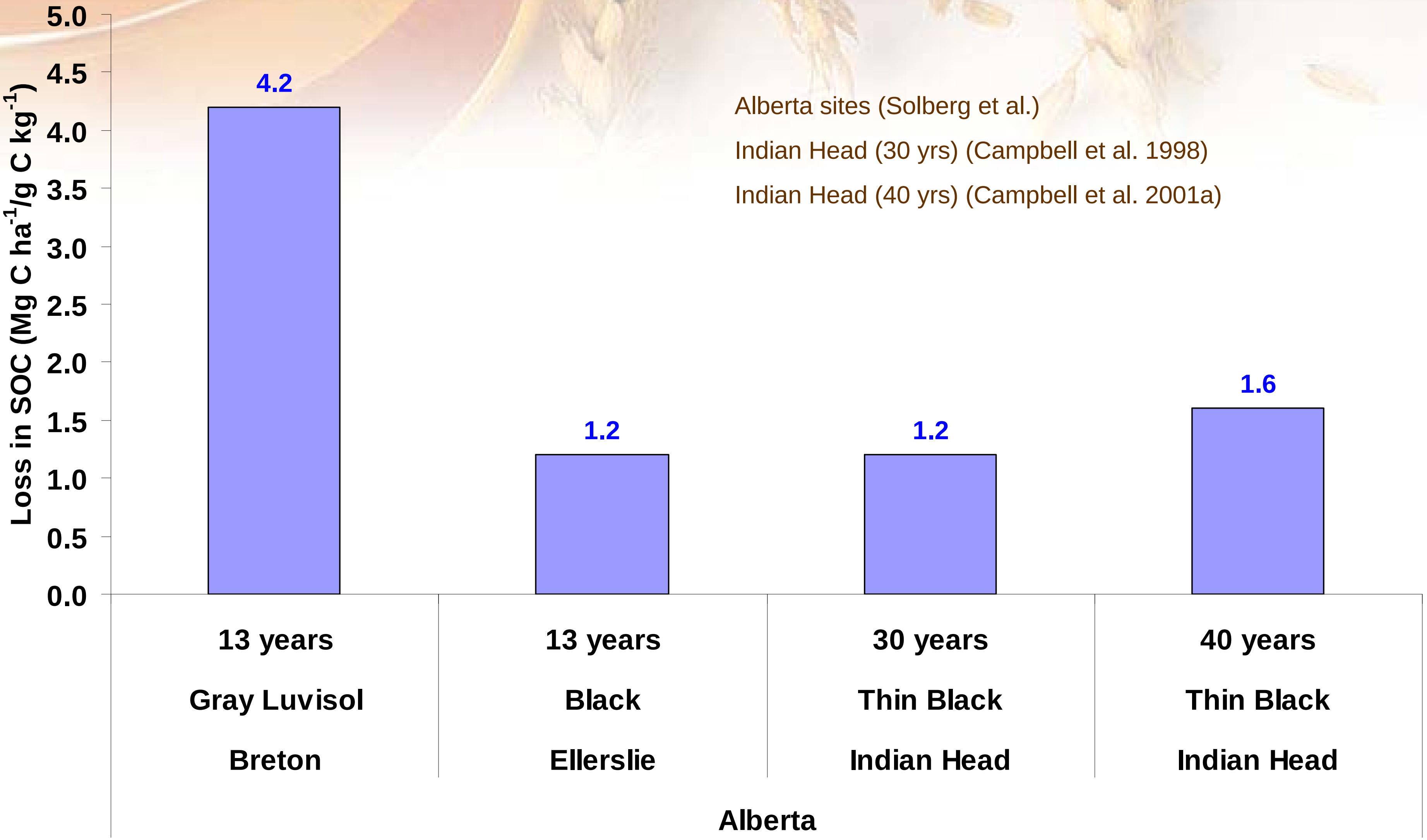


Soil texture influence on SOC gain in the 0 to 15 cm depth 11-12 yr after adopting no-tillage management in the Brown soil zone (adapted from Campbell et al. 1996).

Decrease in soil organic C (SOC) and light fraction organic C (LFOC) due to removing straw compared to its retention or return to land

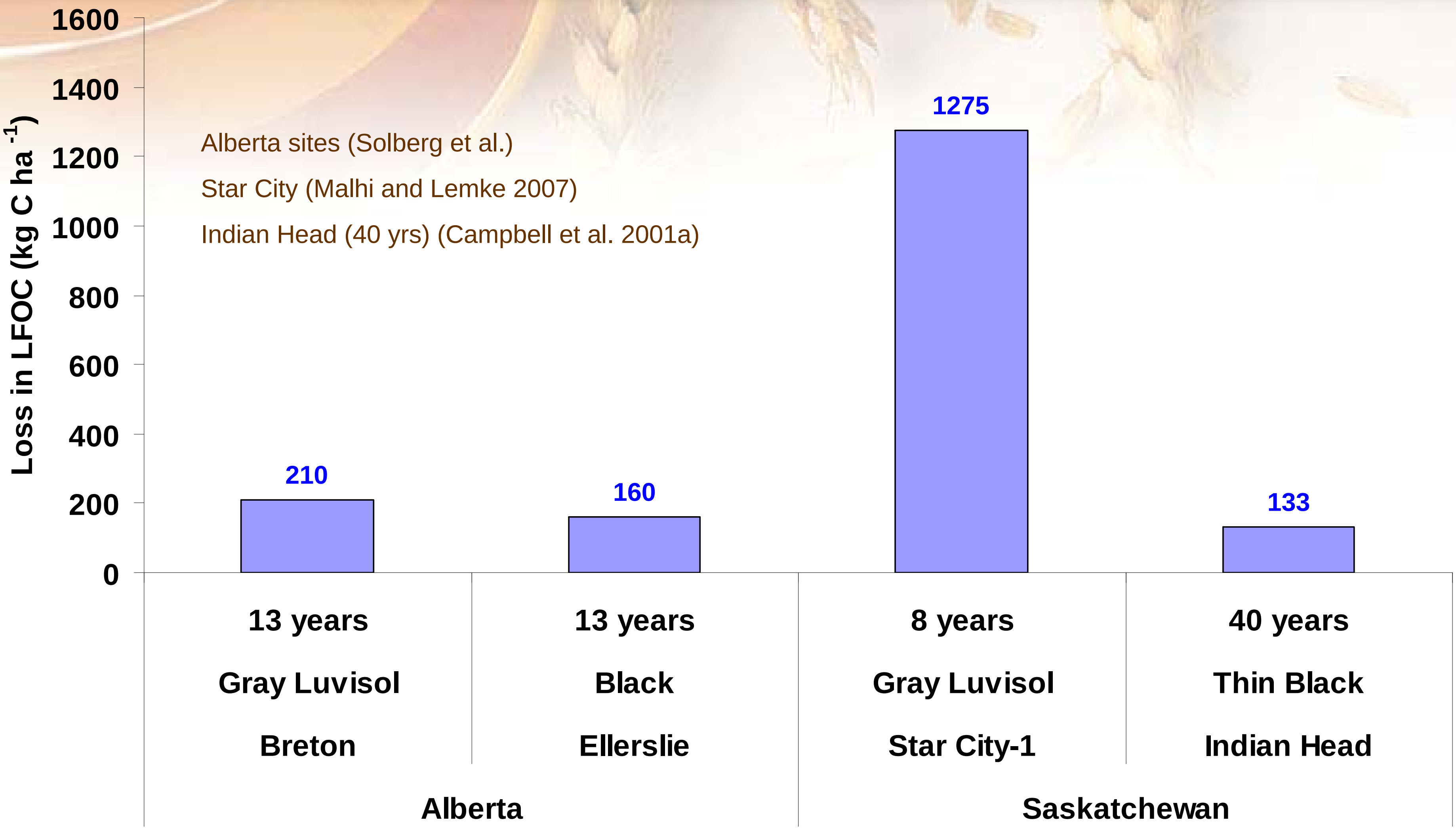
Decrease in SOC due to straw removal

Breton and Ellerslie Alberta (Straw Retained vs. Straw Removed) (CT) (0-30 cm, 0-15cm soil depth)
Star City and Indian Head Saskatchewan (Straw Retained vs. Straw Removed)) (Average of NT and CT treatments) (0-15 cm soil depth)



Decrease in LFOC due to straw removal

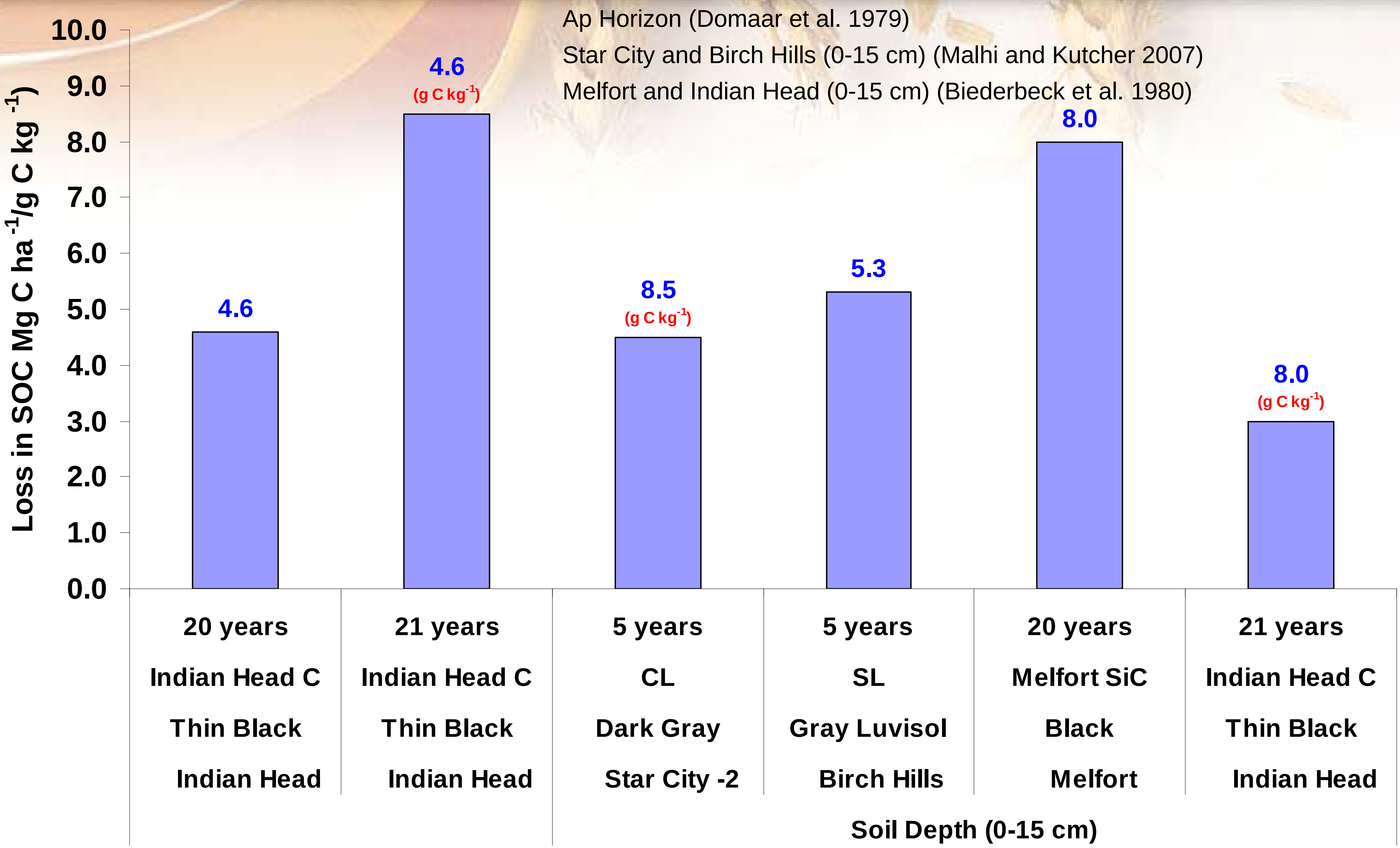
Breton and Ellerslie Alberta (Straw Retained vs. Straw Removed) (CT) (0-30 cm, 0-15cm soil depth)
Star City and Indian Head Saskatchewan (Straw Retained vs. Straw Removed)) (Average of NT and CT treatments) (0-15 cm soil depth)



Decrease in soil organic C (SOC) and light fraction organic C (LFOC) due to burning straw compared to its retention or return to land

