Effects of Crop Rotation and Fertilization on Soil Carbon Sequestration in the Semiarid Region

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INTRODUCTION

- Quantifying changes in soil C is of considerable interest to society because it is a source and a sink for CO2 , a major "greenhouse gas" which allegedly contributes to global warming.
- Soil organic C is readily influenced by crop management practices such as tillage, fertilization, crop rotations and frequent fallowing.
- Annual changes in soil C are very small but variability of measured values can be quite large, thus accurate assessment of trends is difficult and best determined after repeated samplings over many years.
- However, use of reliable simulation models to estimate C trends may provide answers in a shorter time frame.

OBJECTIVE

To develop and test a simple empirical model for its ability to estimate trends in soil C change under various long-term crop rotations in an Orthic Brown Chernozemic loam at Swift Current, Saskatchewan.

MATERIALS AND METHODS

- Twelve crop rotations (Table 1) were established in 1967 on 81, 0.04 ha plots in a randomized complete block design with 3 reps.
- Soil was sampled (0-15 cm depth) in 1976, 1981, 1984, 1990, 1990, 1993, 1996 and 1999.
- Carbon content was determined by dry combustion.
- Bulk density was measured only in 1967 and this used to calculate C mass.

Table 1. Crop rotations and amount of fertilizer applied to treatments (1967-1999)

Rotation No.	Rotation	Fertilizer criteria	Rotation phase cropped	Average N and P applied (kg ha^{-1} yr^{-1})[y]	
				N	P
11	F-(W)[z]	N and P applied	Fallow	13.6	9.6
2	F-W-(W)	N and P applied	Fallow Stubble	13.6 33.9	9.6 9.6
1	F-W-(W)	P applied but no N applied except that in P fertilizer	Fallow Stubble	4.8 6.4	9.6 9.6
5	F-W-W	N applied, no P applied	Fallow Stubble	10.7 23.7	0 0
3	F-Flx-(W)	N and P applied	Fallow Stubble	7.2 29.5	7.9 9.6
13	F-W-W-W-W-W[x]	N and P applied	Fallow Stubble	18.2 31.0	9.4 9.4
8	Cont (W)	N and P applied	Stubble	35.8	9.6
9	Cont (W)[w]	(fallow if less than 60 cm moist soil exists at seeding time: N and P applied)	Stubble	27.6	9.6
10	Cont (W)[w]	(fallow if grassy weeds become a problem: N and P applied)	Stubble	27.3	9.6
19	(W)-Lent[w]	N and P applied	Lentil Wheat	16.5 29.6	9.6 9.6
12	Cont (W)[u]	P applied but no N applied except that in P fertilizer	Stubble	7.9	9.6

[z] Selected plots, indicated in parentheses, were sampled for straw weight at harvest. F=fallow; W=spring wheat; Flx=flax; Lent=grain lentil; Cont=continuous cropping.

[y] Nitrogen and P were applied based on the prescribed treatment. The N was based on soil NO_3 tests, while the P fertilizer was applied to each crop based on the general recommendations of the soil testing laboratory, University of Saskatchewan.

[x] This rotation was established in 1985 from Oat hay-Wheat-Wheat and Flax-Wheat-Wheat rotations that received N and P fertilizers at average rates of 27.9 and 9.3 kg ha^{-1}, respectively. Fertilizer rates are for the 1985-1999 period.

[w] During the first 12 yr, the criteria necessary for summerfallowing in these two rotations were met on several occasions but the action was not implemented; fertilizer rates are for the 1967-1978 period. In 1979, these two rotations were changed to the spring wheat-lentil rotation with N and P applied (i.e. rot. 19); fertilizer rates are for the 1979-1999 period. IN 1990 and 1991 the lentil was erroneously not fertilized with N and P.

[u] In 1980 and 1982, N was inadvertently applied to this system at rates of 70 and 40 kg N ha^{-1}, respectively.

Quantifying Soil and Residue C Decomposition

- Disregarding erosion, net changes in soil C are a function of increases due to residue inputs and decreases due to humus decomposition.
- Quantitatively this can be represented as:

Soil Decomposition

$$SOC_t = C_0(q_1 e^{-k_1 t} + q_2 e^{-k_2 t}) +$$

$$\uparrow \qquad \uparrow$$

Active slow decomposition

$$\downarrow \qquad \downarrow$$

$$\sum_{n=0}^{t}\left[A_n\left(p_1 e^{-r_1(t-n)} + p_2 e^{-r_2(t-n)}\right)\right]$$

Residue decomposition

Where:

SOC_t = amount of C/mass remaining in soil after t years
(NB. ‘t’ is measured to just before residue addition)
C_0 = amount C/mass in soil initially at t=0
q = a proportion of soil C in this soil q_1=0.20, q_2=0.80
k = annual rate of soil C decomposition
A_n = amount of plant residue C added in year n
p = proportion of residue C (NB. $P_1 + P_2 = 1$)
r = annual rate of residue decomposition
Subscript 1 and 2 = differing susceptibility to decomposition with 1 = active pool and 2 = slower pool.

- Values for the active soil organic C pool (q_1 and k_1) and the passive pool (q_2 and k_2) can be obtained from the scientific literature.
- For our soils, we assumed LF plus biomass C (i.e., 20% of total C) was active the C fraction (q_1); thus q_2=80%
- We assumed 1/mrt of humin + humic acids of Chernozems (i.e., 0.00066 yr^{-1}) was k_2
- We estimated k_1 iteratively by matching equation 1 to average measured C trends (a) for fallow systems; (b) for continuous cropping
  k_1 = 0.02 yr^{-1} for F-W;
  = 0.01 yr^{-1} for F-W-W;
  = 0.001 yr^{-1} for Cont W

RESULTS AND DISCUSSION

- We estimated trends in SOC using our two-component equation.
- For example, we show the relative impact of each component of the equation for fallow-wheat and the wheat-lentil rotation (Fig. 1a and 1b).

