Quantitative Changes in Soil Organic C over 37 years under Conventional Tillage - Effect of Crop Rotations and Fertilizers

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INTRODUCTION

- Scientists and the agricultural community require methods of quantifying C sequestration in soils. This is important re "C Trading".
- Measuring changes in soil organic C (SOC) is tedious because such changes are small, slow and field variability high.
- Quantification using models may be a more effective mode of assessing SOC changes.
- A 37-yr crop rotation experiment, being conducted at Swift Current, Saskatchewan, in which SOC is regularly monitored, provided an opportunity to test three models for their effectiveness in quantifying SOC changes.

MATERIALS AND METHODS

The rotation experiment was initiated in 1967 on land that was in fallow-wheat (F-W) for the previous 60 years.

- Ten cropping systems (Table 1) in which SOC was measured in the 0-15cm depth in 1976, 1981, 1984, 1990, 1993, 1996 and 2003, were assessed.
- The three models tested were Century (Parton et al. 1987), the Introductory C Balance Model (ICBM) (Andren and Katterer, 1997) and the Campbell et al. model (Campbell et al. 2000).
- All three models require estimates of C inputs from crop residues. We estimated these Inputs for ICBM and the Campbell et al. model from measured grain yields, using Straw/grain ratios and root/straw ratios we had developed. Century used its simulated Yields. We assumed 45% C in residues.
- The regressions for converting grain yields to C inputs used in this study are shown in Table 2.

RESULTS AND DISCUSSION

TRENDS IN SOC

- Large standard errors are evidence of large variability usually encountered in measured SOC (Fig. 1).
- SOC in fallow-containing systems was generally constant till about 1990 then tended to increase thereafter (Fig. 1).
- SOC in extended rotations increased in first decade (Fig. 1), tended to level off in droughty 1980's, then increased after 1990 due to above-average precipitation (Fig. 2) which led to greater C inputs (Fig. 3).
- The Campbell et al. model simulated SOC trends fairly well (Fig. 1), but tended to overestimate the lower SOCs and underestimate the higher values (Fig. 4a).
- ICBM also simulated SOC well (Fig. 1), but also tended to underestimate higher SOCs (Fig. 4b).
- Century simulated SOC trend in Cont W (N + P) but underestimated SOC quite markedly, especially for F-W and F-W-W (Fig. 1). This inaccuracy was related to its underestimate of soil water conserved during summerfallow, which then depressed N mineralization, resulting in low yields (Fig. 5) and C inputs, and poor simulation of SOC (Fig. 4c).

GAIN IN SOC (1967-2003) TABLE 1

- SOC gain between 1967 and 2003 in the 0 - 15cm depth ranged between 3.04 Mg ha^{-1} in F-W-W (+P) and 11.18 Mg ha^{-1} in W-Lent (N + P).
- On average, F-W-W (N + P) gained 140 kg C $ha^{-1}yr^{-1}$, about 25 kg $ha^{-1}yr^{-1}$ more than for F-Flx-W (N + P), and 50-60 kg $ha^{-1}yr^{-1}$ more than F-W-W without N or without P, but about 45 kg $ha^{-1}yr^{-1}$ less than for F-Rye-W (N + P).
- Cont W (N + P) gained 236 kg C $ha^{-1}yr^{-1}$, i.e., 130 kg $ha^{-1}yr^{-1}$ more than Cont W (+ P) and 65 kg $ha^{-1}yr^{-1}$ less than W-Lent (N + P).
- These rates of gain were much less than obtained in a 6-yr study in a Brown Chernozem at Lethbridge (Bremer et al. 2002) where Cont W gained 250 kg C $ha^{-1}yr^{1}$ more than F-W and 130 kg $ha^{-1}yr^{-1}$ more than F-W-W.

EFFICIENCY OF CONVERSION OF RESIDUE C TO SOC

- We used regressions relating grain yield to straw yield, and root yield to straw yield to estimate C inputs (Table 2).
- We calculated efficiency of conversion of C inputs to SOC gained (%) (Table 1).
- Efficiencies were lowest for poorly fertilized systems (6 -7%), intermediate for well-fertilized fallow-containing systems (9 - 12%), and highest for well-fertilized continuous cropping systems (12 - 17%).
- We can make first estimates of the influence of crop management on SOC gains for degraded soils in the semiarid prairies by using estimates of C inputs (Table 2) and efficiencies of conversion (Table 1).

CONCLUSIONS

- Using SOC measured periodically during 37 years in a crop rotation experiment in the semiarid prairies at Swift Current, we tested the effectiveness of 3 models in estimating SOC changes and trends.
- The ICBM and Campbell et al. models performed reasonably well and better than Century, perhaps because their yield (C inputs) do not have to be modelled as is the case for Century.
- In any event, results with Century were less convincing and this model requires further work.

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Table 1. SOC gain, C input and efficiency of conversion[z] of C input to SOC (%) (1967-2003)

Treatment[y]	SOC gain ($Mgha^{-1}$)	SOC gain per year ($kgha^{-1}yr^{-1}$)	Mean C input ($kgha^{-1}$)	Total C input ($Mgha^{-1}$)	Efficiency of conversion of input C to SOC(%)
F-W-W(+ P)	3.04	82	1421	51.2	5.9
F-W-W(N+P)	5.15	140	1611	58.0	8.9
F-Flx-W(N+P)	4.31	116	1162	41.8	10.3
F-Rye-W(N+P)	6.87	185	1634	58.8	11.7
F-W-W(+N)	3.39	92	1397	50.3	6.7
Cont W(N+P)	8.75	236	1983	71.4	12.3
F-W (N+P)	4.71	127	1379	49.6	9.5
Cont W (+P)	3.90	105	1504	54.1	7.2
W-Lent(N+P)[x]	11.18	302	1840	66.2	16.9
F-W-W-W-W-W[w] (N+P)	9.21	250	nd[v]	nd[v]	nd[v]

[z] SOC gain (1967 - 2003) ÷ total C inputs (1967-2002). We assume starting SOC in 0-15cm depth in 1967 for all plots was 30.5 $Mgha^{-1}$ (Campbell et al. 2000a).