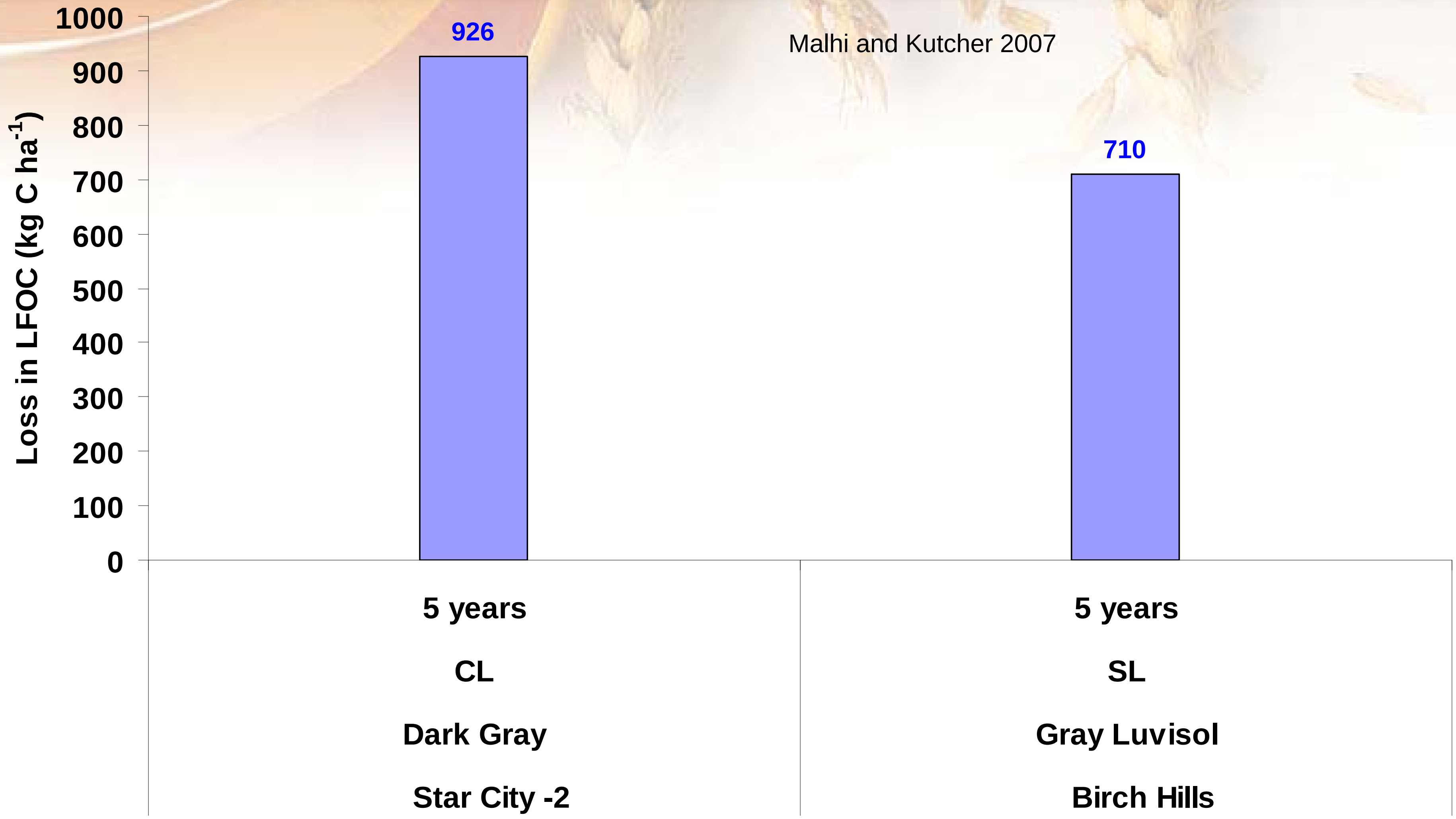
Decrease in SOC due to burning

Retained vs. Burnt



Decrease in LFOC due to burning

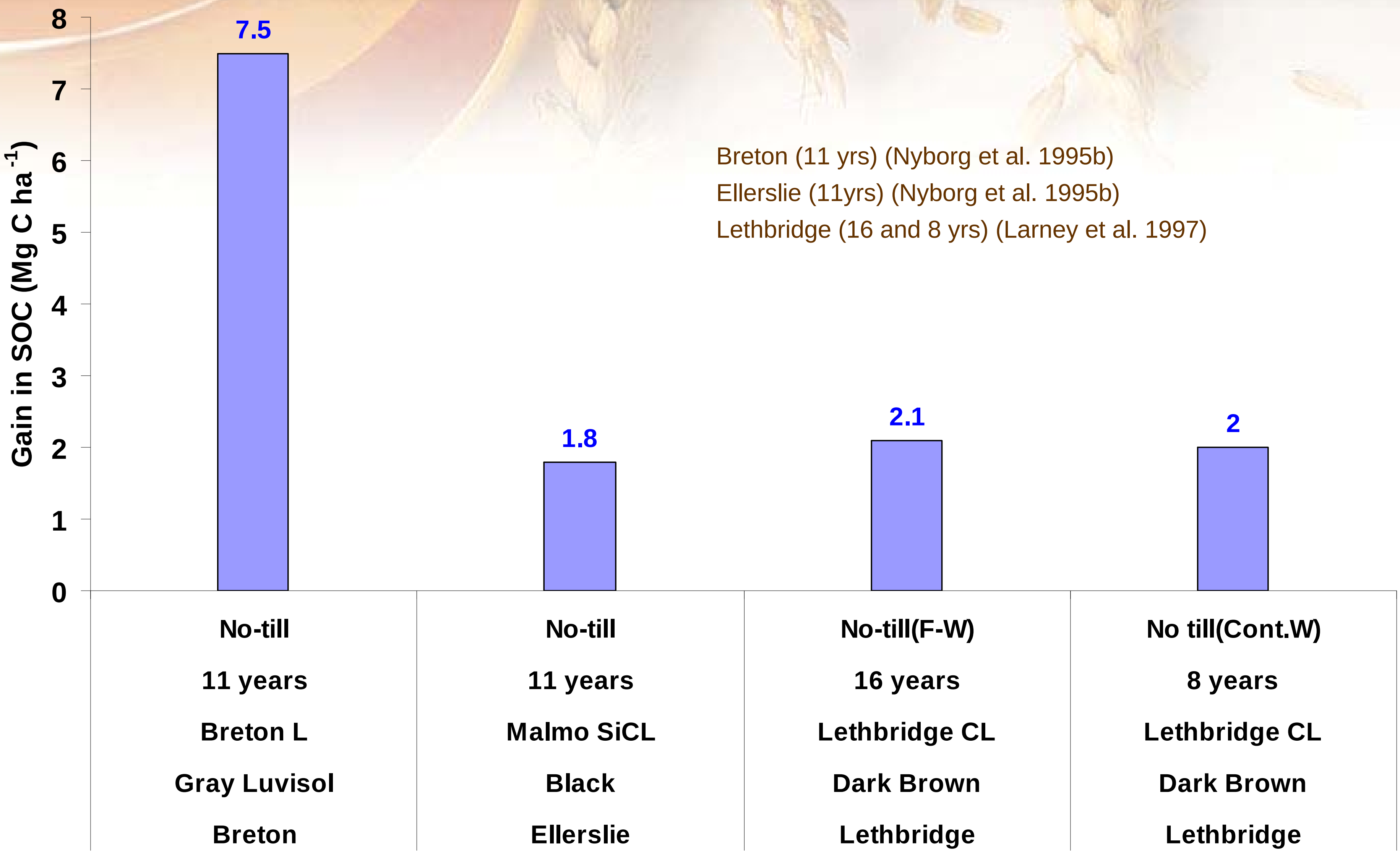
Retained vs. Burnt - Soil Depth (0-15 cm)



Increase in soil organic C (SOC) and light fraction organic C (LFOC) due to adoption of no-till (NT) or minimum (MT) compared to conv. tillage (CT)