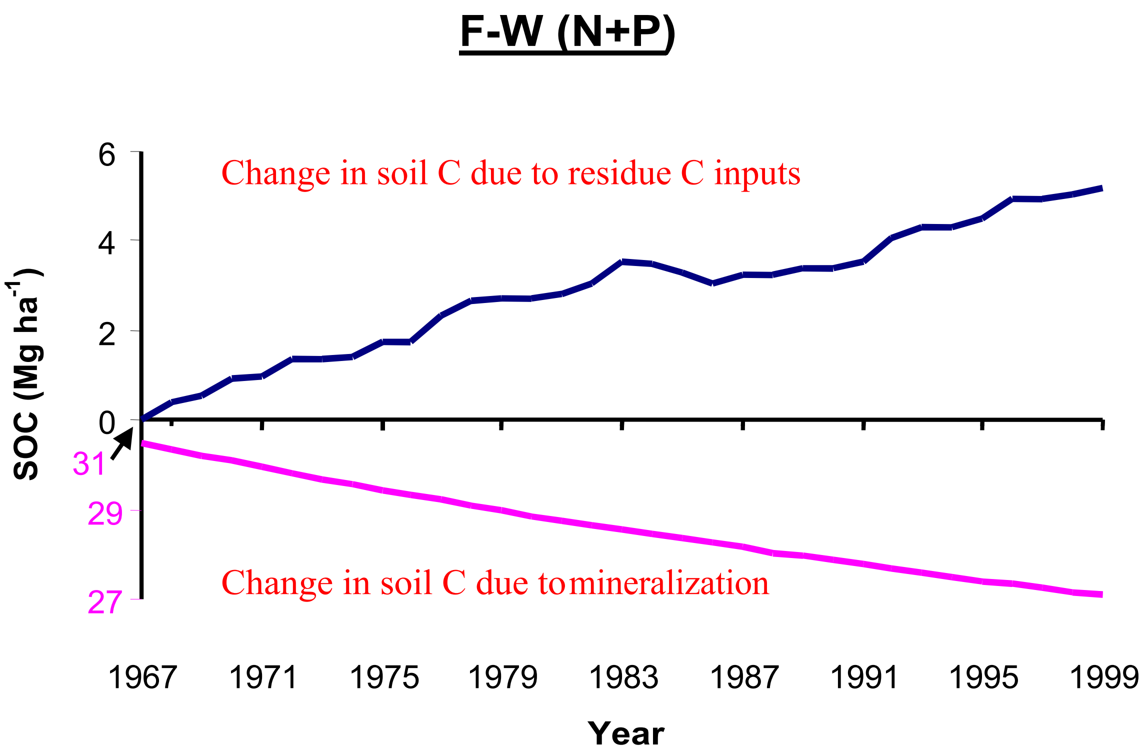


Fig. 1a

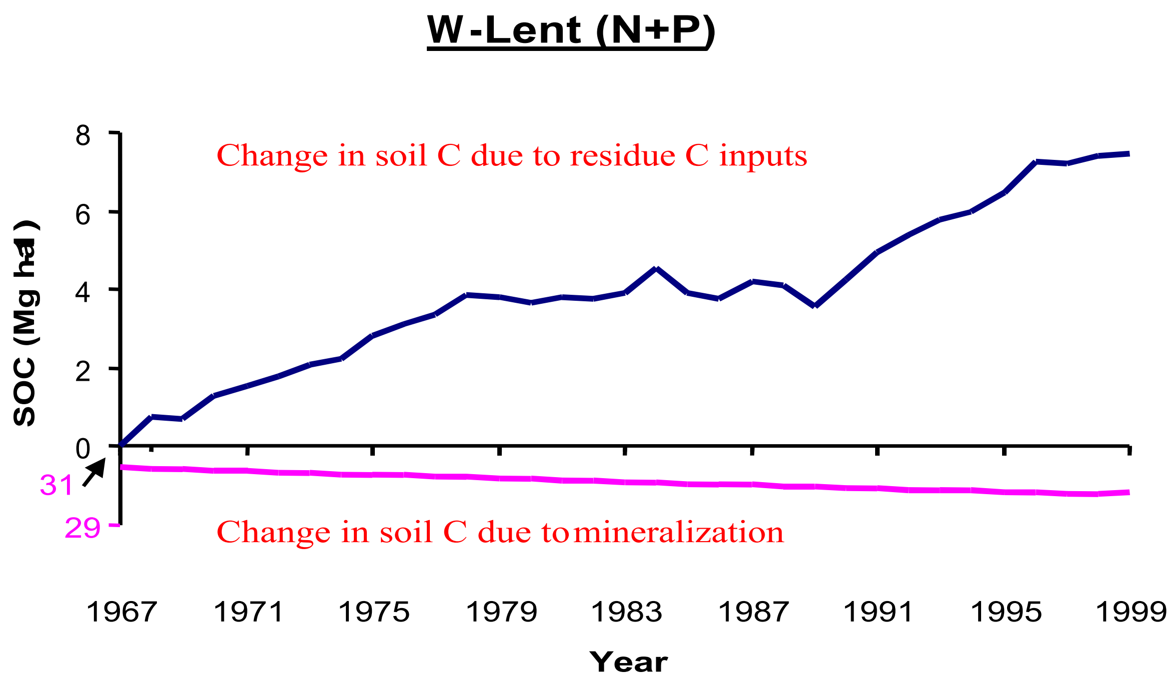


Fig. 1b

- In Fig. 2 we show the net C trends (0-15 cm depth) as estimated from equation 1, and the measured soil organic C on the sampling dates, together with standard errors (Sx) (Note: C lost by erosion was estimated with EPIC model and this added to the measured C because our model does not account for this type of loss).

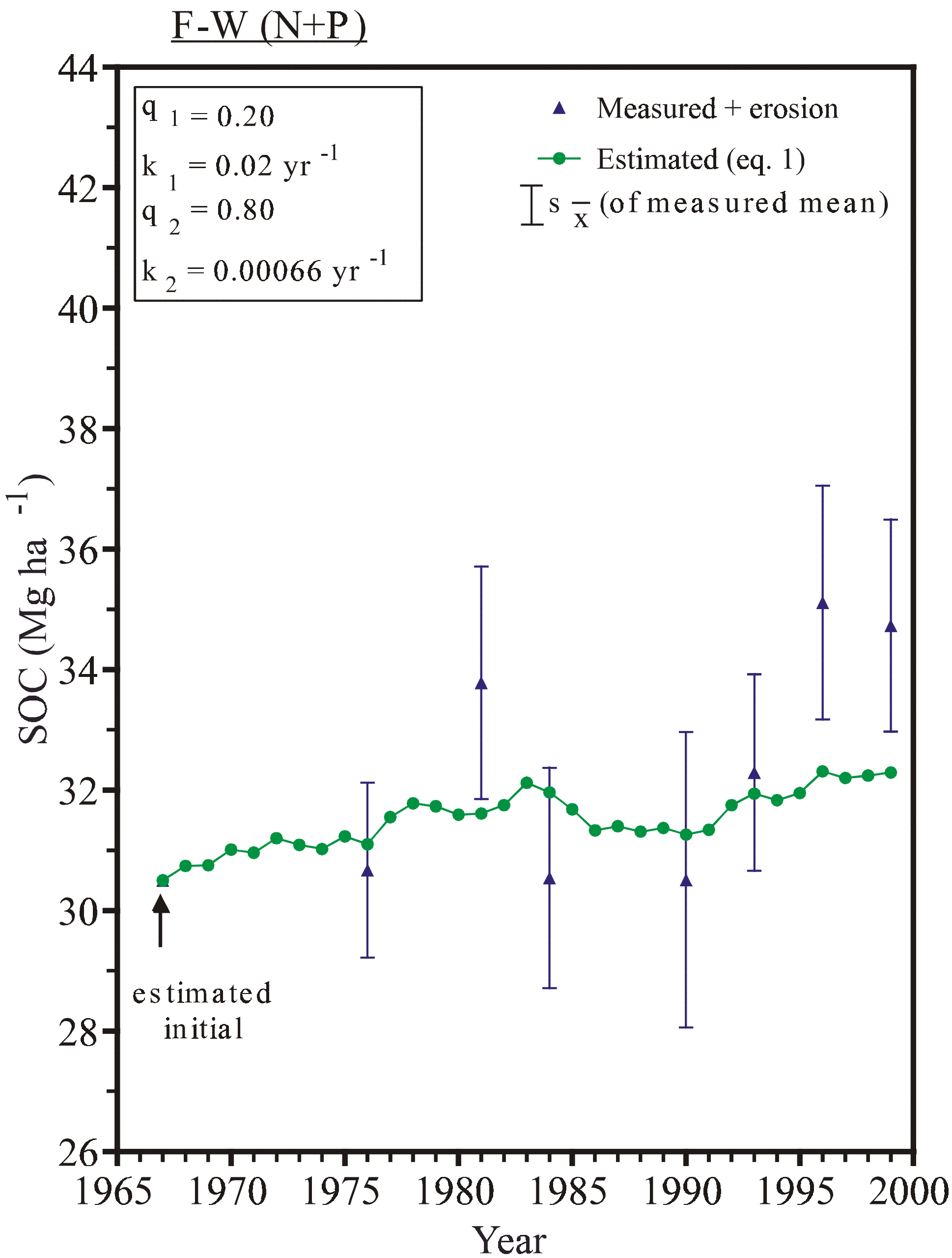

F-W (N+P)
q 1 = 0.20
k 1 = 0.02 yr -1
q 2 = 0.80
k 2 = 0.00066 yr -1
Measured + erosion
Estimated (eq. 1)
s x (of measured mean)
estimated initial
SOC (Mg ha -1)
Year
26
28
30
32
34
36
38
40
42
44
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 2a