[y] F = fallow, W = spring wheat, Flx = flax, Rye = fall rye, Lent = grain lentil, Cont = continuous. N and P applied based on soil test (N) and general recommendation (P).

[x] This rotation was constructed in 1979 from two extra Cont W (N+P) rotations.

[w] This rotation was established in 1985 from an Oat hay-W-W and Flx-W-W rotations receiving N + P.

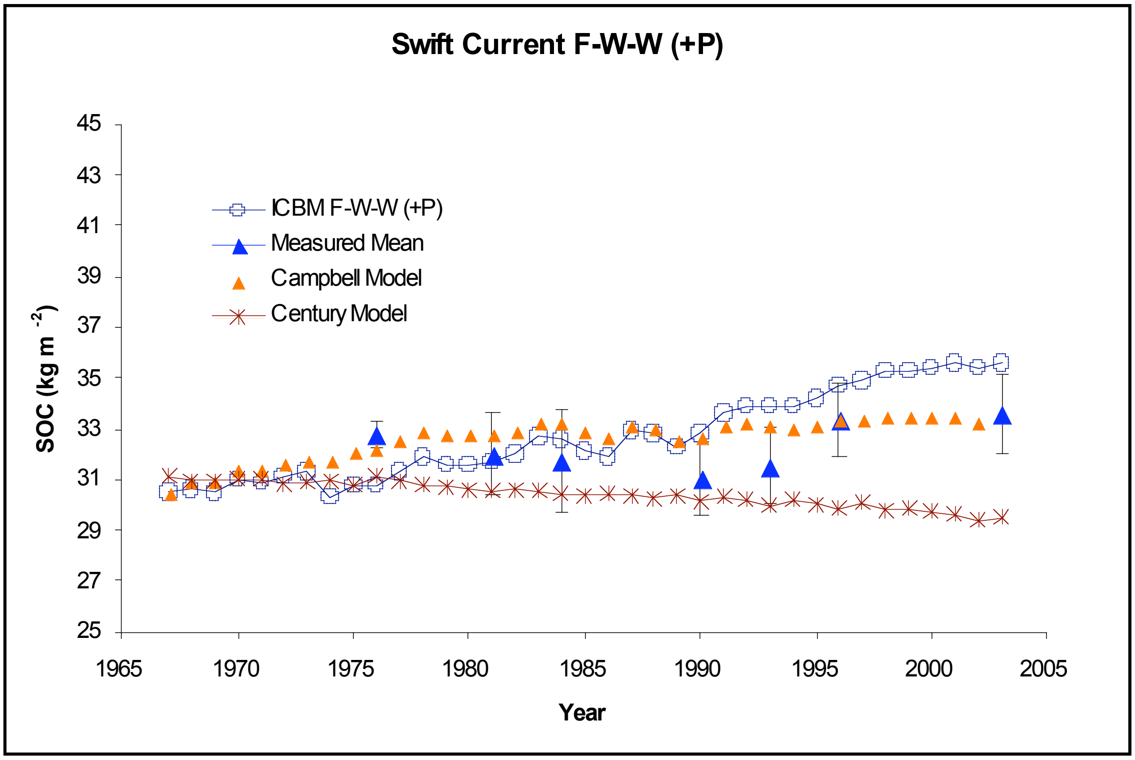
[v] nd = not determined.

Table 2. Regressions for converting grain yields (y)[z] to C inputs[y]

Crop	Regression
Hard Red spring wheat	C input = 1.20 Y + 64
Fall rye	C input = 0.86 Y + 794
Flax	C input = 1.39 Y + 36
Grain lentil	C input = 0.88 Y + 746

[z] Units = $kgha^{-1}$

[y] Calculated from regressions relating straw yield to grain yield; assuming root/straw ratio = 0.59 and C in residues = 45%.