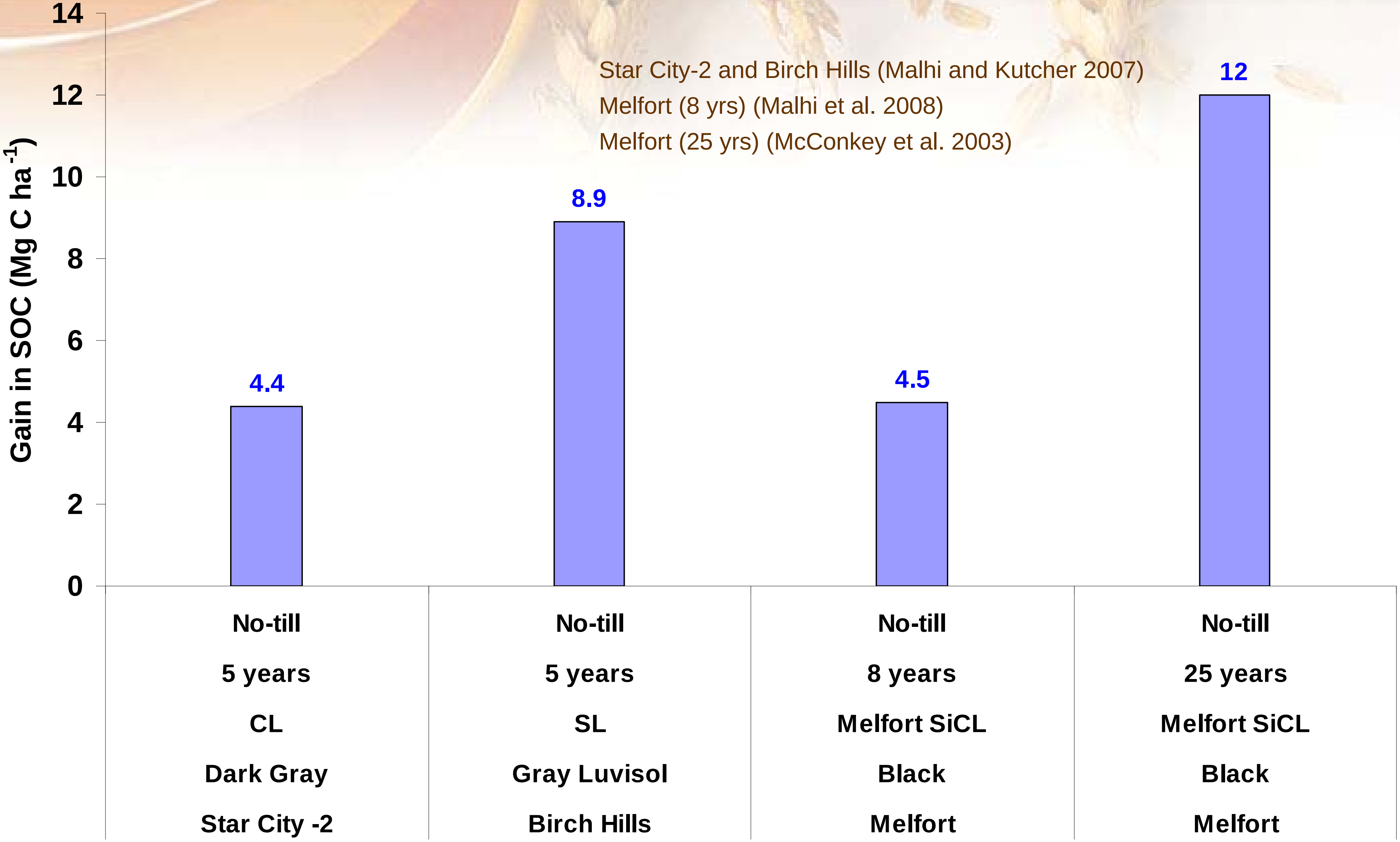
Alberta – Gain in SOC due to NT

Depth = 0-15 cm for all sites except Breton (23 years) is 0-20 cm soil depth



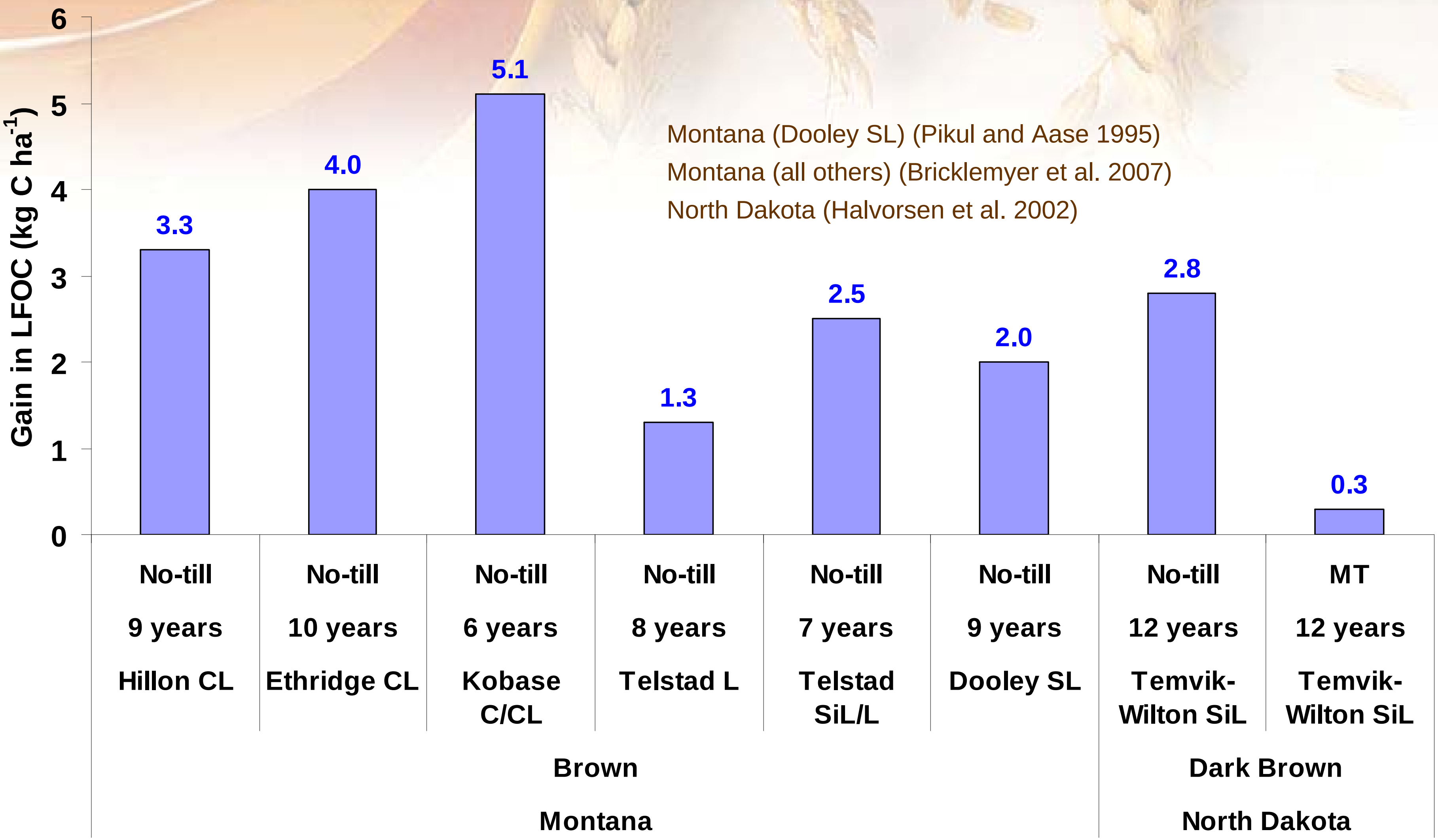
Saskatchewan – Gain in SOC due to NT - Black and Gray soils

0-15 cm soil depth



Montana and North Dakota – Gain in LFOC due to NT or MT

Depth = 0-20 cm for all sites except Montana Dooley SL is (0-9 cm) and North Dakota site is (0-15 cm)



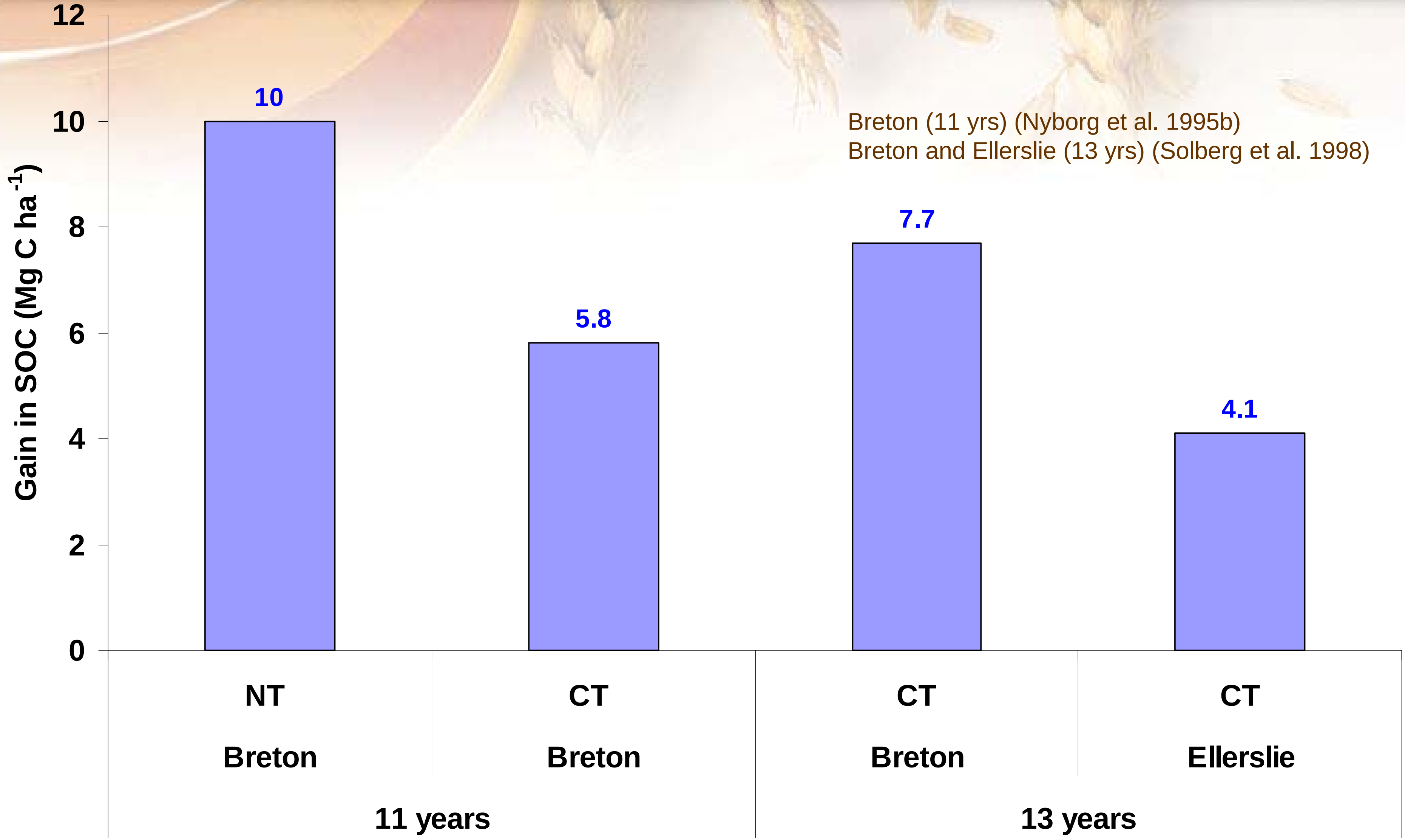
Mass LFOC Gain due to NT

Depth = 0-15 cm

Increase in soil organic C (SOC) and light fraction organic C (LFOC) as affected by fertilizers

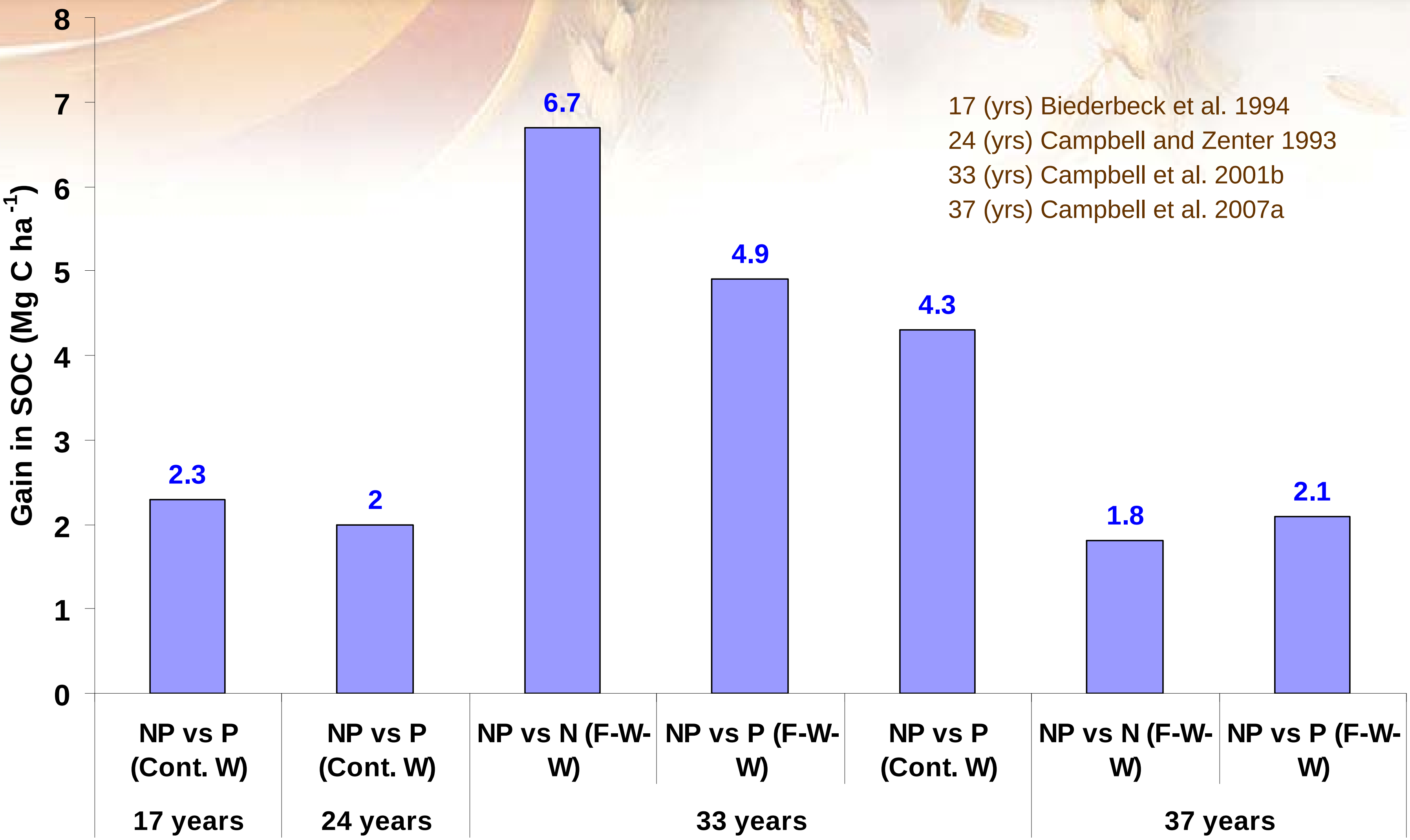
Alberta – Gain in SOC due to N fertilizer in cropland

0-15 cm soil depth except Breton 23 years (0-20 cm) and Breton 13 years (0-30 cm)



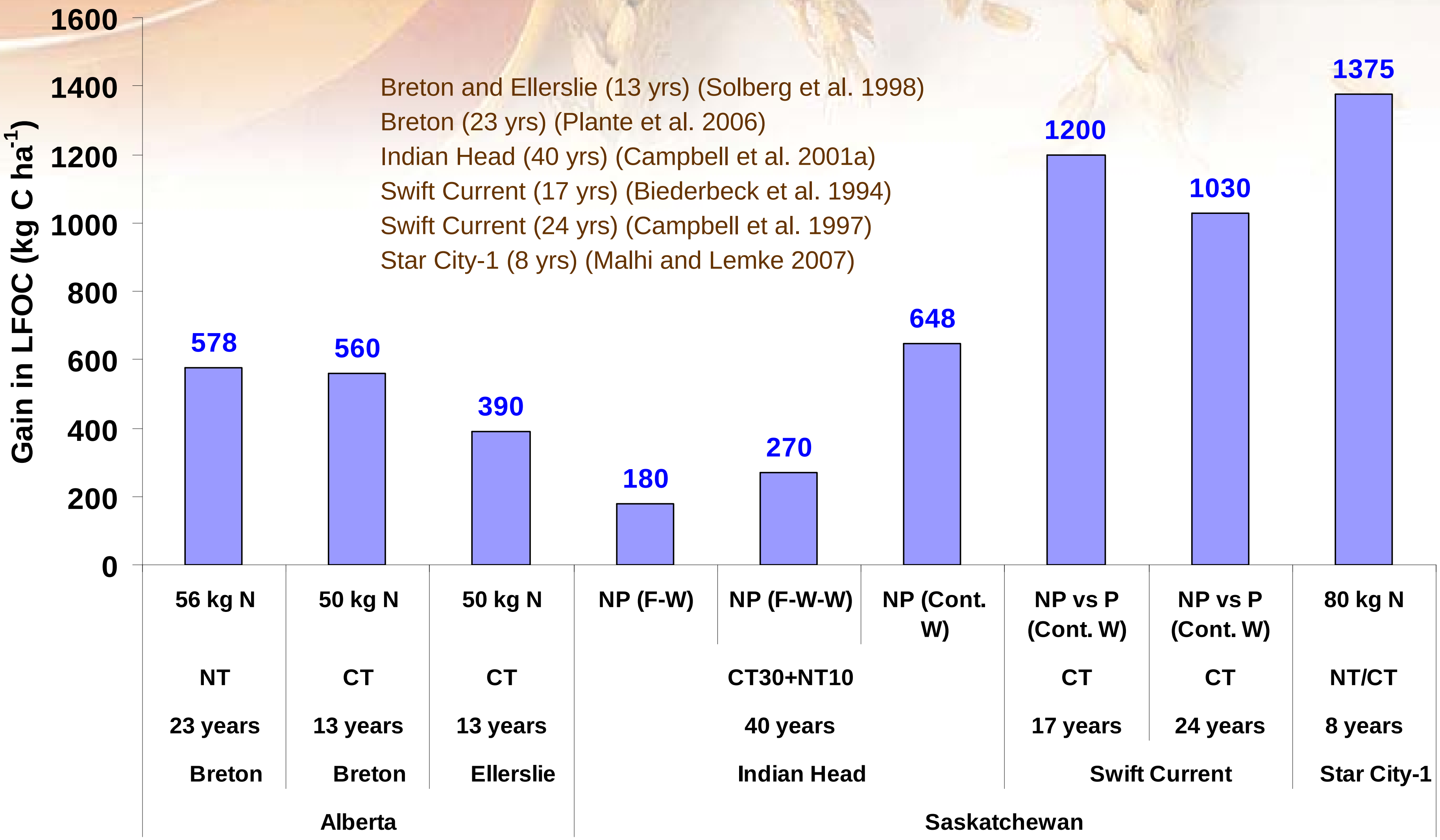
Swift Current – Gain in SOC due to balanced fertilization in cropland