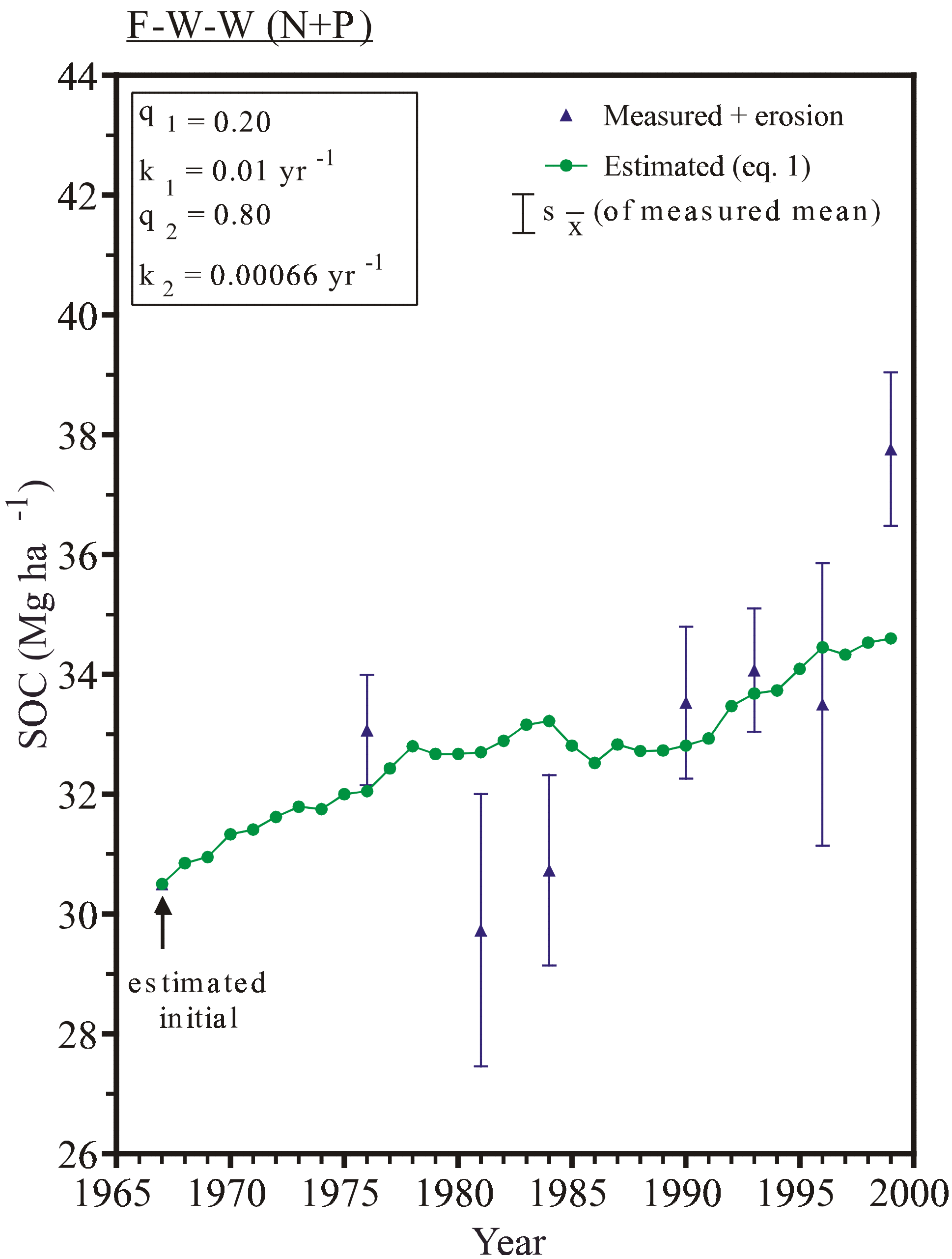
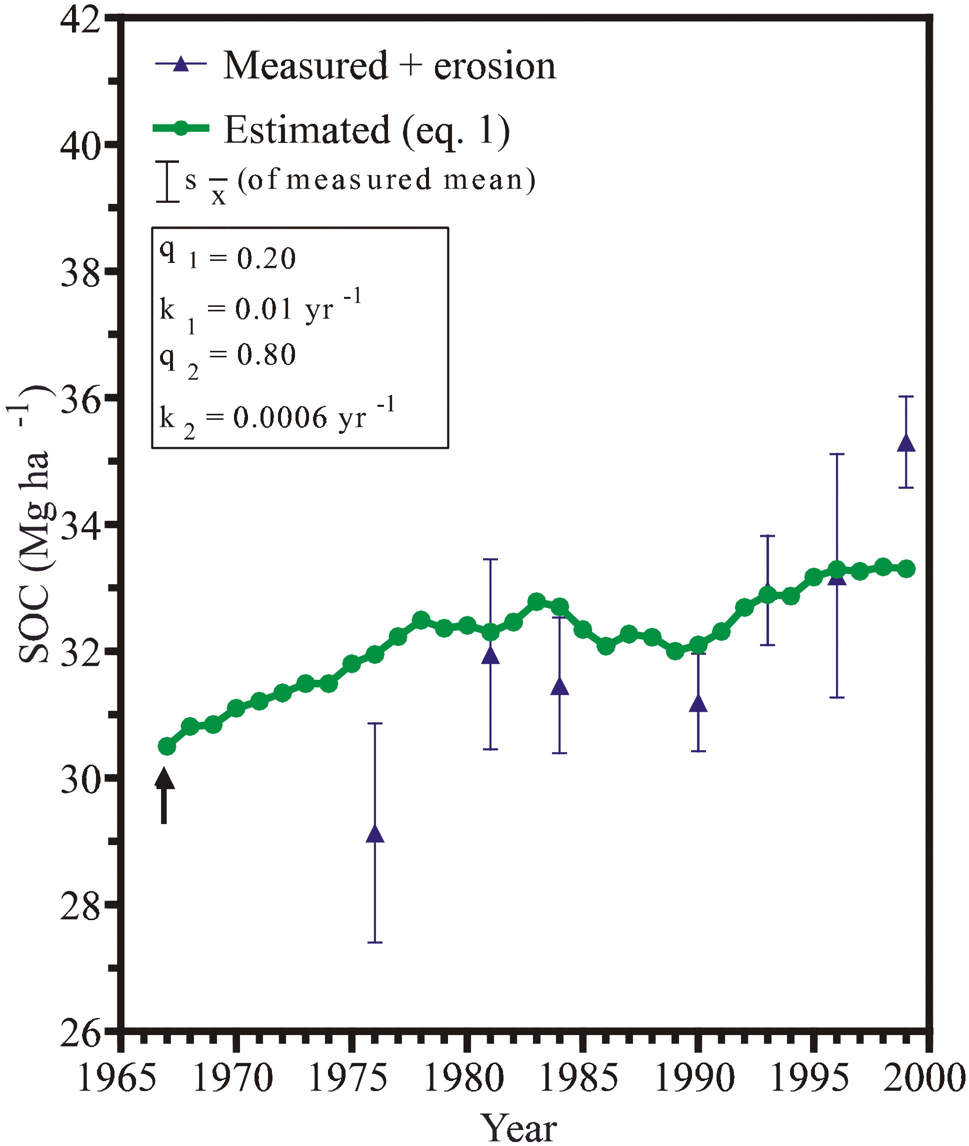