Swift Current F-W-W (+P)
ICBM F-W-W (+P)
Measured Mean
Campbell Model
Century Model
SOC (kg m -2)
Year
45
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1965
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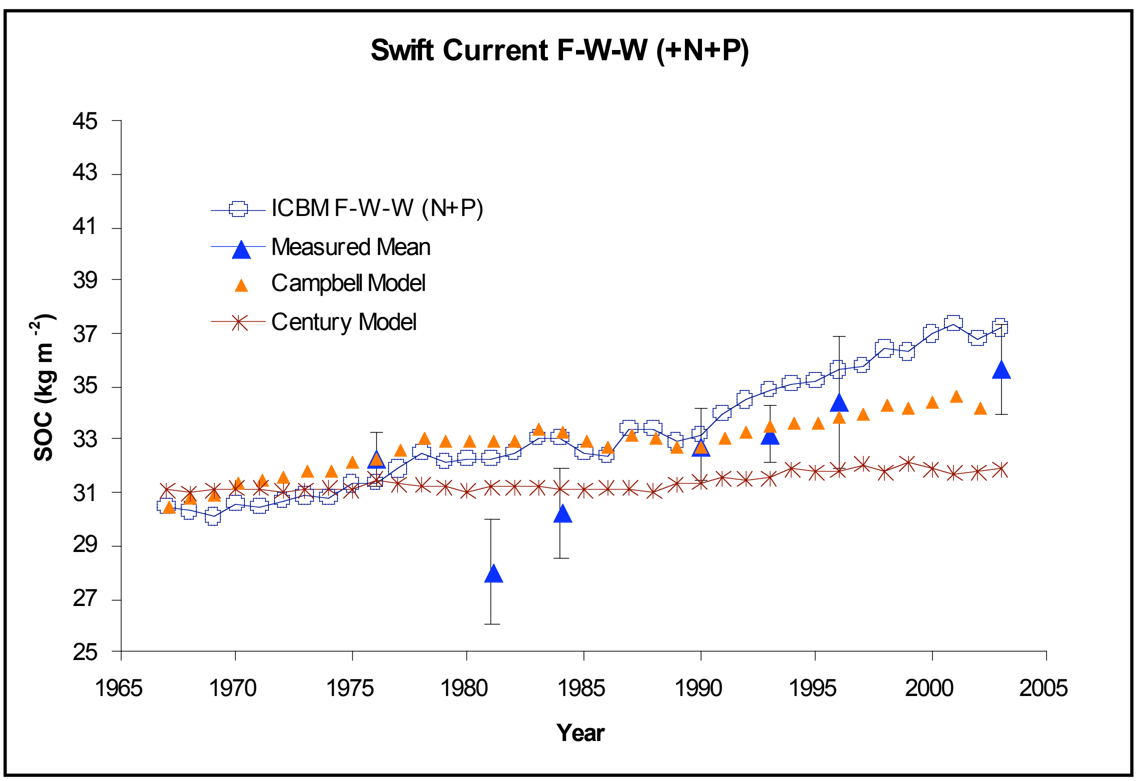
Swift Current F-W-W (+N+P)
ICBM F-W-W (N+P)
Measured Mean
Campbell Model
Century Model
SOC (kg m -2)
Year