0-15 cm soil depth for Swift Current 17 years (0-7.5 cm) and Swift Current 24 years (0-7.5 cm)

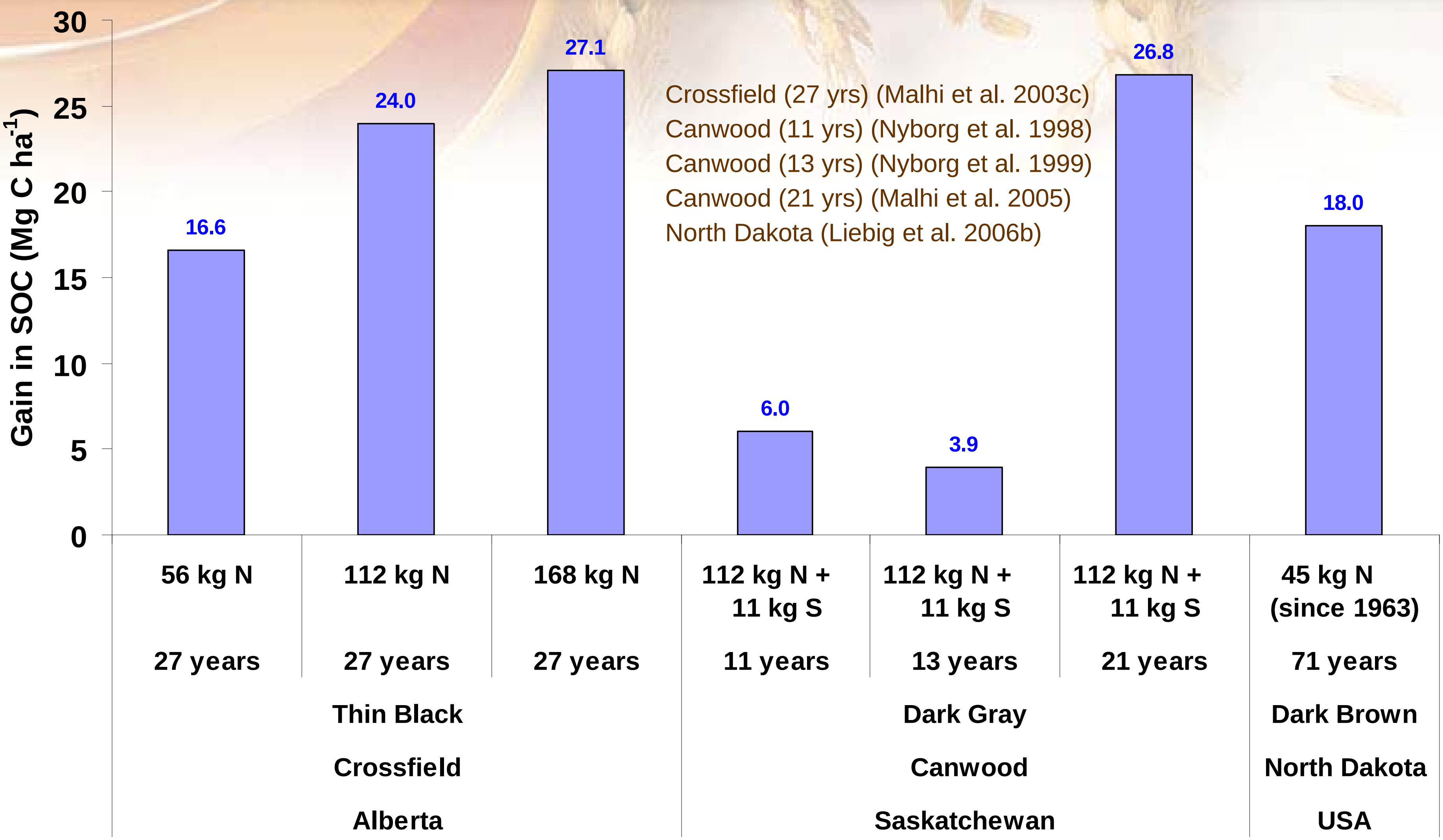


Gain in LFOC due to fertilizers in cropland

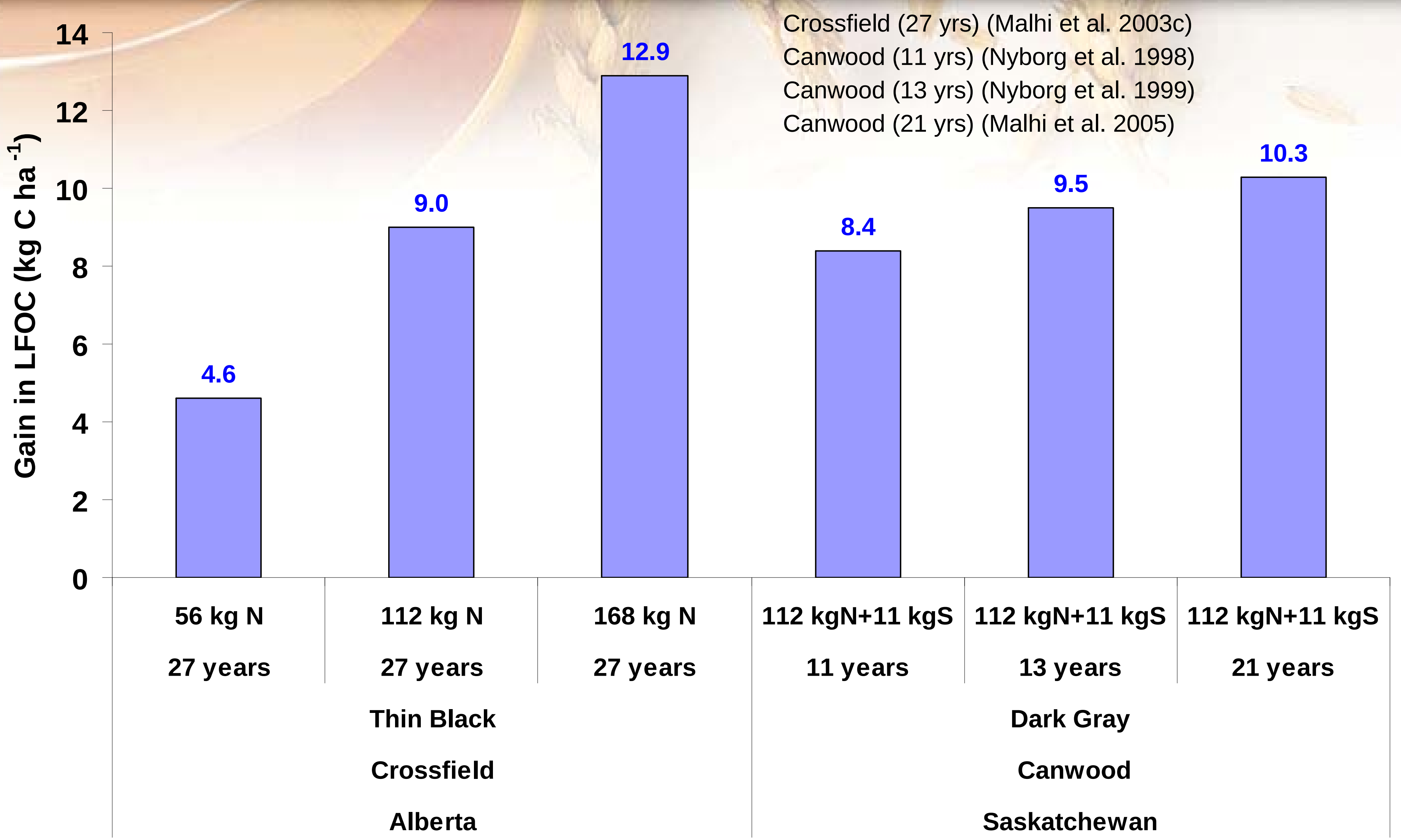
0-15 cm soil depth except Breton 23 years (0-20 cm), Breton 13 years (0-30 cm), Swift Current 17 years (0-7.5 cm) and Swift Current 24 years (0-7.5 cm)



Gain in SOC due to N or balanced fertilization in grassland



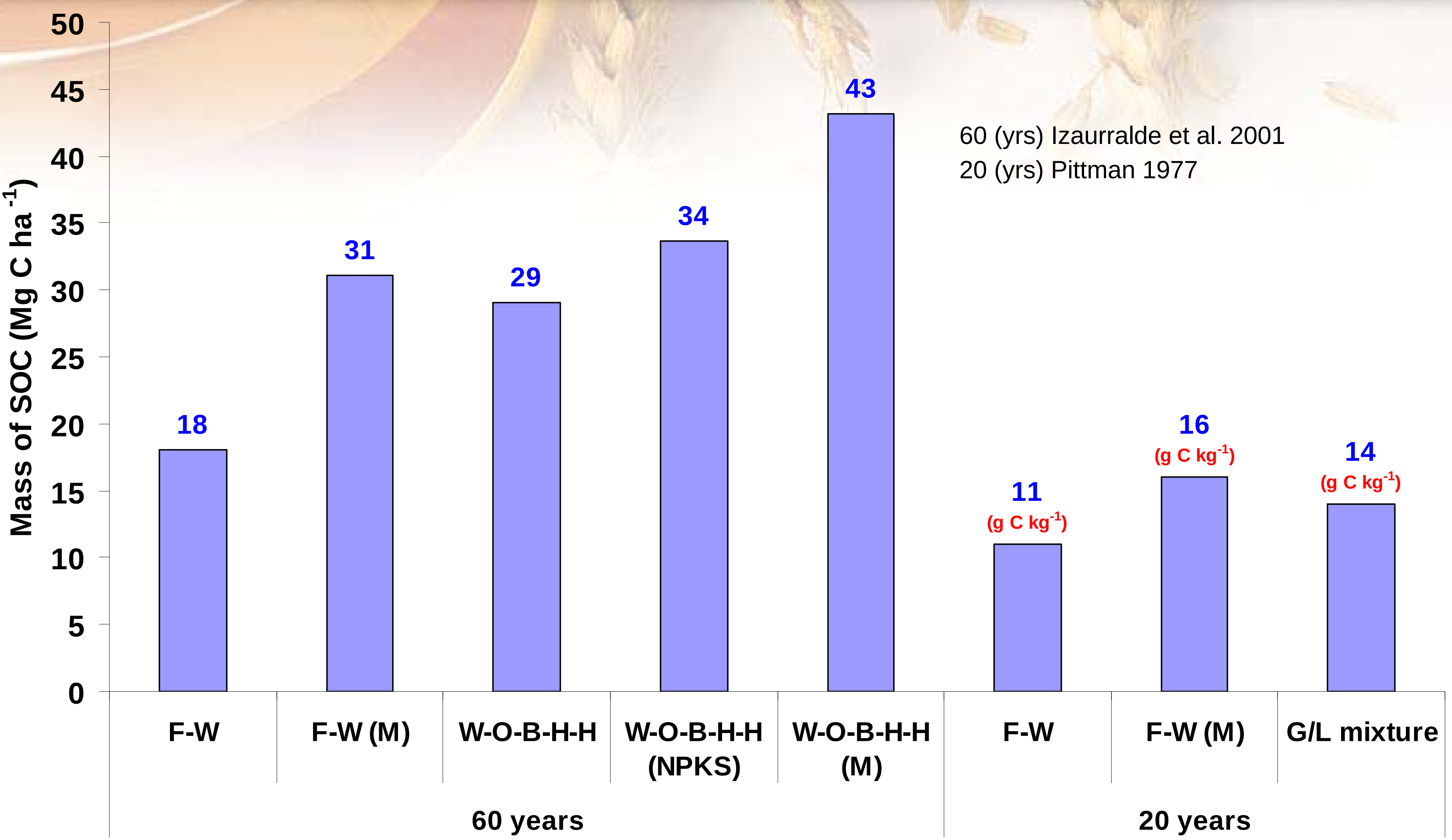
Gain in LFOC due to N or balanced fertilization in grassland