F-W-W (N+P)
q 1 = 0.20
k 1 = 0.01 yr -1
q 2 = 0.80
k 2 = 0.00066 yr -1
Measured + erosion
Estimated (eq. 1)
s x̄ (of measured mean)
estimated initial
SOC (Mg ha -1)
Year
26
28
30
32
34
36
38
40
42
44
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 2b

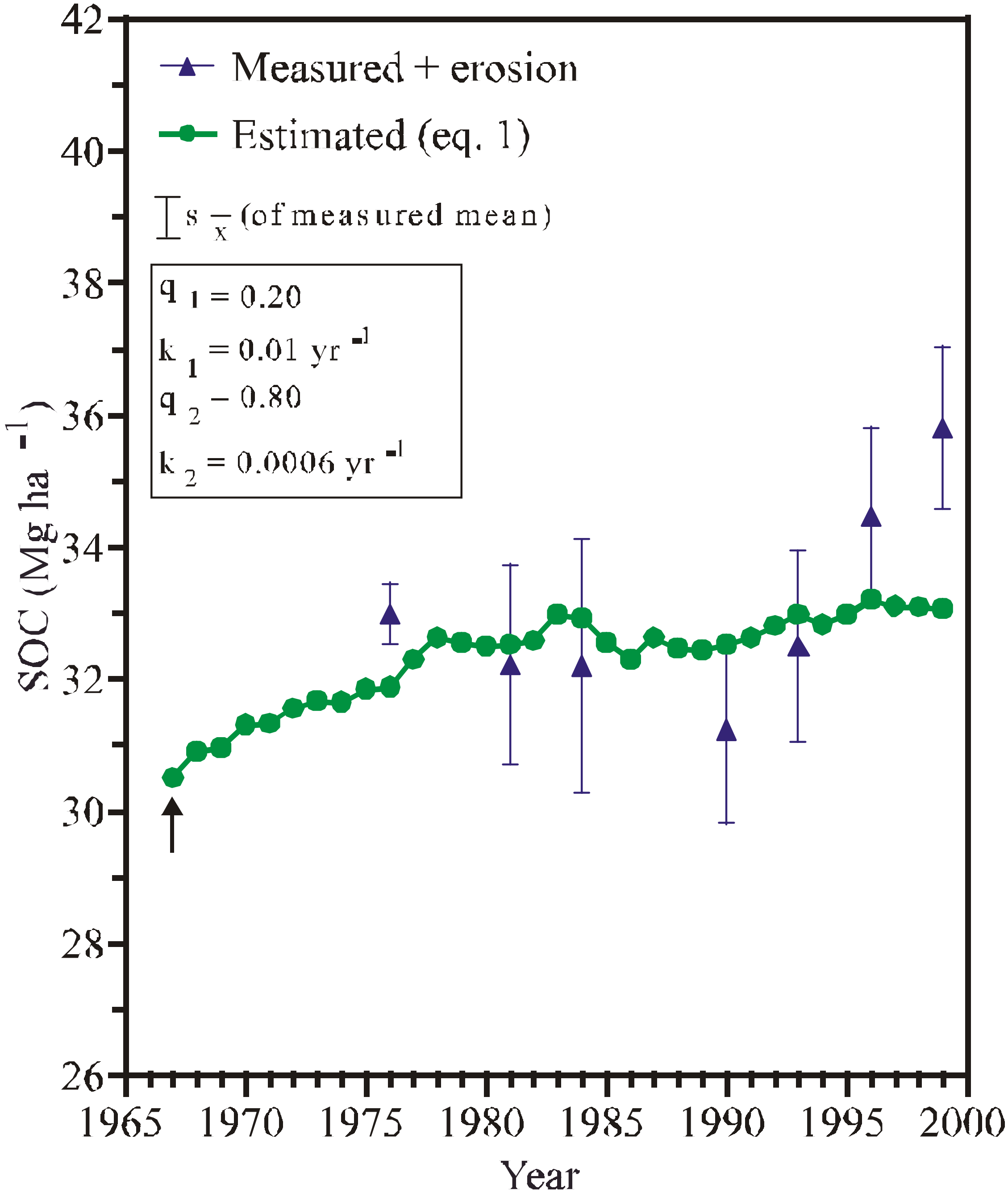
F-W-W (+N)



Measured + erosion
Estimated (eq. 1)
s x̄ (of measured mean)
q 1 = 0.20
k 1 = 0.01 yr -1
q 2 = 0.80
k 2 = 0.0006 yr -1
SOC (Mg ha -1)
42
40
38
36
34
32
30
28
26
1965
1970
1975
1980
1985
1990
1995
2000
Year

Fig. 2c

F-W-W (+P)



Measured + erosion
Estimated (eq. 1)
s x̄ (of measured mean)
q 1 = 0.20
k 1 = 0.01 yr -1
q 2 = 0.80
k 2 = 0.0006 yr -1
SOC (Mg ha -1)
42
40
38
36
34
32
30
28
26
1965
1970
1975
1980
1985
1990
1995
2000
Year