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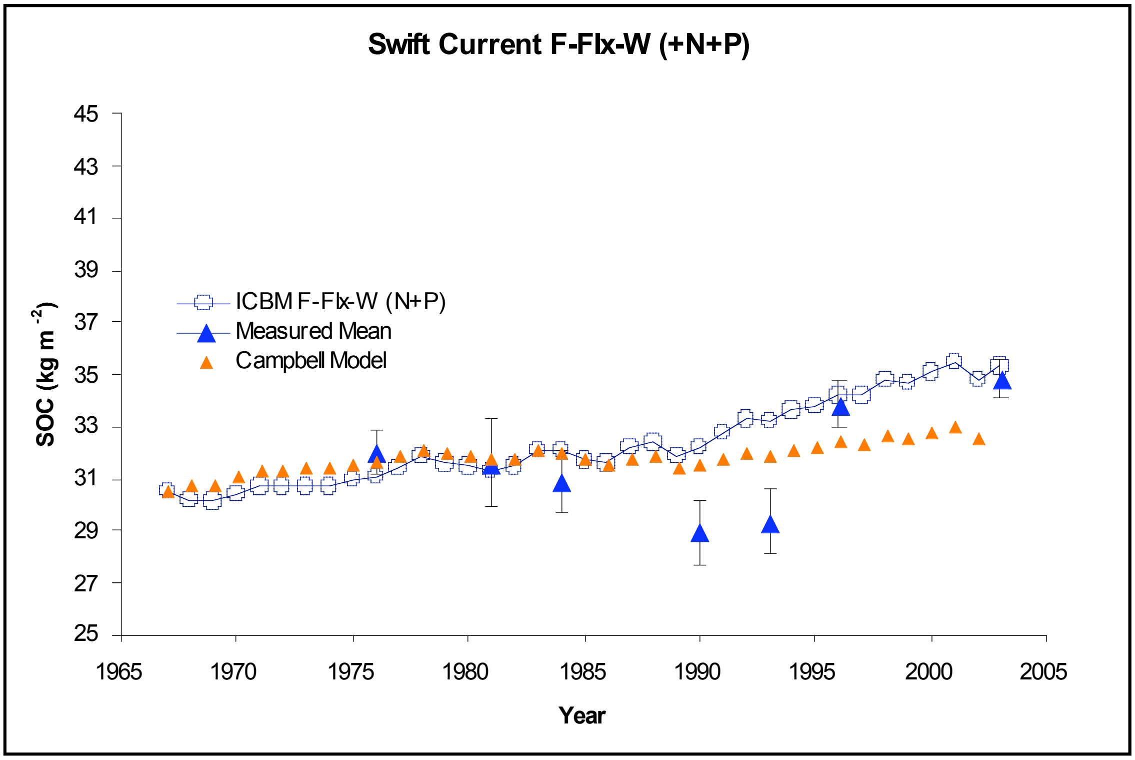
Swift Current F-Flx-W (+N+P)
SOC (kg m-2)
Year
ICBM F-Flx-W (N+P)
Measured Mean
Campbell Model
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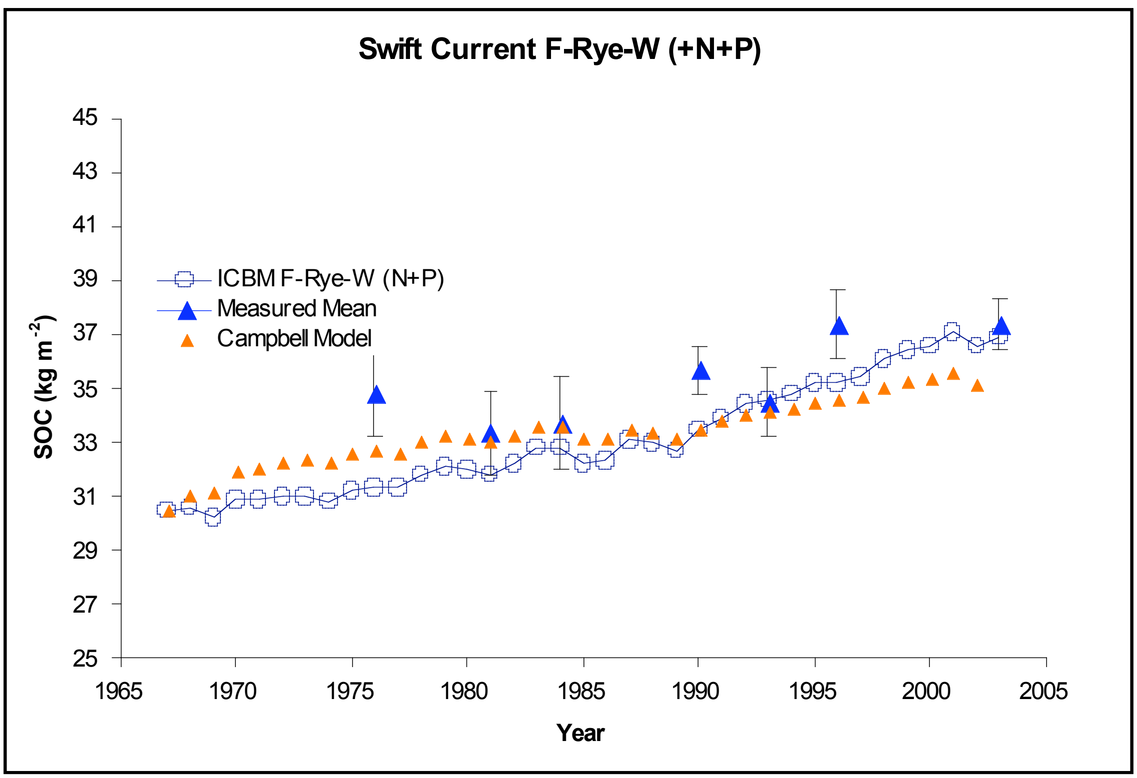
Swift Current F-Rye-W (+N+P)
SOC (kg m-2)
Year
ICBM F-Rye-W (N+P)
Measured Mean
Campbell Model
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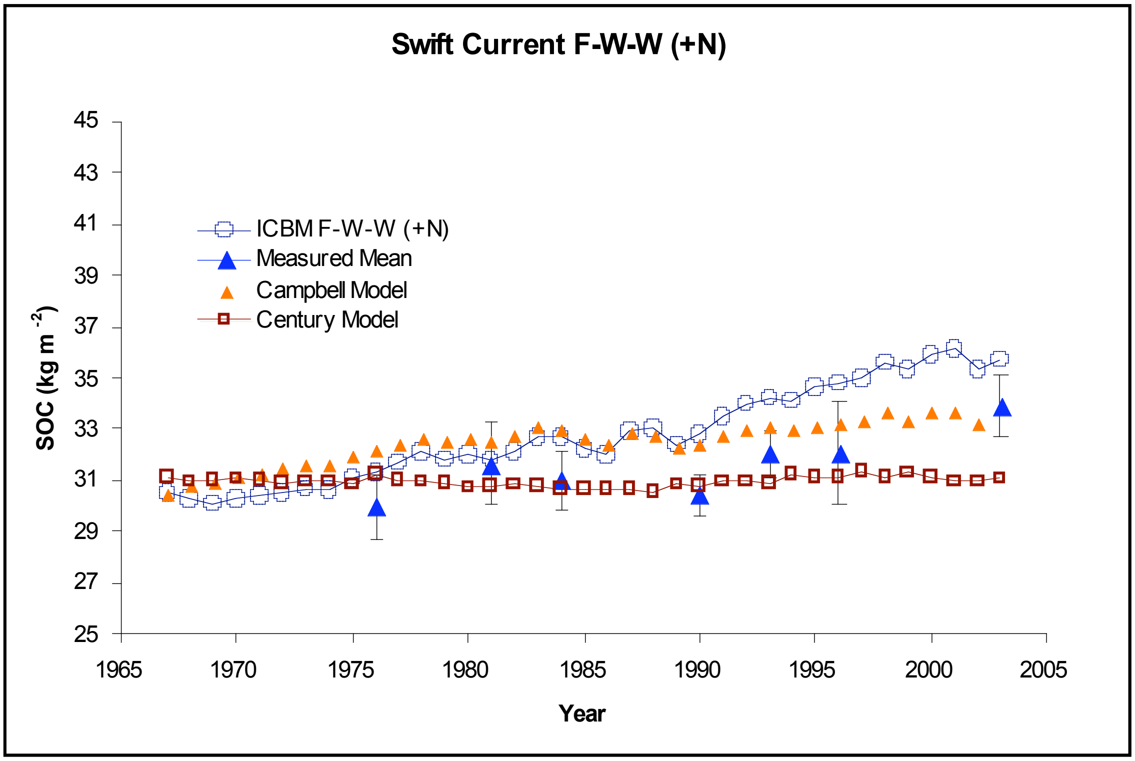