Effect of manure addition on soil organic C (SOC), light fraction organic C (LFOC) and mineralizable C (C_{min})

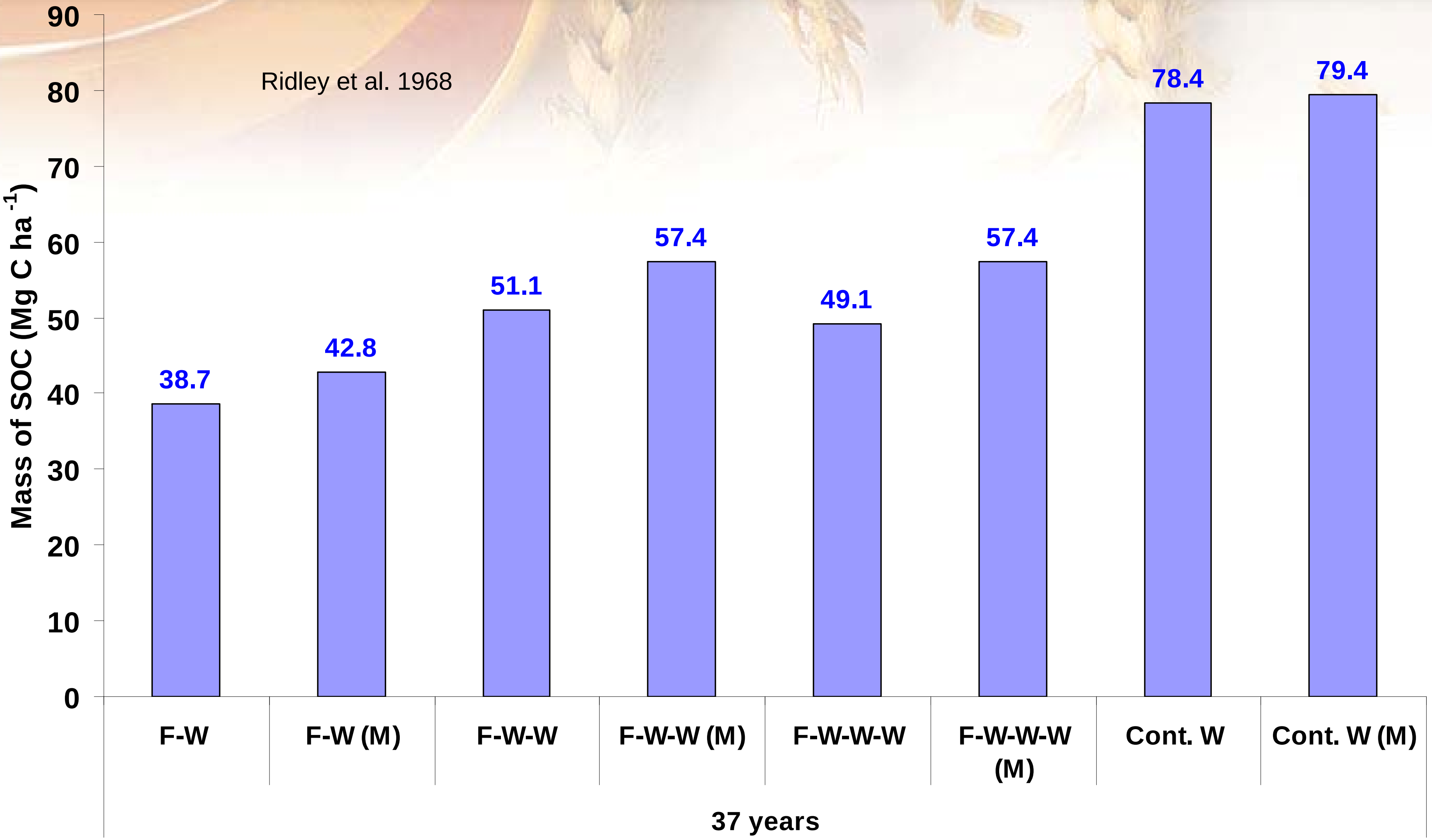
Breton - Concentration or mass of SOC – Manure