Fig. 2d

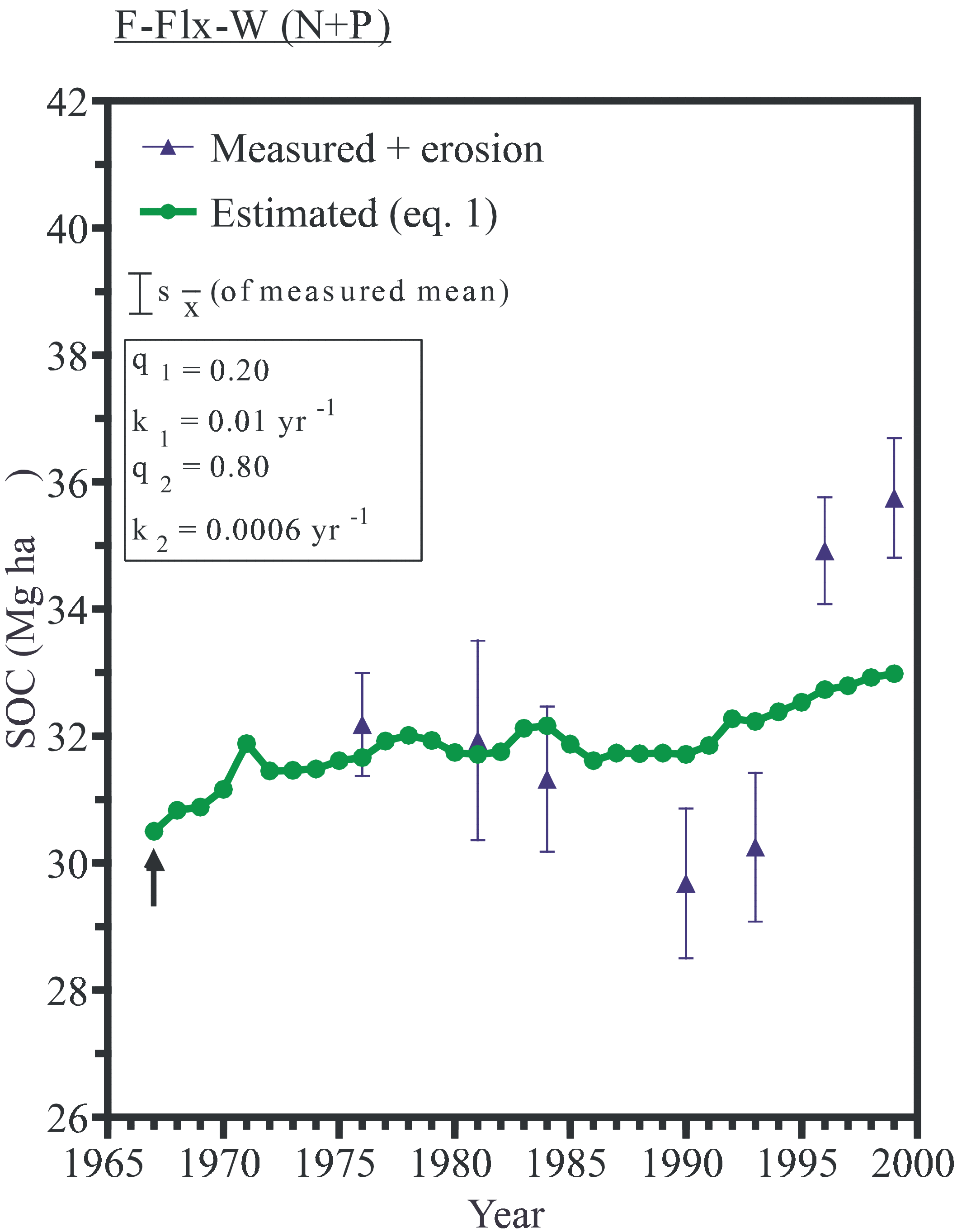

F-Flx-W (N+P)
Measured + erosion
Estimated (eq. 1)
s x̄ (of measured mean)
q 1 = 0.20
k 1 = 0.01 yr -1
q 2 = 0.80
k 2 = 0.0006 yr -1
SOC (Mg ha)
42
40
38
36
34
32
30
28
26
1965
1970
1975
1980
1985
1990
1995
2000
Year

Fig. 2e

F-Rye-W (N+P)

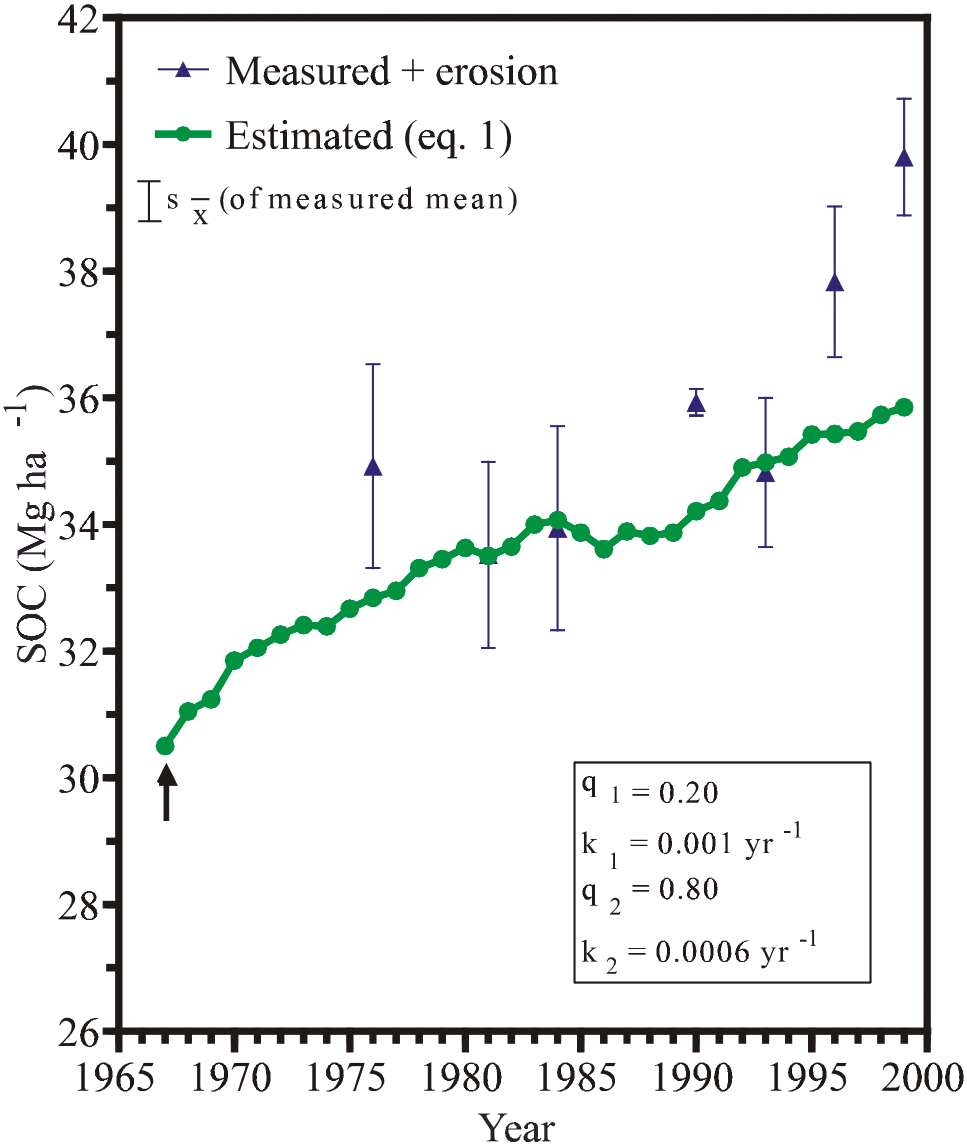


Fig. 2f

F-W-W-W-W-W (N+P) (1985-1999);
was OH-W-W & Flx-W-W (N+P) (1967-1984)