Swift Current F-W-W (+N)
ICBM F-W-W (+N)
Measured Mean
Campbell Model
Century Model
SOC (kg m -2)
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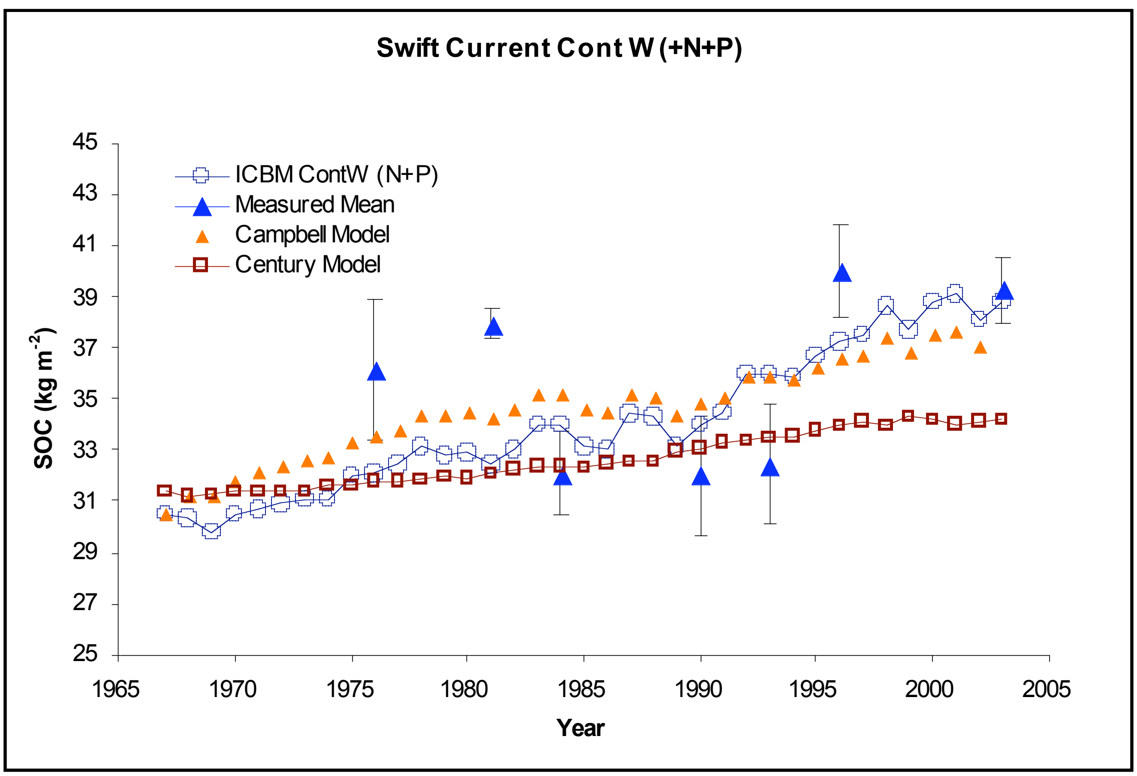
Swift Current Cont W (+N+P)
ICBM ContW (N+P)
Measured Mean
Campbell Model
Century Model
SOC (kg m-2)
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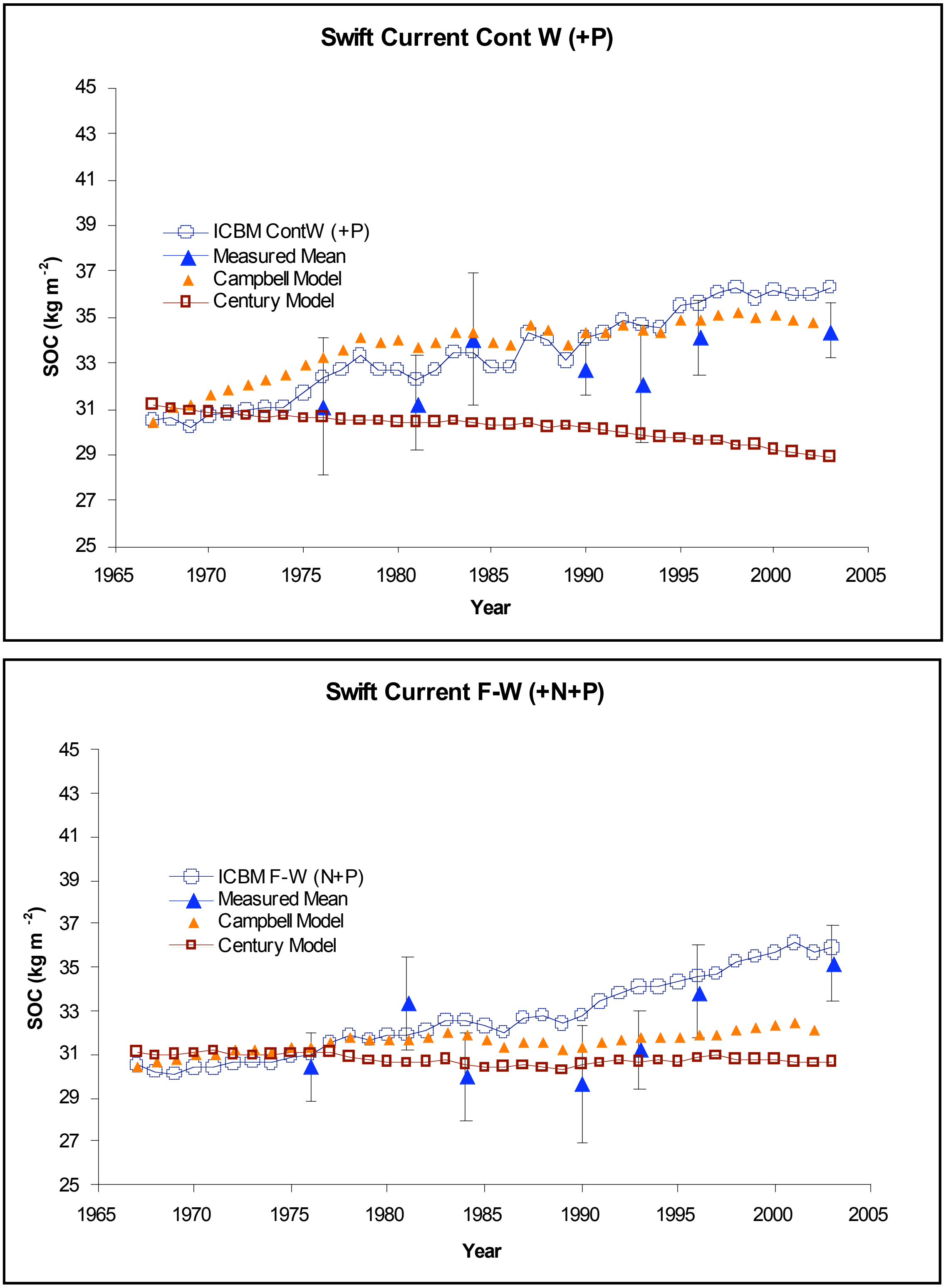