Gray Luvisol - Alberta



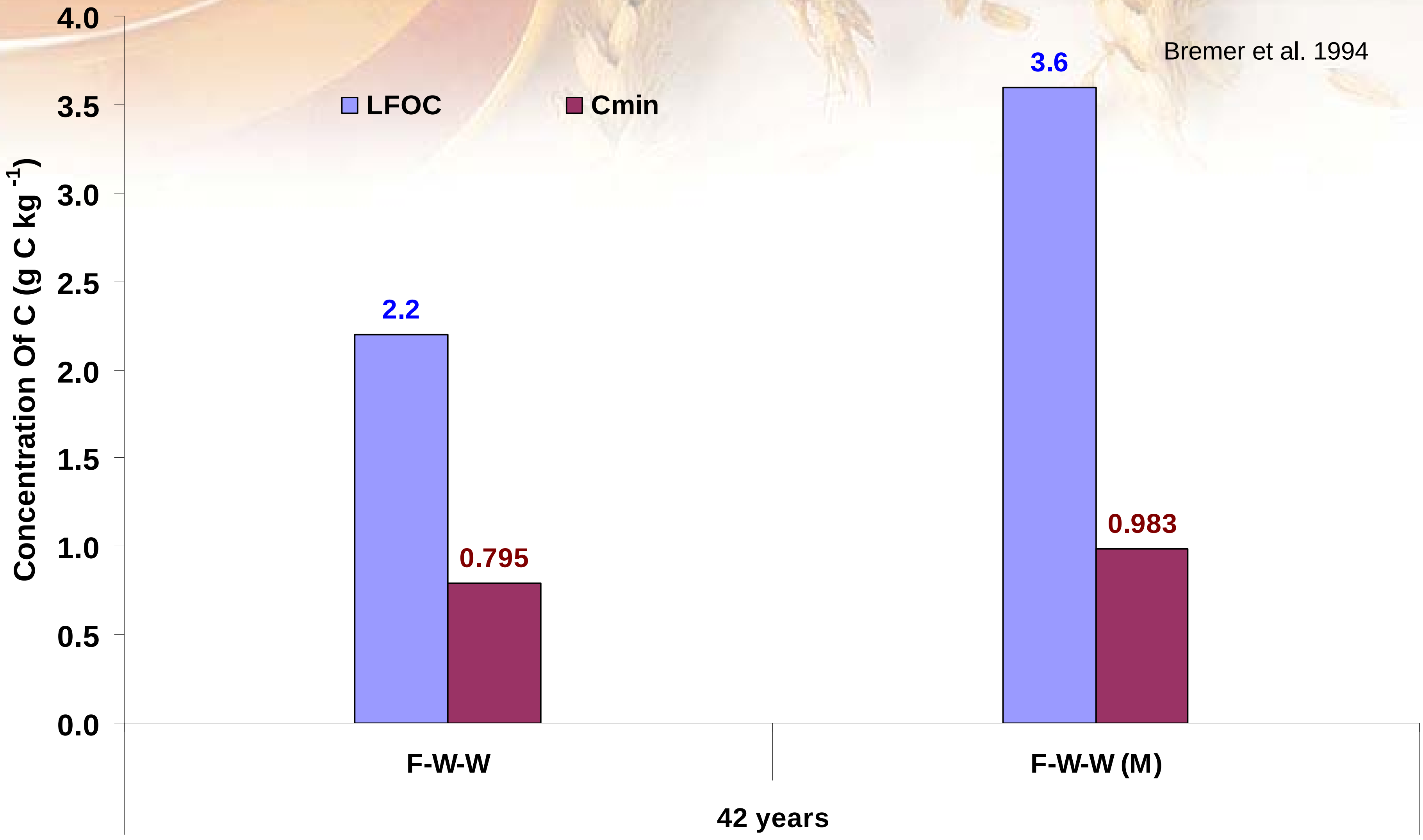
Winnipeg – Mass in SOC – Manure

Black Red River C - Manitoba

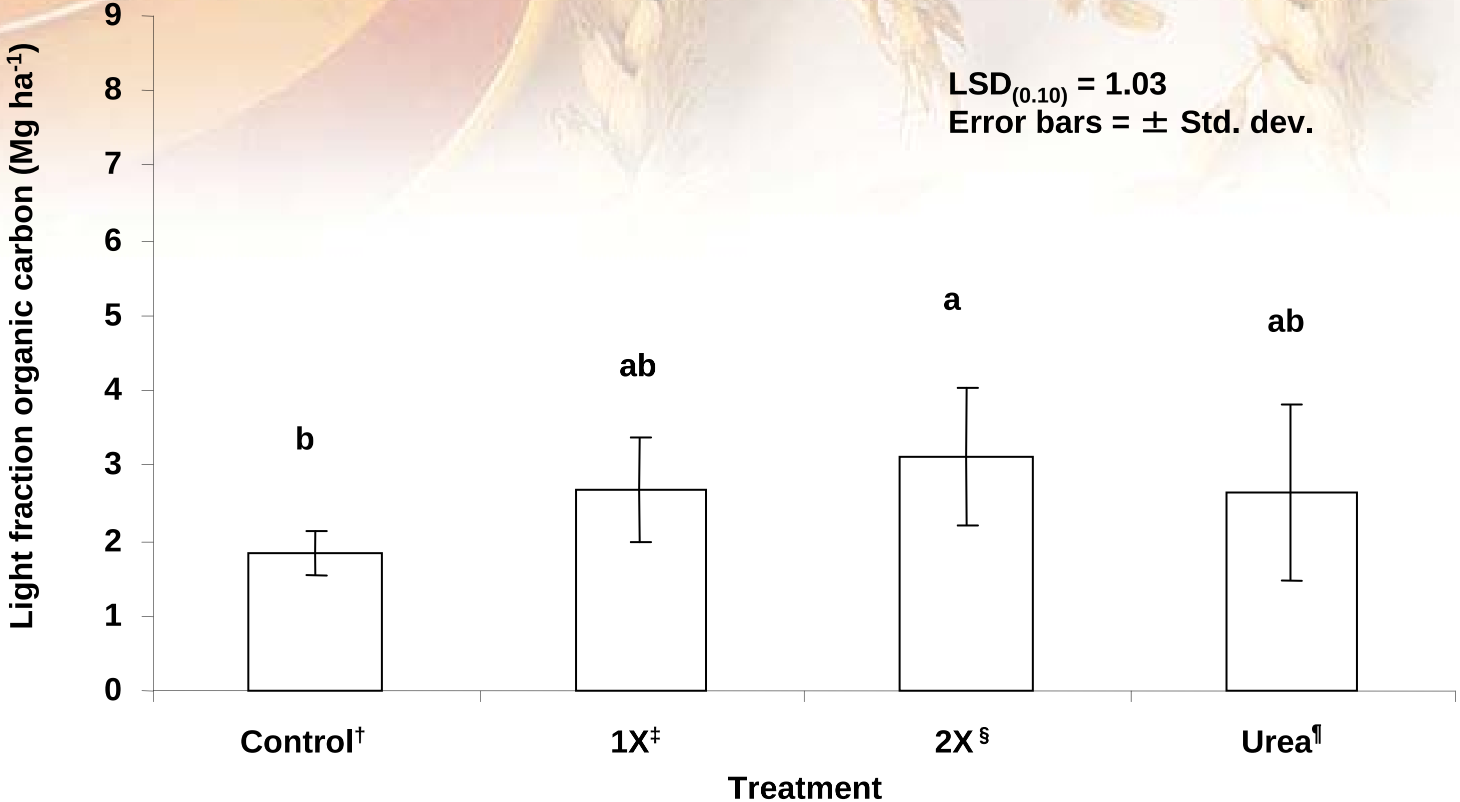


Lethbridge - Concentration in LFOC and C_{min} - Manure

Dark Brown Lethbridge CL - Alberta



Liquid Hog Manure – Saskatchewan, less effect than SCM

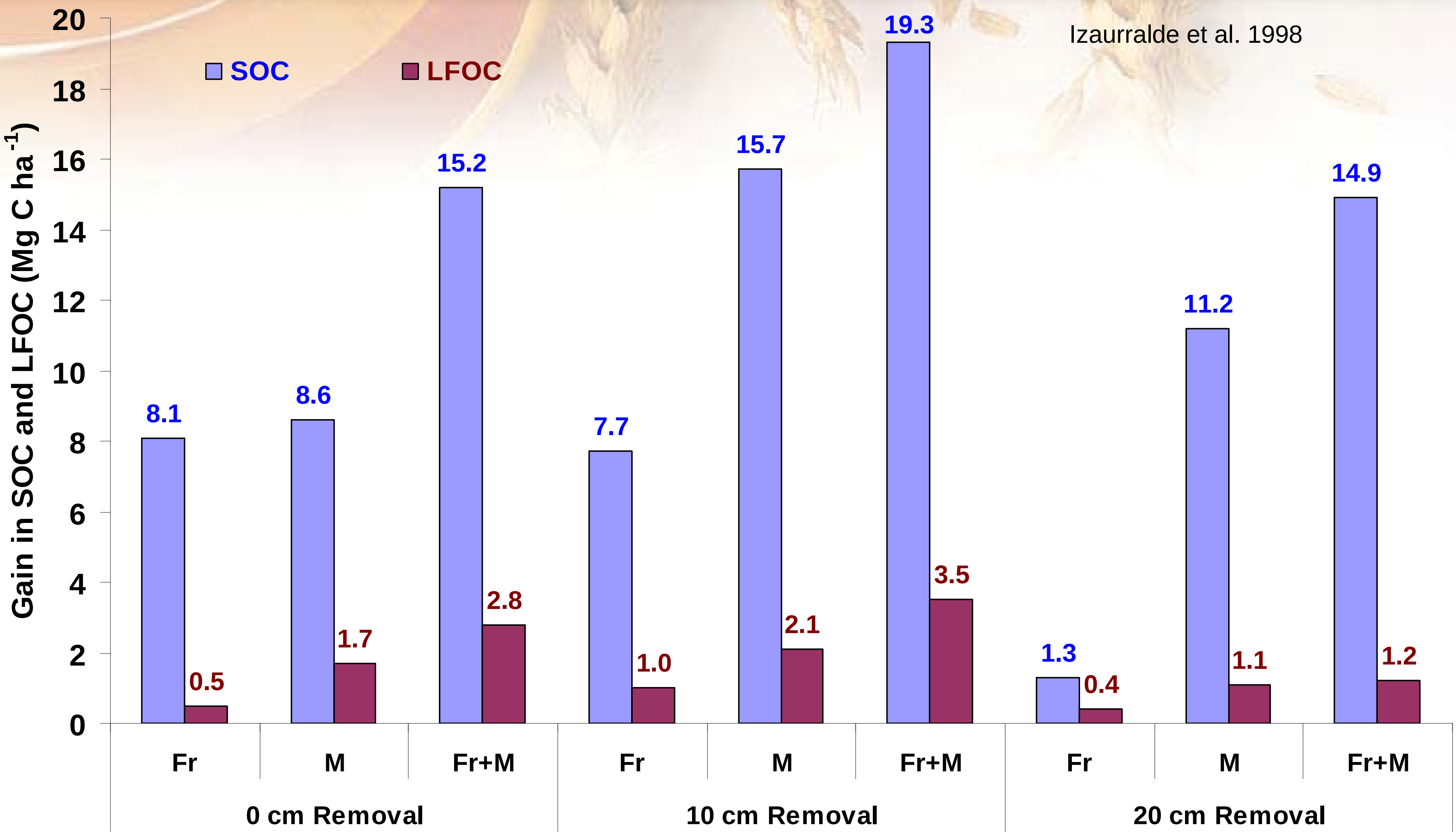


Light fraction organic C in the 0-15 cm soil depth under various liquid swine manure (LSM) and fertilizer treatments at Melfort, Saskatchewan. Bars followed by the same letter are not significantly different at $p \leq 0.10$ (†Control - no LSM or fertilizer applied; ‡LSM applied at 37,000 L ha-1 annually; § LSM applied at 74,000 L ha-1 every second year; ¶Urea applied at 80 kg N ha-1) (adapted from King 2007).

Increase in soil organic C (SOC) and/or light fraction organic C (LFOC) from combined use of fertilizers (Fr) and manure (M) on eroded soils

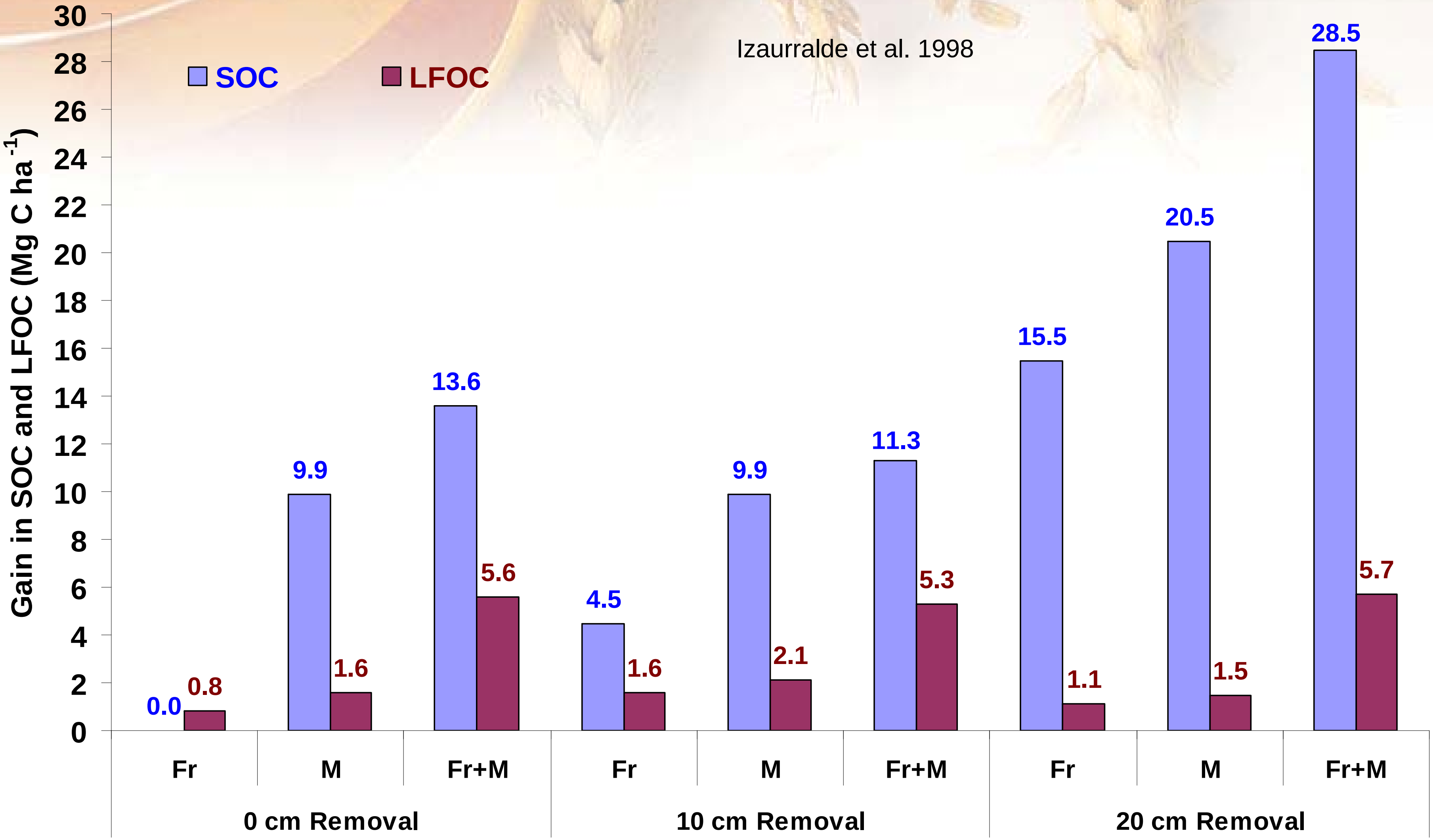
Cooking Lake – Gain in SOC and LFOC – Manure + Fertilizer

Black - Cooking Lake L – - 5 years – (CT); Chemical fertilizers (Fr) and manure (M)



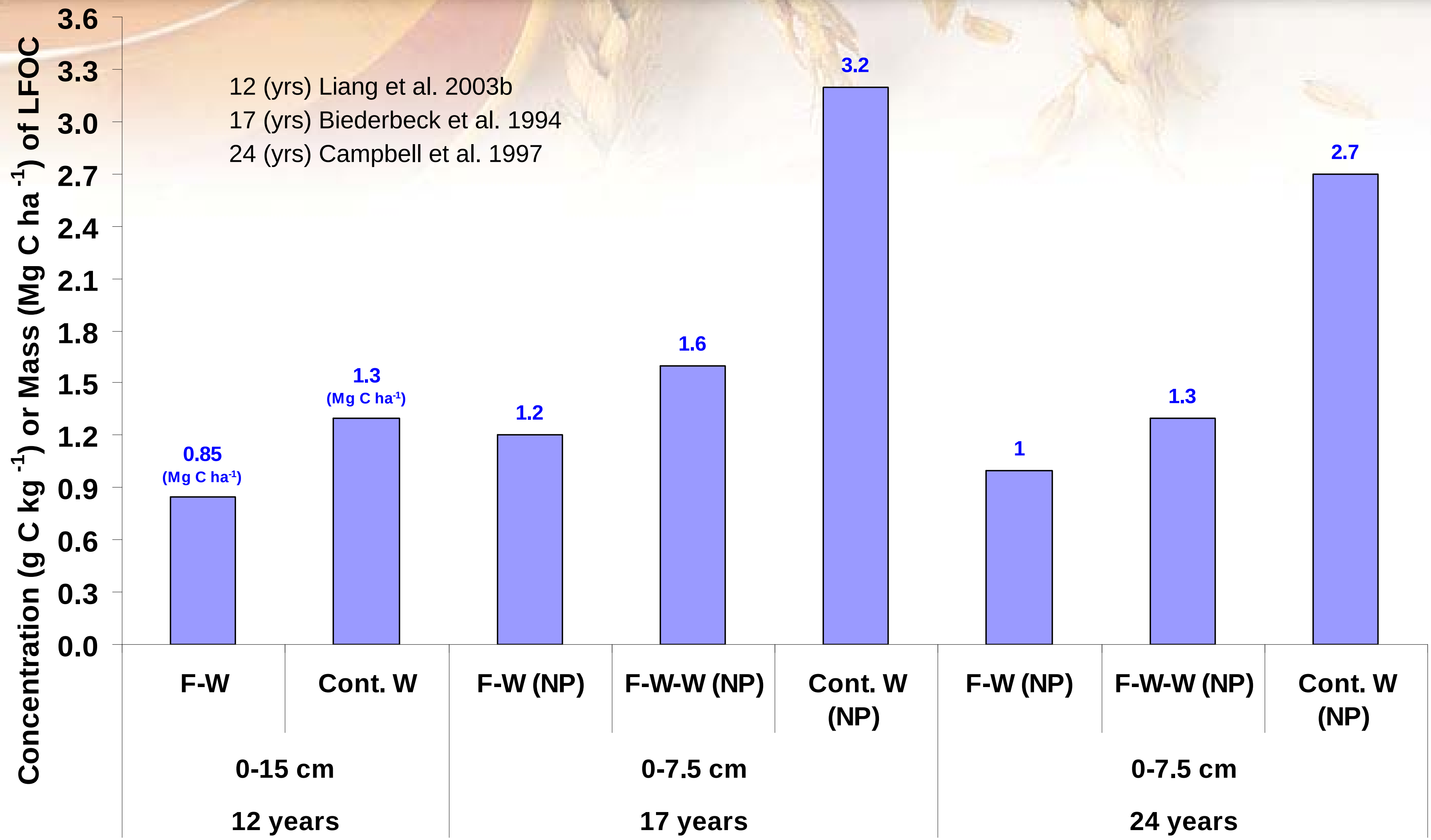
Josephburg – Gain in SOC and LFOC – Manure + Fertilizer

Gray Luvisol - Angus Ridge SiCL - 5 years – (CT); Chemical fertilizer (Fr) and Manure (M)