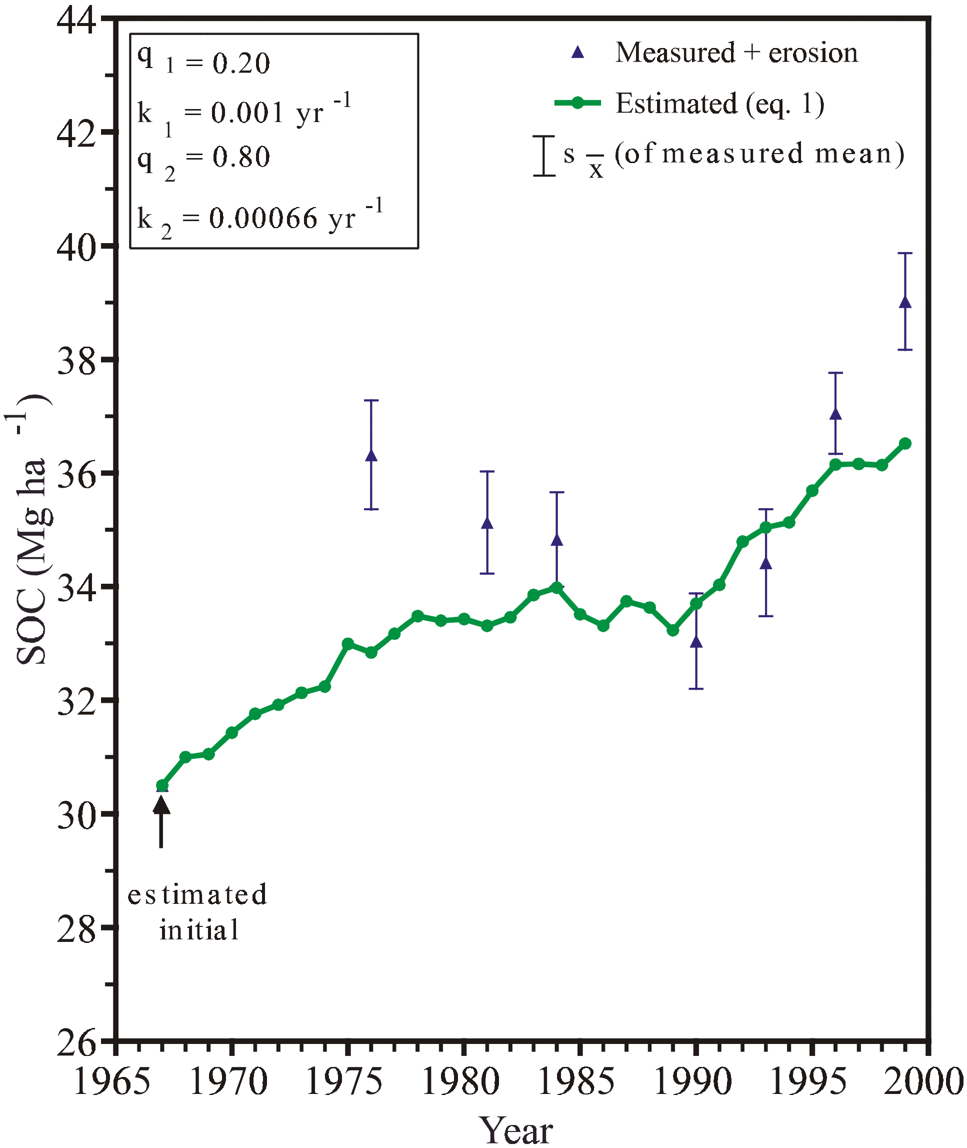


Fig. 2g

Cont W (+P)