Figure 1. Trends in SOC in 0-15 cm depth, 1967-2003, as measured and modeled by ICBM, Campbell et al. 2000, and Century. Vertical bars on measured points are standard error of the mean.

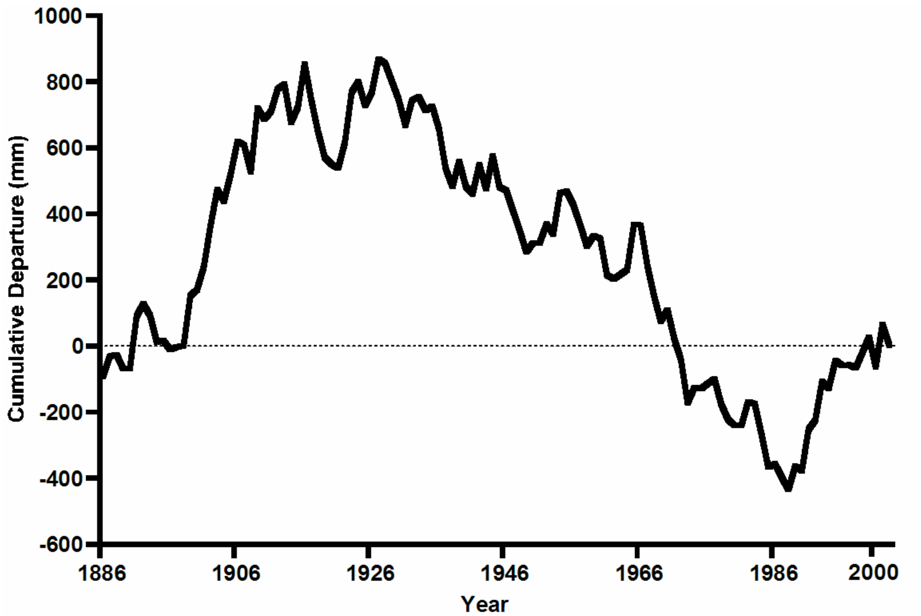


Figure 2. Accumulated departure from the long-term mean growing season (1 May to 31 August) precipitation at Swift Current for the period 1886 - 2003. (Long-term mean = 210 mm). (Note: Only slopes are meaningful. Positive slopes denote period of above average precip; negative slopes denote period of drought; zero slope denotes period of average precip.).

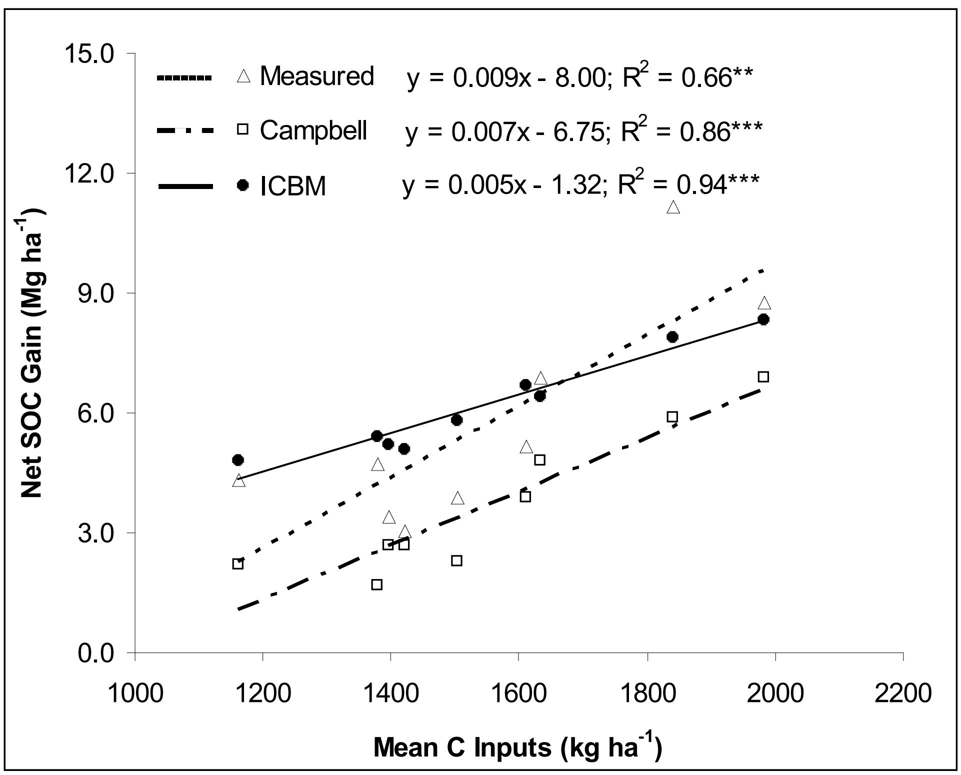
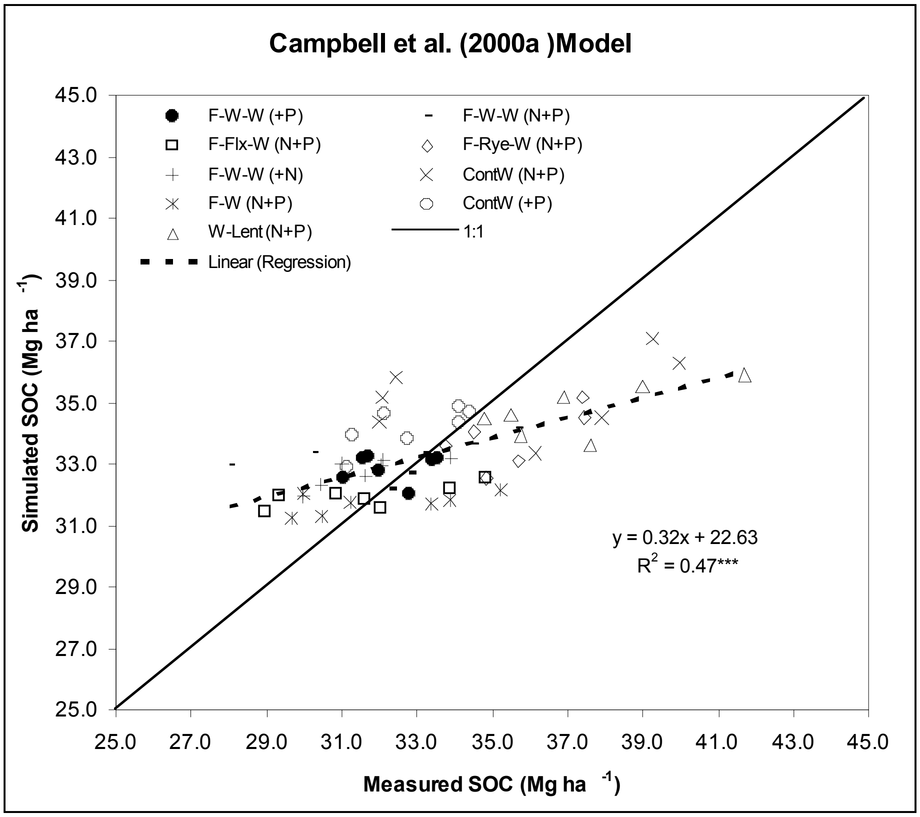