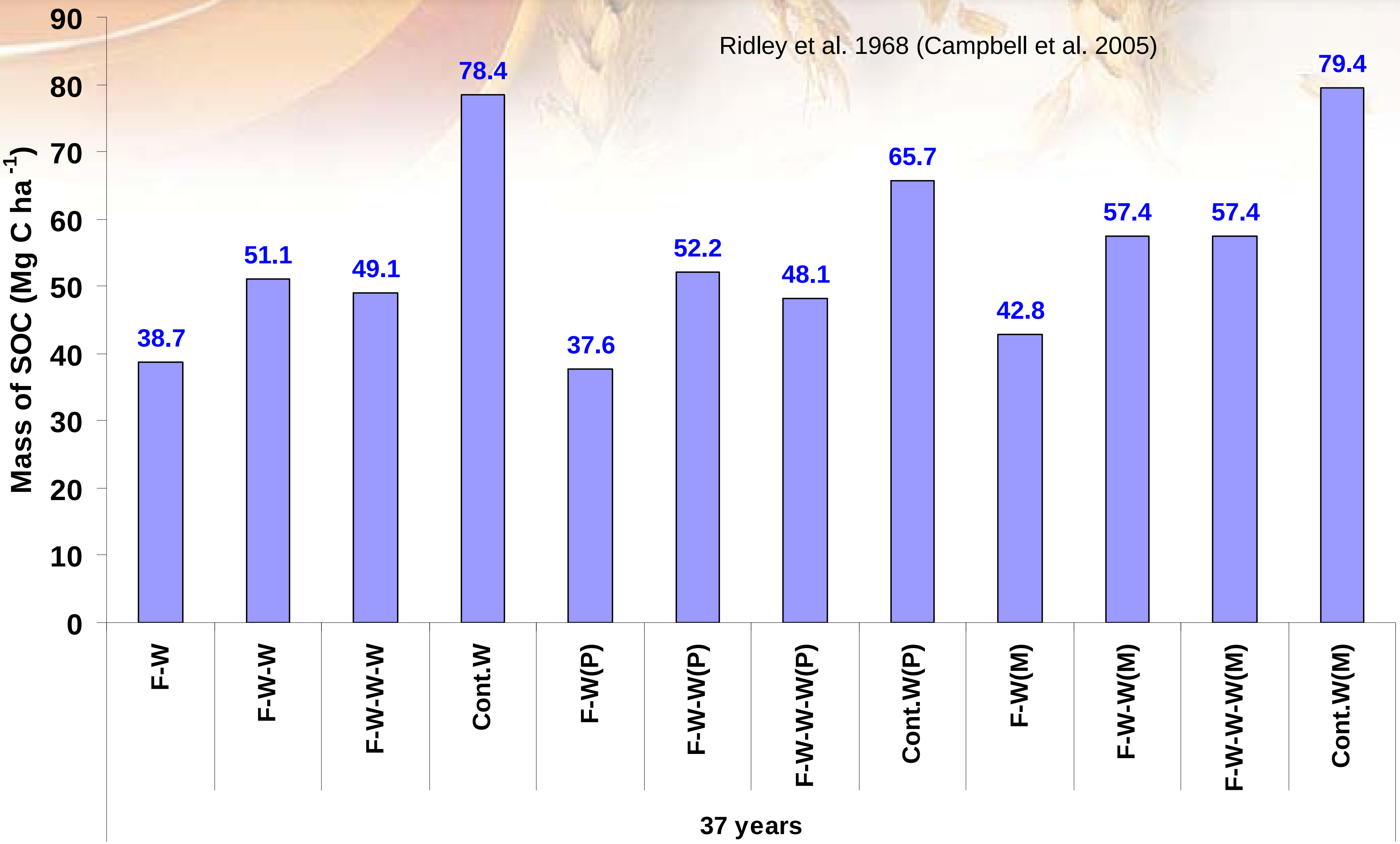


Effect of cropping frequency (CF) or summer fallow frequency (SFF) in a crop rotation on soil organic C (SOC), light fraction organic C (LFOC) and mineralizable C (C_{min})

Swift Current – Concentration or Mass of LFOC - Brown - Switon L and Switon SiL – Summerfallow or cropping frequency



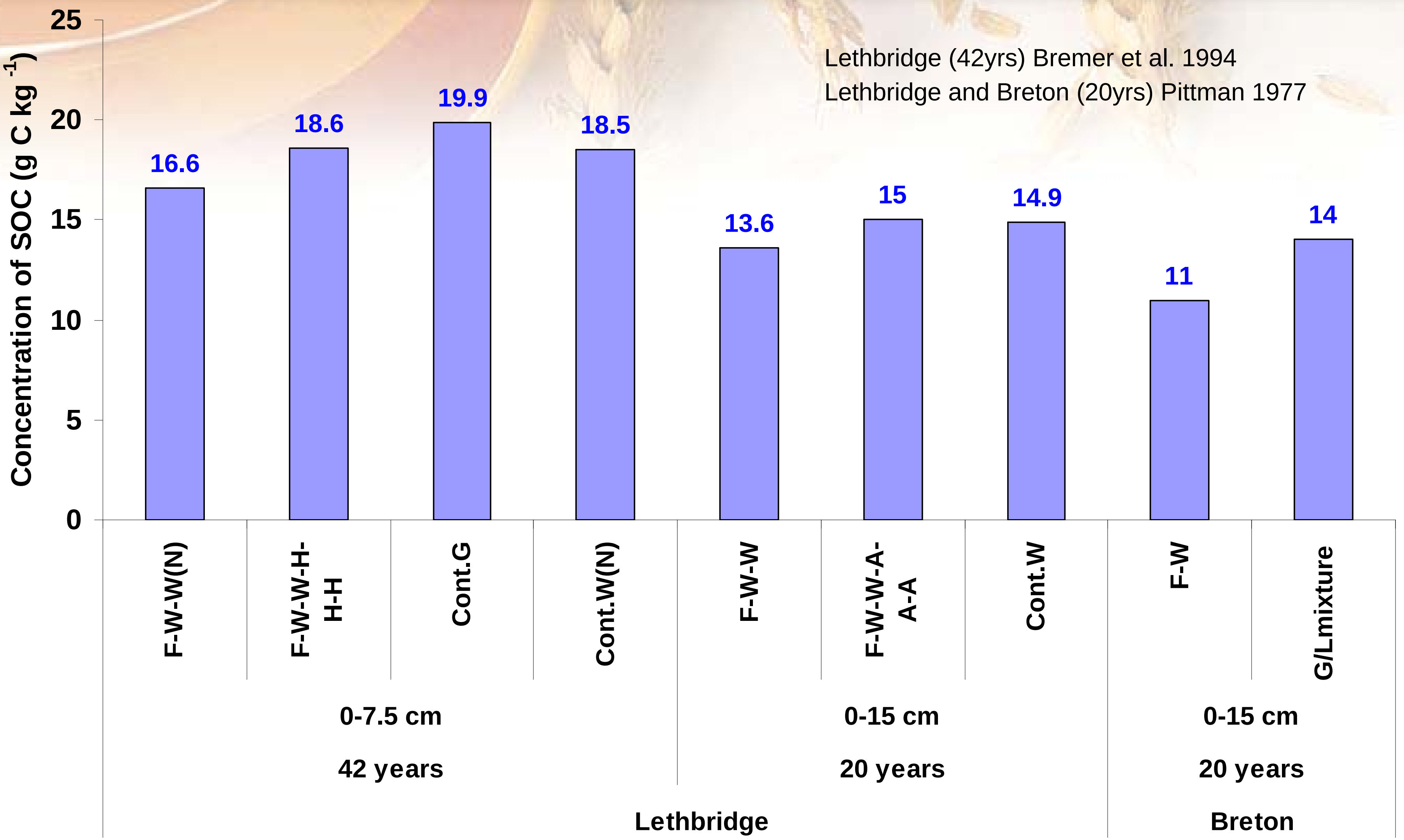
Winnipeg – Mass of SOC – Summer fallow or cropping frequency (Red River C 0-15 (cm) depth)



Effect of crop type (including forages), green manure, and other crop management practices in a crop rotation on soil organic C (SOC), light fraction organic C (LFOC) and mineralizable C (Cmin)

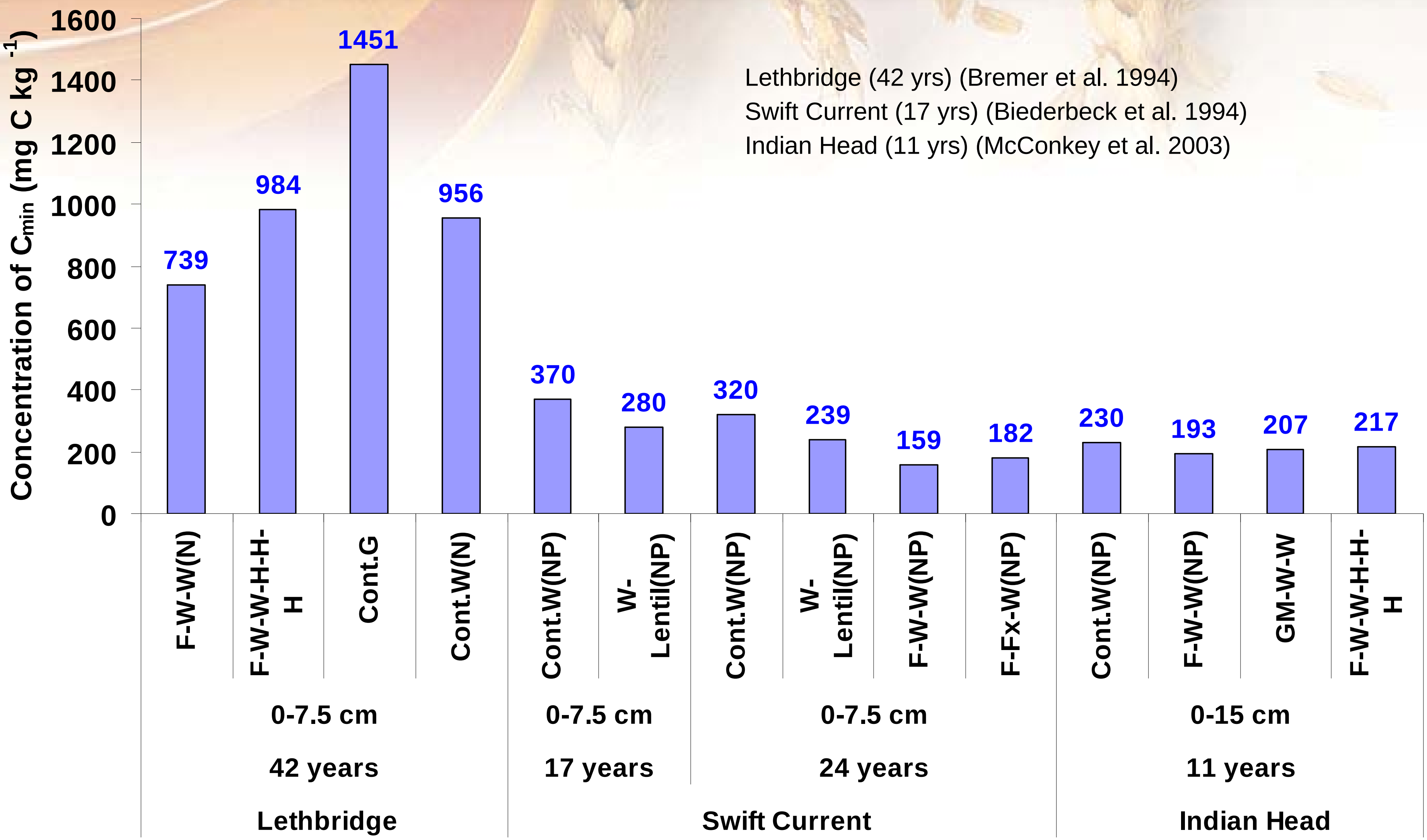
Concentration of SOC – Crop type

Lethbridge - Dark Brown Lethbridge CL;
Breton - Gray Luvisol Breton L



Concentration of SOC – Crop type

Lethbridge Dark Brown Lethbridge CL
Swift Current Brown Swinton L
Indian Head Thin Black Indian Head C