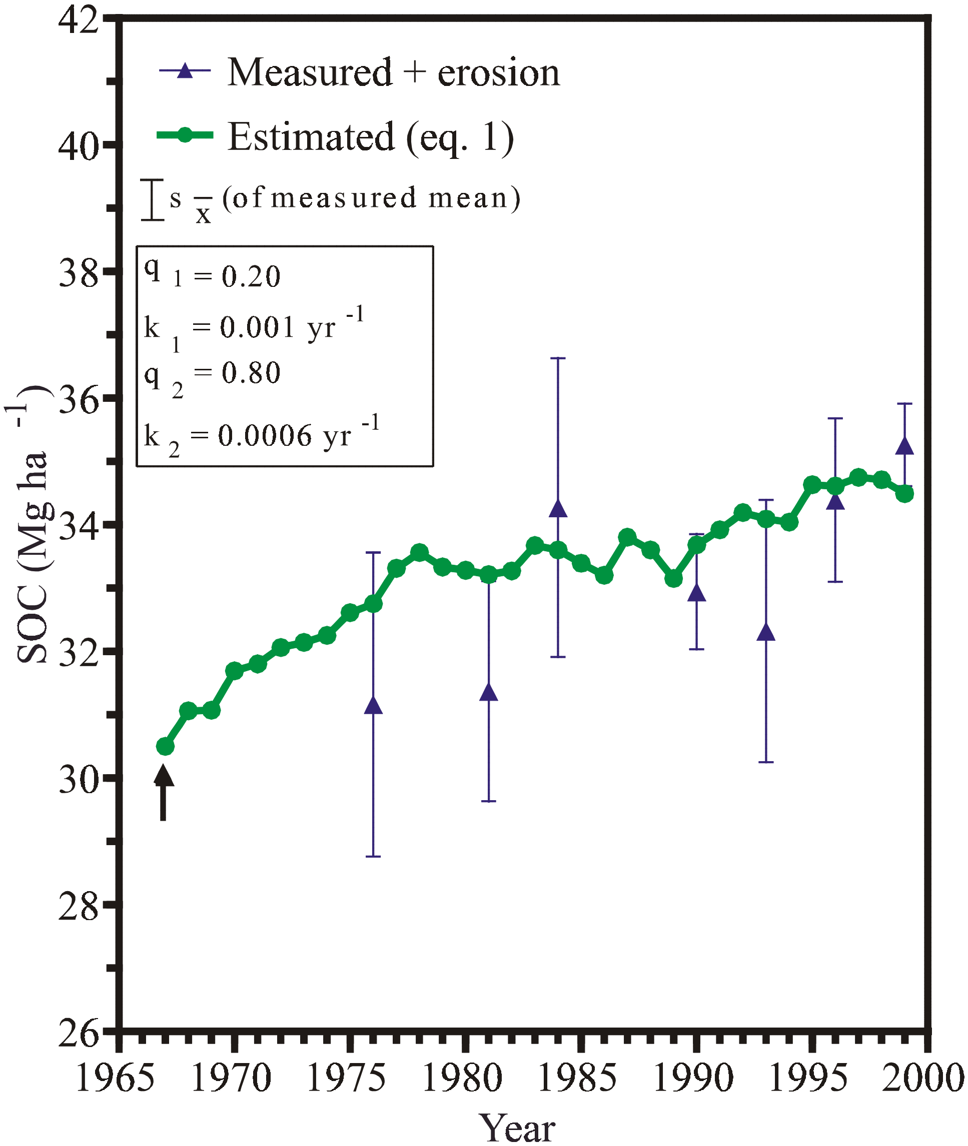


Fig. 2h

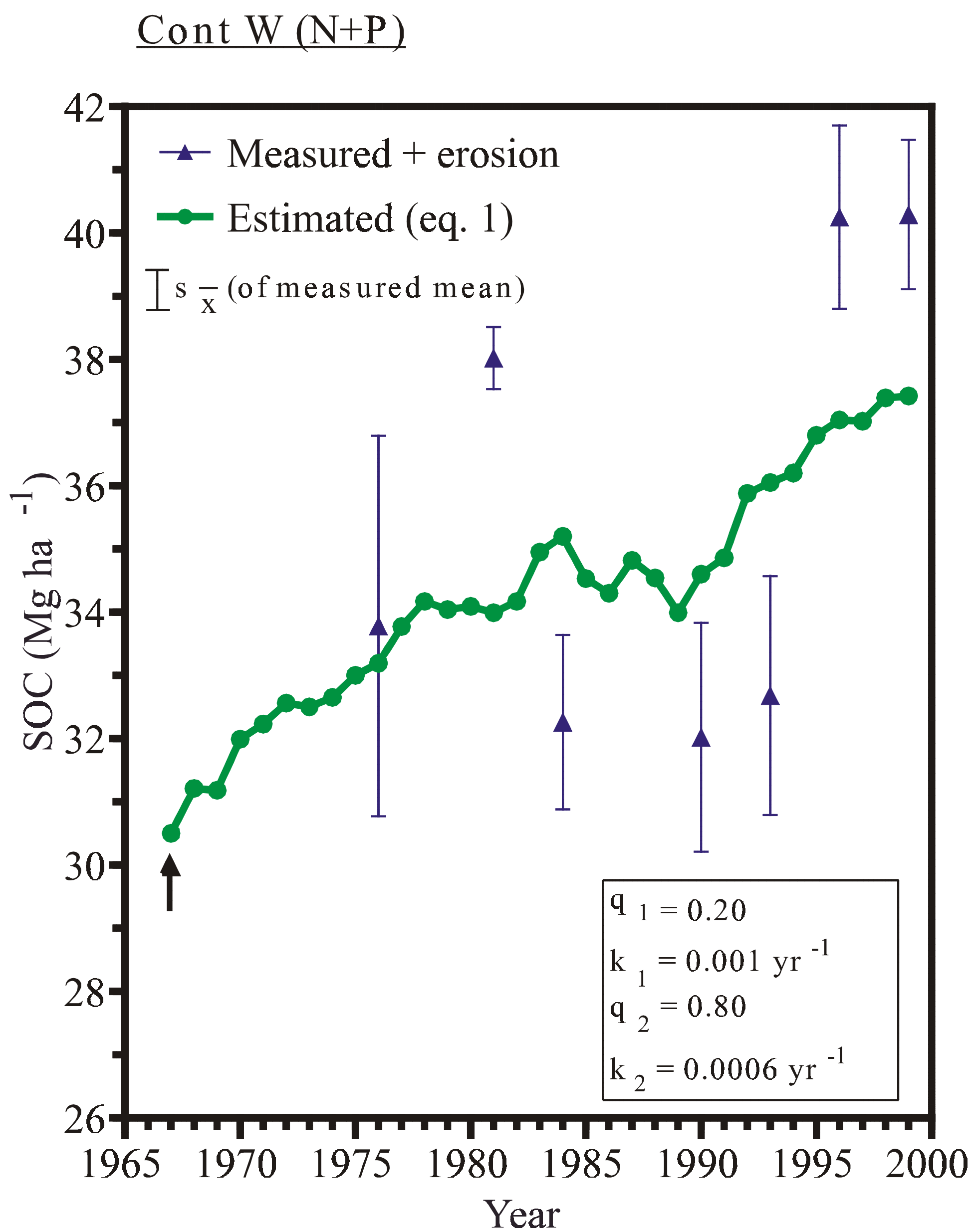

Cont W (N+P)
Measured + erosion
Estimated (eq. 1)
$s_{\bar{x}}$ (of measured mean)
$q_1 = 0.20$
$k_1 = 0.001\ yr^{-1}$
$q_2 = 0.80$
$k_2 = 0.0006\ yr^{-1}$
SOC (Mg ha^{-1})
Year
42
40
38
36
34
32
30
28
26
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 2i

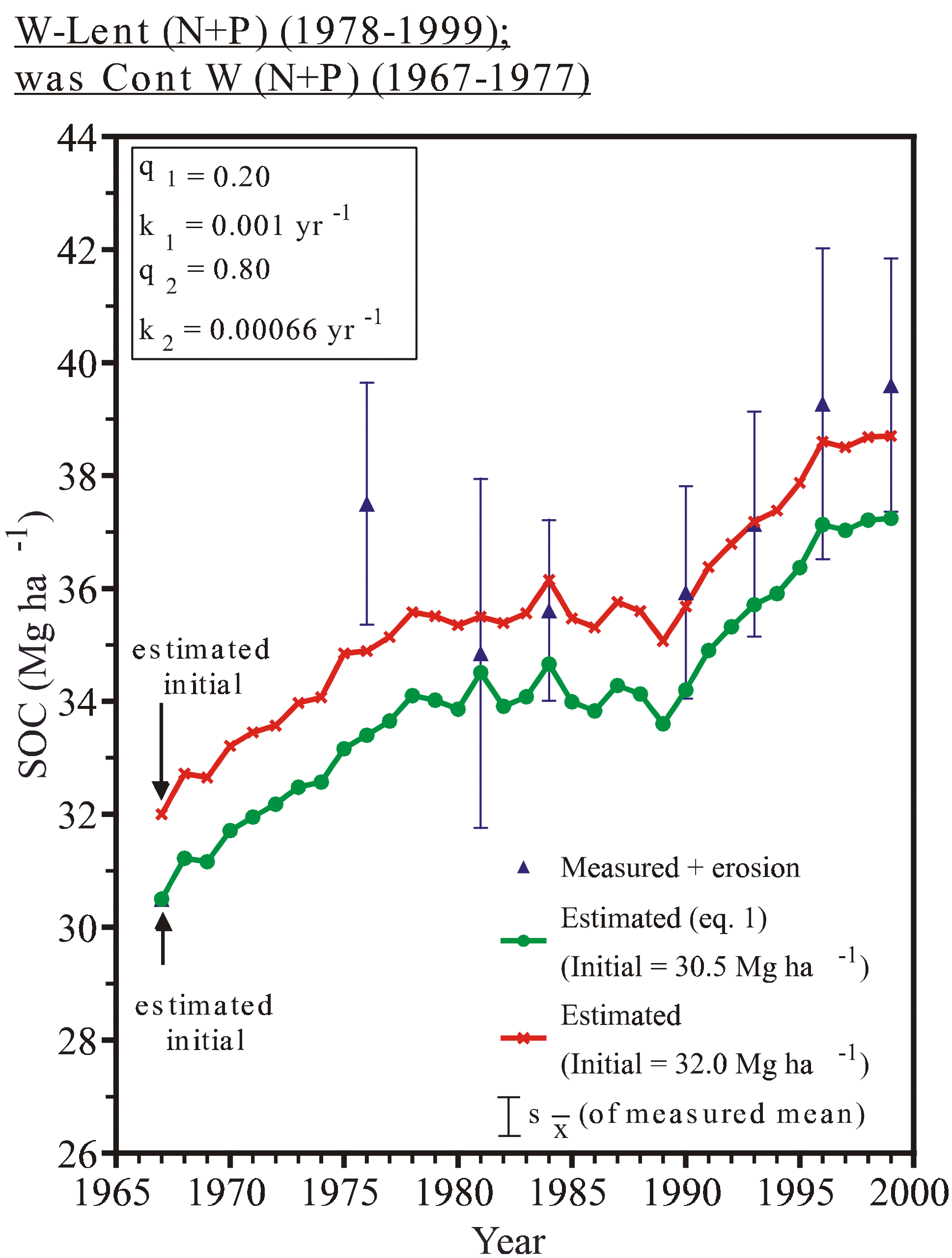


Fig. 2j

- Large variability in measured data makes estimating soil C changes very difficult.
- Increases in soil C were low in frequently fallowed systems, except where a fall-seeded crop (e.g., fall rye) was included.
- Cropping annually and fertilizing adequately had a positive impact on soil C.
- Above-average weather in 1990s (Fig. 3) increased the rate of soil C accumulation in all systems.

- Note: Our equation consistently underestimated measured values for wheat-lentil unless we assumed that initial SOC in these plots was about 1.5 Mg ha-1 greater than assumed for the other treatments (Fig. 2).