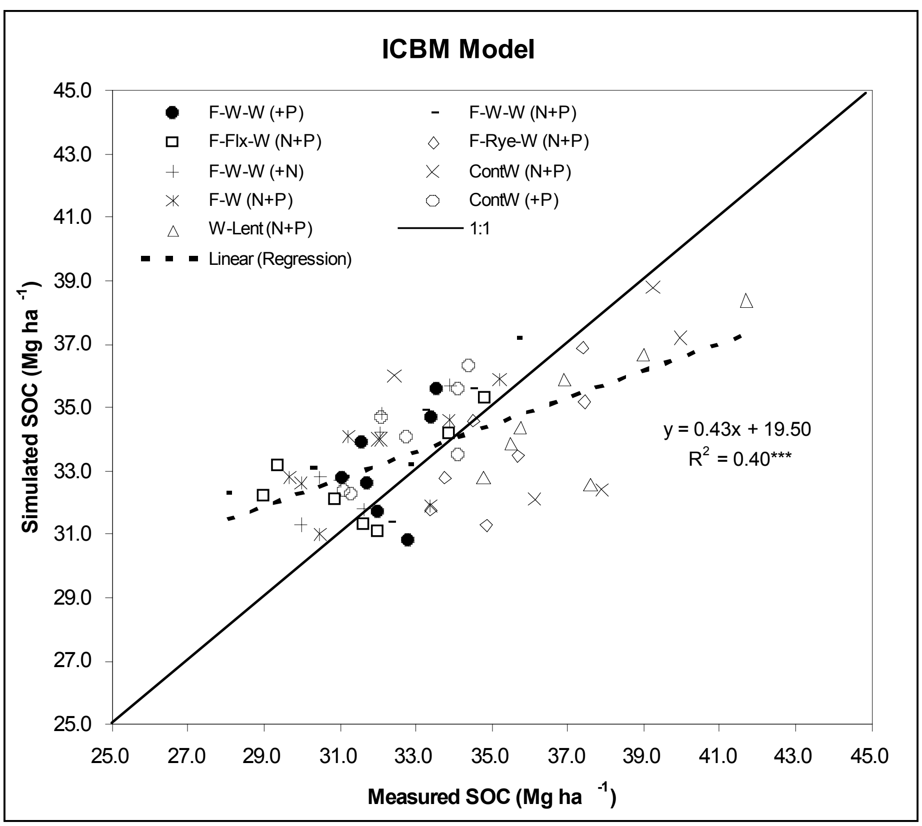
Figure 3. Relationship between net SOC gain in 0-15cm depth (measured and modeled) between 1967 and 2003 and C inputs. [Note: SOC in 1967 assumed to be 30.5 Mg ha-1 in all plots as measured in F-W (N+P) in 1976, Campbell et al. 2000].

a.



Campbell et al. (2000a)Model
F-W-W (+P)
F-W-W (N+P)
F-Flx-W (N+P)
F-Rye-W (N+P)
F-W-W (+N)
ContW (N+P)
F-W (N+P)
ContW (+P)
W-Lent (N+P)
1:1
Linear (Regression)
y = 0.32x + 22.63
R2 = 0.47***
Simulated SOC (Mg ha -1)
Measured SOC (Mg ha -1)

b.



ICBM Model
F-W-W (+P)
F-W-W (N+P)
F-Flx-W (N+P)
F-Rye-W (N+P)
F-W-W (+N)
ContW (N+P)
F-W (N+P)
ContW (+P)
W-Lent (N+P)
1:1
Linear (Regression)
y = 0.43x + 19.50
R2 = 0.40***
Simulated SOC (Mg ha -1)
Measured SOC (Mg ha -1)

c.