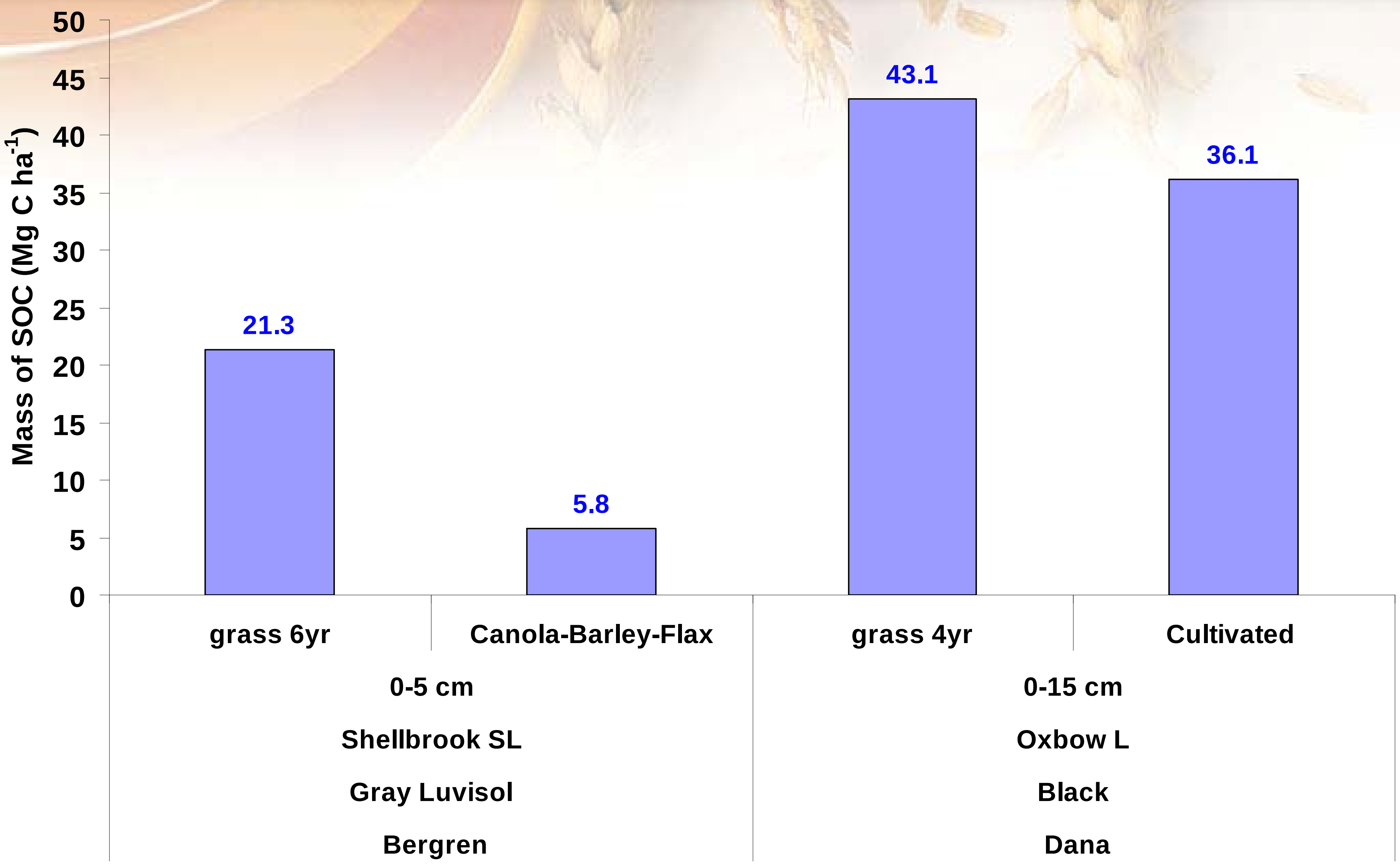


Soil organic C (SOC) and light fraction organic C (LFOC) as affected by land use (conversion to grassland versus cultivated land) at various locations in Saskatchewan, Canada

Saskatchewan - Mass of SOC - Land use effect

Black and Gray sites

Bergren (Mensah et al. 2003)
Dana (Mensah 2000)



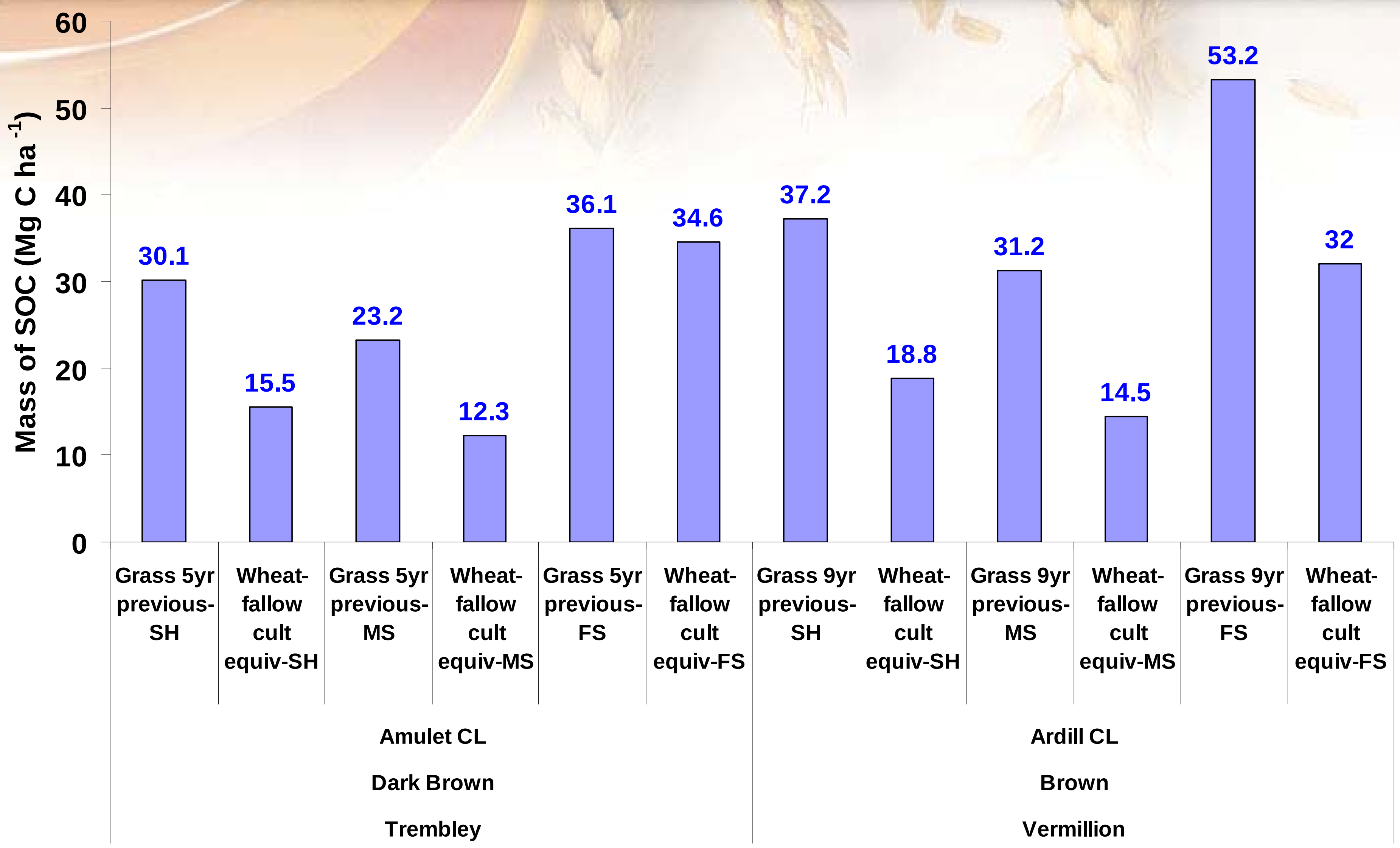
Mass of LFOC - Land use effect
Dark Brown

Soil organic C (SOC) and light fraction organic C (LFOC) as affected by conversion of land use from cultivated land to grassland on different landscape position (SH – shoulder, MS – middle slope, and FS – foot slope) at various locations in Saskatchewan, Canada

Mass SOC – Conversion to grassland

Tremblay and Vermillion

Nelson et al. 2002



Summary of Findings

- Retaining straw added an additional 1.068 Mg C ha^{-1} yr^{-1} or 0.400 g C kg^{-1} soil yr^{-1} over straw burning and up to 0.695 Mg C ha^{-1} yr^{-1} or 0.405 g C kg^{-1} soil yr^{-1} compared to straw removal practices.

- Annual application of N, P, or other nutrients increased C sequestration by 0.906 Mg C ha^{-1} yr^{-1} at 56 kg N ha^{-1} under NT and by 1.620 Mg C ha^{-1} yr^{-1} at 150 kg N ha^{-1} under CT.

- On a perennial grassland for hay production where soil was deficient in both N and sulfur (S), annual application of S fertilizer in a combination with N was required to store additional soil organic C (SOC - by up to 1.275 Mg C ha^{-1} yr^{-1} with 120 kg N plus 11 kg S ha^{-1} yr^{-1}), demonstrating the importance of balanced fertilization.

Summary Of Findings (Continued)

- Compared to fertilized cropping systems, the addition of manure had greater improvement in SOC, which was maintained at a higher level in the long-term (e.g., 33.7 Mg C ha^{-1} for NPKS fertilized vs. 43.2 Mg C ha^{-1} for manure after 60 yr).

- Integrated or combined use of manure and fertilizers resulted in much higher SOC (3.888 Mg C ha^{-1} yr^{-1}) compared to the application of manure (3.140 Mg C ha^{-1} yr^{-1}) or fertilizers alone (1.534 Mg C ha^{-1} yr^{-1}); this effect was particularly notable in eroded soils.

- The adoption of continuous annual cropping systems, or mixed crop rotations of annual grain and perennial forage crops, usually resulted in higher SOC than crop rotations with summer fallow.

Summary of Findings (Continued)

- Compared to total organic matter in soil, young or labile fractions (i.e., light fraction organic C [LFOC] or light fraction organic N [LFON]) were much more responsive to changes in management practices.
- The conversion of annually cultivated lands to perennial grassland resulted in substantial increases in SOC when compared to cultivated soils.
- The gains and losses in SOC due to changes in management practices will not occur indefinitely.
- The economic and energy input costs of C sequestration in agroecosystems, along with the negative impacts, if any, of C sequestration on total greenhouse gas (i.e., CO_2, N_2O and CH_4) emissions should be considered in the calculation of net C change.

Conclusions

- Storage of organic C and N can be increased in cultivated soils by implementing proper soil (elimination of tillage and minimizing summer fallow frequency), crop residue (returning residue), nutrient management (balanced fertilization, and combined use of organic amendments and mineral fertilizers) and land use (conversion of marginal cultivated lands to perennial grassland) practices that prevent loss of C from soil and/or increase C input.
- The findings suggest that reduction of summerfallow frequrncy and adoption of no-till may be the most effective techniques/practices to increase storage of C and N in soil, as long as crop residues are returned to soil and nutrient deficiencies in crops are properly prevented.
- The findings also suggest that these soils can be used as a short-term CO_2 sink.
- Furthermore, it would appear C and N storage in soil provides the accompanying benefits of more sustainable crop production (due to an improvement in soil quality and nutrient supplying power), and reducing the potential for greenhouse gas emissions.

Research Gaps and Future Needs

- Quantitative research information is needed on the actual contribution of erosion in the loss of C from cultivated fields, especially during summer fallow.
- There is also a need for research related to various mechanisms of organic C decline in soil, as it is important to distinguish the fate of C lost through various methods (erosion, CO_2, leaching). For example, biologically oxidized C is presumed to be emitted to the atmosphere, while eroded C may be buried deep in soil where further decomposition and turnover of C can be much slower.
- Because young/dynamic fractions in organic matter are much more sensitive to management practices, soil samples should also be analyzed for LFOC, LFON, C_{min}, N_{min} and microbial biomass C.

Research Gaps and Future Needs

- Future research is needed on the fate of sequestered C in soil over the long term after the management practices are altered. Research information is also needed regarding the mechanisms involved in the sequestration of C into more stable organic C pools.
- There is little research information on the contribution of roots and stubble in increasing the storage of organic C in soil, and future research should concentrate on the contribution of roots and stubble in increasing SOC storage.
- This is also suggested that existing long-term experiments must be continued, and more new long-term experiments should be established, as long-term experiments provide vital information to evaluate management effects on OM, validate models to predict OM dynamics, and calculate C sequestration efficiency.

Research Gaps and Future Needs

- Few studies have reported the C sequestration efficiency (defined as: Mass of C sequestered in soil/Mass of C input to soil x 100) of management practices.
- There has been no report on the economic benefits (Net $ returns = Added $ returns from increased crop yield due to C – Additional input costs of C sequestration) from sequestered C in soil.
- Future reports/research should include calculations of C sequestration efficiency (Mass of C sequestered in soil/Mass of C input to soil x 100)) and economic benefits/return ratio (Net $ returns = Added $ returns from increased crop yield due to C – Additional input costs of C sequestration) for various C enhancing management practices under various cropping systems.
- Because the majority of C is sequestered in the surface soil layers, soil samples are rarely collected below 30 cm. Future C sequestration studies should also address changes in organic C below 30 cm, especially in cropping systems that include perennial forages in the rotation.

Acknowlegements

- The authors would like to thank Darwin Leach for preparing the colored slides.