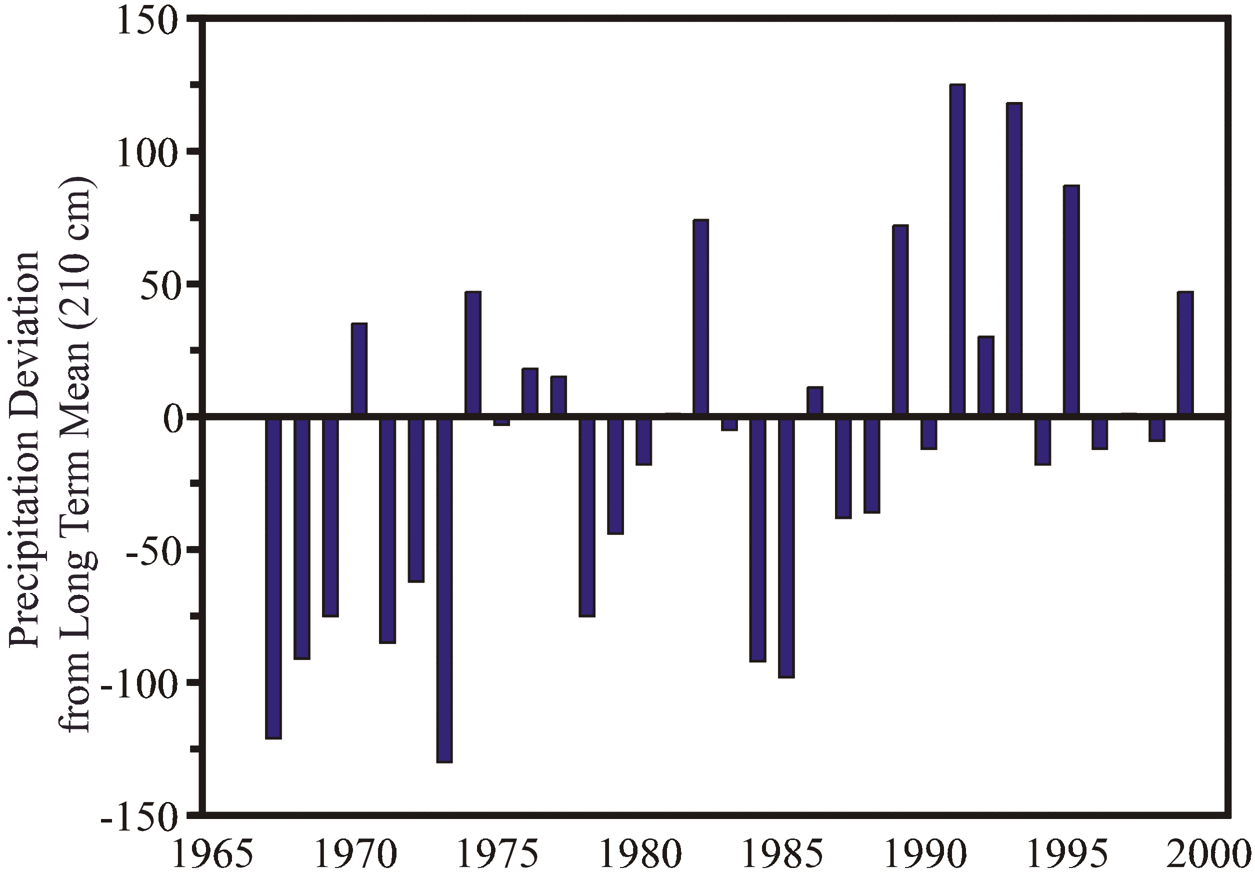


Fig. 3

- This suggests that considerable C may be sequestered due to an increase in cropping frequency (even without reducing tillage).

- We developed a relationship between change in soil C (D SOC/yr) and fallow frequency (Fig. 4)

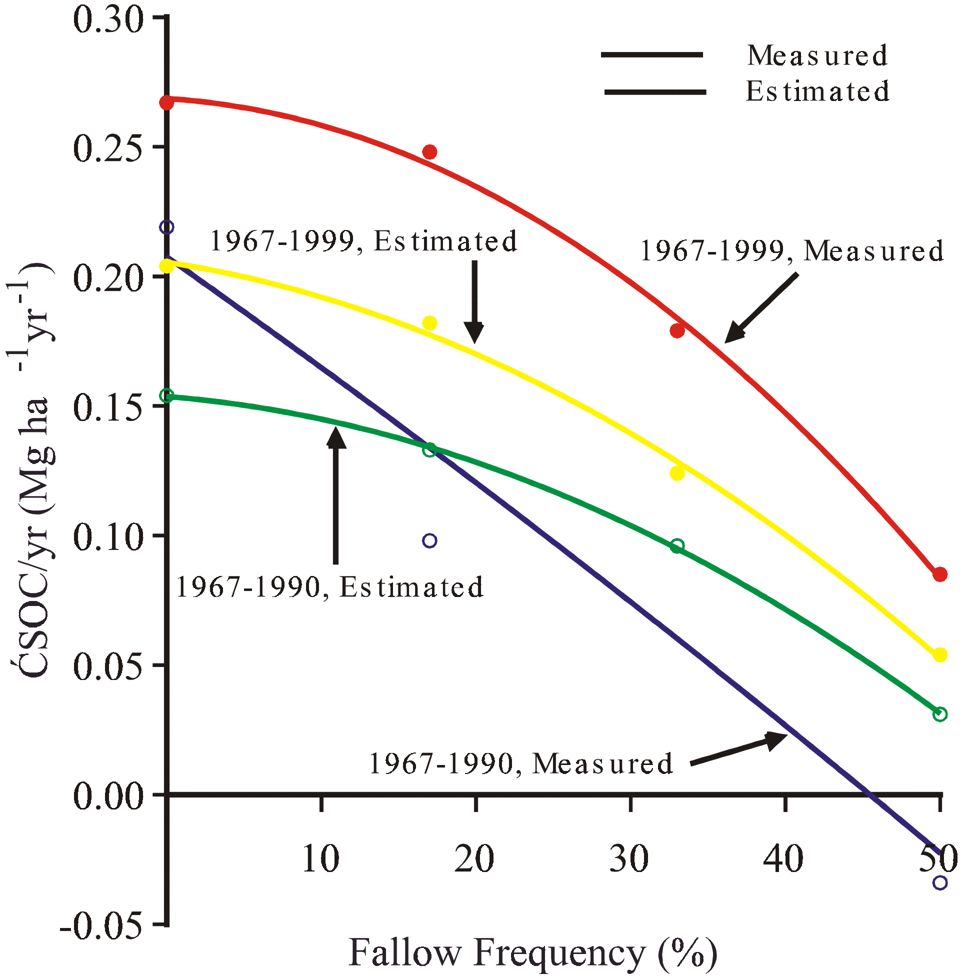


Fig 4

- We used values for trends in fallow frequency over 1976-1998 period on Canadian prairies (Table 2) to estimate D SOC/yr for 1976 and 1998 from Fig. 4. Then estimated the average amount of C that may have been sequestered in the Brown and Dark Brown soil zones during these years due to more frequent cropping (Table 3).

Table 2. Trends in fallow frequency on the Canadian prairies

	Proportion of land in fallow					
Soil Zone	1976	1980	1985	1990	1995	1998
Brown	0.47	0.47	0.44	0.43	0.44	0.38
Dark Brown	0.42	0.40	0.32	0.31	0.25	0.20
Black and Gray	0.26	0.28	0.17	0.17	0.13	0.09

Data derived from analysis of Stats Canada data

Table 3. Estimate of C sequestered in Brown and Dark Brown Soil Zones of the Canadian prairies (1976 vs 1998) due to changes in fallow frequency

Soil Zone and C sequestered	1976	1998
BROWN (million ha)	6.5	6.5
[y]Mean rate of C sequestered (Mg ha^{-1} yr^{-1})	0.03	0.075
C sequestered per year (Mg)	195,000	487,500
DARK BROWN (million ha)	8.5	8.5
[y]Mean rate of C sequestered (Mg ha^{-1} yr^{-1})	0.06	0.165
C sequestered per year (Mg)	510,000	1,402,500

[y]Fallow frequency from Table 2 used with Fig. 3, to estimate this value.

SUMMARY

- Soil organic C (SOC) is readily influenced by crop management practices. This was shown by results of this 33-yr crop rotation experiment at Swift Current.
- Cropping annually, proper fertilization, and including fall rye in rotations increased SOC, as did a decade of favourable weather which increased crop residues and thus C input.
- Measured SOC values were very variable. However, our empirical model effectively simulated trends in SOC.
- We present a useful relationship relating rate of SOC change to fallow frequency for "first-round" estimates.