Quantitative Changes in Soil C over 17 years under Minimum Tillage, Well Fertilized Crop Rotations in the Brown Soil Zone

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INTRODUCTION

- Scientists and the agricultural community are seeking ways to quantify C sequestration in soils as influenced by crop management.
- We know that C sequestration can be increased by reducing tillage and summerfallowing, by improved crop nutrition and re-establishing perennial grasses.

- However, measuring soil C changes is tedious because changes are small, slow and field variability high. Consequently, quantification using models may be a more effective approach.

- After assessing results of the first 18 years of the "Old Rotation" experiment at Swift Current, a new study was initiated on a nearby site in 1987 where we employed more up-to-date management.

- We monitored soil organic C (SOC) at regular intervals.

In this paper our goal was to compare the effectiveness of 3 models in quantifying the effect of cropping frequency, wheat class, legume green manure (LGM), flexible cropping based on spring soil moisture, and re-grassing cropped land, on C sequestration.

MATERIALS AND METHODS

- The "New Rotation" experiment was initiated in 1987 on a medium-textured, Brown Chernozem that had grown fallow-wheat (F-W) under conventional tillage with minimum fertilization for the previous 60 years.
- We employed minimum tillage, snow trapping, and fertilized plots based on soil tests.
- Measured SOC in 0-15cm depth in 7 crop rotations (Table 1), in 1990, 1993, 1996 and 2003. Starting SOCs for each treatment in1987 were estimated (Campbell et al. 2000).

- Tested 3 models [Century (Parton et al. 1987); the introductory C Balance model (ICBM) (Andren and Katterer, 1997), and the Campbell model (Campbell et al. 2000)], for their ability to quantify C sequestration.
- The models require estimate of C inputs. For ICBM and Campbell models we estimated C inputs which we derived from (i) grain yields and their relationship to straw yields (Table 2), and (ii) root yields to straw yields ratio. Century model simulated its own yields. We assumed 45% C in crop residue.
- For the Campbell model k_1 was assumed to be 0.02 yr^{-1} for F-W-W, F-Hy-Hy and LGM-W-W; for F-W-W-W and Cont W (if water) (fallowed 2 years) we assumed $k_1 = 0.01\ yr^{-1}$; for Cont W and crested wheatgrass, $k_1 = 0.001\ yr^{-1}$.
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RESULTS AND DISCUSSION

TRENDS IN SOC (1987 - 2003)

- Between 1990 and 2003 only Cont W, and to a lesser extent Cont W (if water) had higher SOC in the 0-15cm depth than the other treatments (Table 1).
- SOC increased in most rotations between1987 and 1996 (Fig. 1) due to the above average growing season precipitation during this period (Fig. 2), then SOC approached a new steady state. This suggests that we must be careful how far we attempt to extend projected SOC gains when estimating likely benefits of adopting best management practices in agriculture.

GAIN IN SOC (1987-2003)

- SOC gains in 0-15cm depth between 1987-2003 ranged between 0 (F-Hy-Hy) and 7.50 Mg ha^{-1} (Cont W) (Table 3).
- SOC gains (kg $ha^{-1}yr^{-1}$) were directly proportional to cropping frequency (F-W-W = 135, F-W-W-W = 335, and Cont W = 441).
- LGM-W-W gained SOC at a much higher rate than F-W-W (329 vs 135 kg $ha^{-1}yr^{-1}$).
- Canada Western Red Spring (CWRS) wheat, although out-yielded by Canada Prairie Spring (CPS) wheat by 26%, gained SOC at a higher rate (135 vs 0 kg $ha^{-1}yr^{-1}$).
- The 2 years of fallow, due to inadequate spring soil water in the Cont W (if water) treatment, resulted in 46% less SOC gain than Cont W (236 vs 441 kg $ha^{-1}yr^{-1}$).
- SOC gain under the grass was 282 kg $ha^{-1}yr^{-1}$ (Table 3) but most of the gain occurred in the last 7 years (Table 1).

MODEL ESTIMATES OF SOC TRENDS

- Both ICBM and the Campbell models performed equally well in simulating SOC trends ($r^2 = 0.55^{**}$) (Figs. 3 and 4).
- Century was less effective ($r^2 = 0.22^{*}$), partly because of its limited ability to simulate yields (Fig. 5).
- C input, and therefore yield, is the main factor influencing SOC gain (Fig. 6); while measured yields are used in ICBM and the Campbell model, Century uses simulated yields.

EFFICIENCY OF CONVERSION OF RESIDUE C TO SOC

- We calculated efficiency of conversion of C inputs to SOC gained (Table 3).
- Efficiencies increased with cropping frequency, were higher for systems that included LGM, and in systems with CWRS wheat compared to CPS wheat.
- Efficiency of conversion was 8% for F-W-W, 15% for LGM-W-W, and 21% for Cont W.

CONCLUSIONS

When a medium-textured Brown Chernozem that had been managed as fallow-wheat with minimum fertilization and tilled conventionally for 60 years was converted to minimum tillage with snow management and proper fertilization, SOC gains in the 0- to 15-cm depth were observed over 17 years in most systems examined, reflecting the above-average precipitation received in this period. SOC gains were directly proportional to cropping frequency, was greater for legume green manure containing systems than monoculture wheat, and greater under CWRS wheat class than under CPS wheat, even though the latter had 26% greater yield. Summerfallowing for 2 years in 17 caused a marked suppression in SOC gains. SOC gains were moderate under crested wheatgrass but gains were only evident after 10 years. In all other systems SOC gains reached a new steady state after 10 years. Of the three models tested, ICBM and the Campbell models were the most effective in simulating SOC trends; Century performed less effectively perhaps because of difficulties in simulating yields.