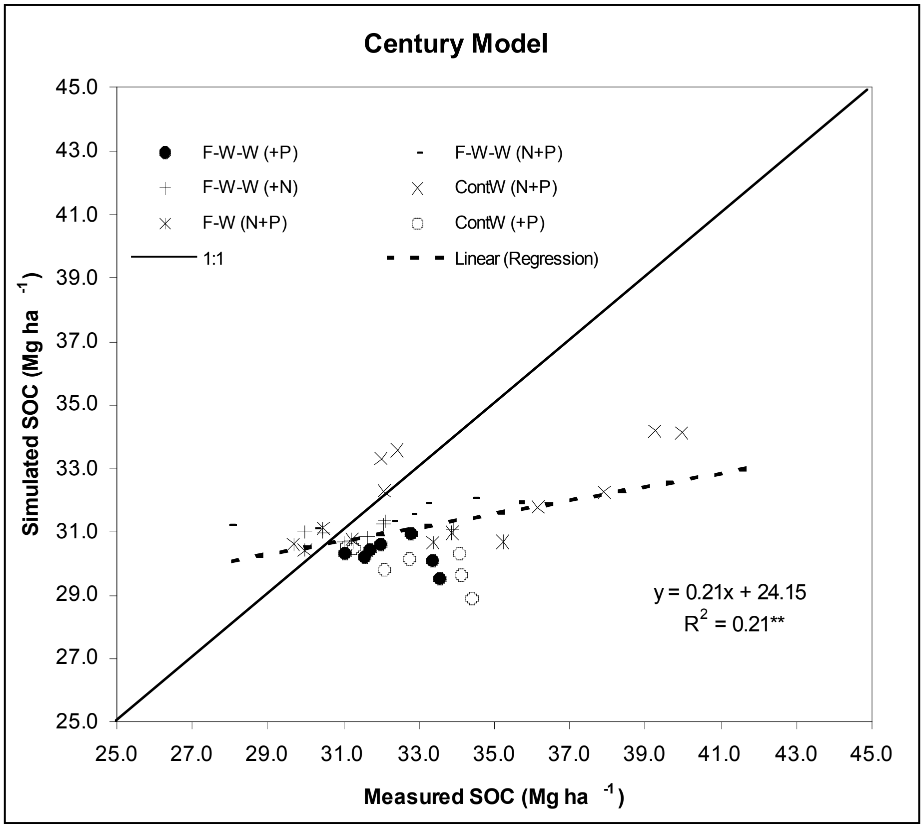


Figure 4. Relationship between simulated SOC in 0-15 cm depth and measured SOC for the a) Campbell et al. (2000a) model, b) ICBM model, and c) Century model.

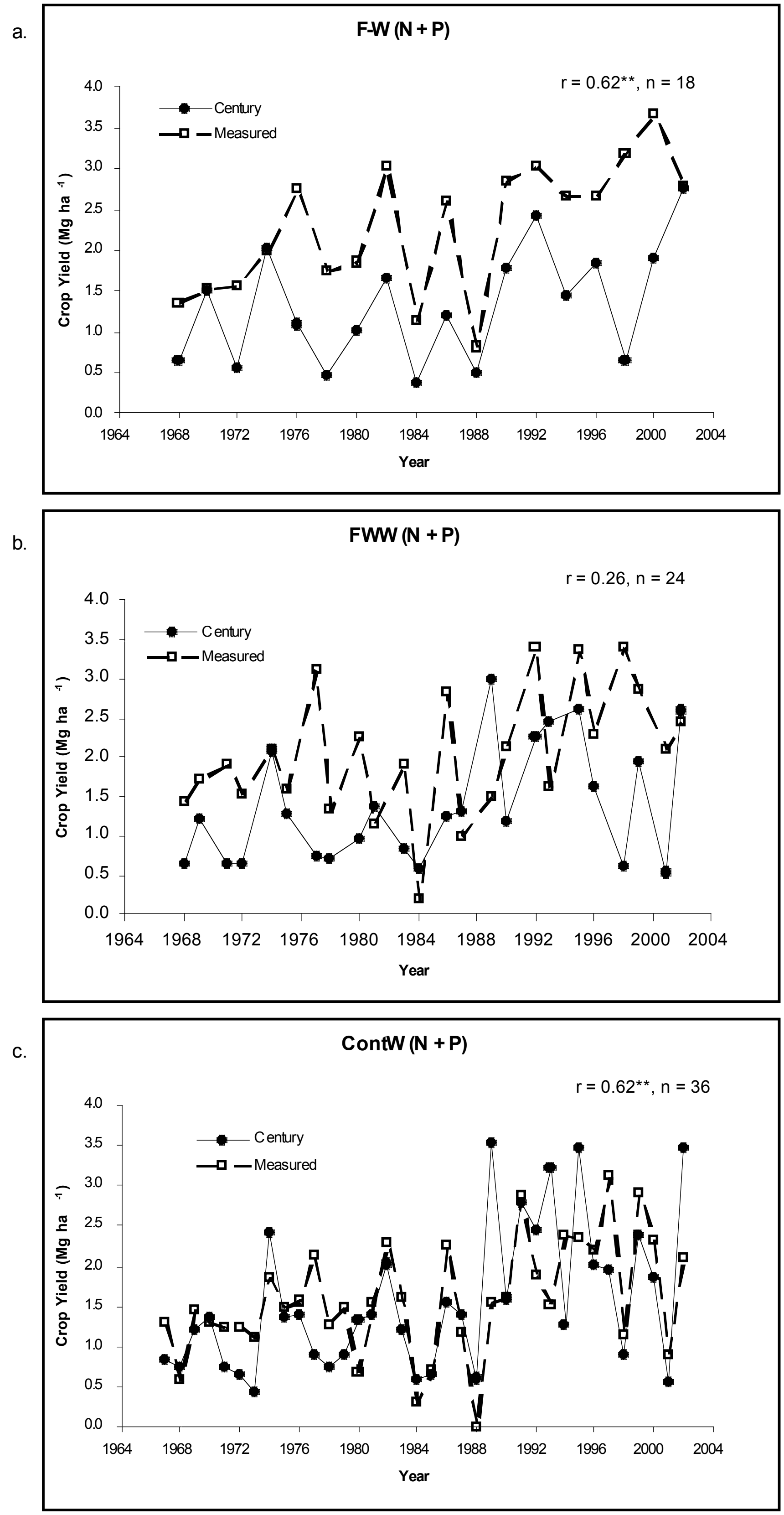


Fig. 5. Measured and estimated crop yield by Century on the a) F-W (N + P) (only one phase estimated), b) F-W-W (N + P), and c) ContW (N + P) treatments at Swift Current SK.