REFERENCES

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Campbell, C. A., Zentner, R. P., Selles, F., Biederbeck, V. O., McConkey, B.G., Blomert, B. and Jefferson, P. G. 2000. Quantifying short-term effects of crop rotations on soil organic carbon in southwestern Saskatchewan. Can. J. Soil Sci. **80:** 193-202.

Parton, W. J., Schimel, D. S., Cole, C. U. and Ojima, D. S. 1987. Analysis of factors controlling soil organic matter levels in great plains grasslands. Soil Sci. Soc. Am. J. **51:** 1173-1179.

Table 1. Effect of rotation on trends in soil organic C in 0-15 cm depth (1990-2003)

Treatment[y]	0-15 cm[z]				
	1990	1993	1996	2003	mean
	------------------(Mg ha^{-1})--------------------------				
F-W-W	29.88	30.37	33.35	31.80	31.35
F-Hy-Hy	30.46	30.75	31.75	29.91	30.72
LGM-W-W	28.94	31.79	32.19	33.38	31.57
F-W-W-W	28.21	30.12	33.09	32.94	31.09
Cont W	30.53	35.00	35.24	36.70	34.37
Cont W (if water)	30.52	33.51	35.55	34.26	33.46
CWG	29.75	29.79	31.08	34.20	31.20
Mean	29.47	31.09	32.88	32.64	31.52
LSD ($P<0.05$)	Treat** = 2.95; Year* = 1.76; Treat x year^{ns} =5.64				

[z] Estimated starting SOC in 0-15 cm depth based on Campbell model are, respectively, 29.5, 29.9, 27.8,27.3, 29.2, 29.5 and 29.4 Mg ha^{-1} for the rotation treatments listed in sequence from F-W-W to CWG.

[y] F = fallow, W = Canada Western red spring wheat, Hy = Canada prairie spring wheat (high yielding), LGM = legume green manure, Cont = continuous, Cont W (if water) = crop annually but fallow if spring moisture too low, CWG = crested wheatgrass cut for hay.

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

Crop	Regression
Canada Western red spring wheat	C input = 1.20 Y + 64
Canada prairie spring wheat[x]	C input = 0.76 Y + 484

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

[y] Calculated from regressions relating straw to grain yield; assuming root/straw ratio = 0.59 and C in residue = 45%. For CWG only root mass (i.e., 0.59x hay yields) was used to estimate C inputs.

Table 3. SOC gain, C input and efficiency of conversion[z] of C input to SOC (%) (1987-2003)

Treatment	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	2.30	135	1759	28.14	8.17
F-Hy-Hy	0.01	0	1689	27.02	0.04
LGM-W-W	5.58	328	2319	37.10	15.04
F-W-W-W	5.64	332	1904	30.46	18.52
Cont W	7.50	441	2281	36.50	20.54
Cont W (if water[y])	4.76	280	2202	35.23	13.51
CWG	4.80	282	552	8.83	54.36

[z] SOC gain (1987-2003) ÷ total C inputs (1987-2002) for 0-15cm depth.
[y] This treatment was fallowed twice.

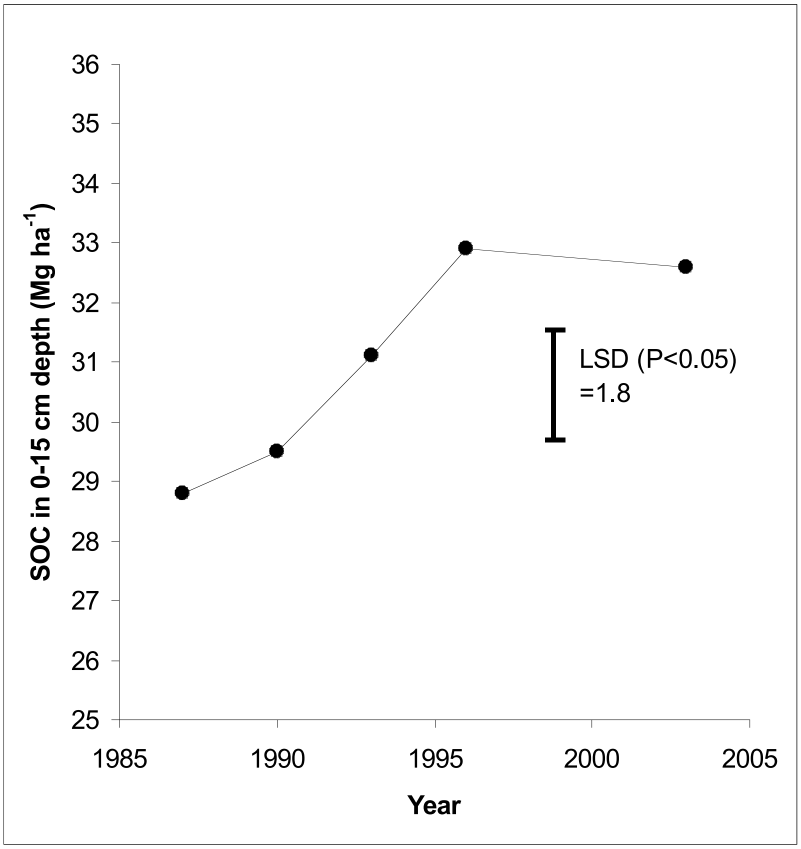


Fig. 1. Trends in SOC (1987-2003) averaged over rotations

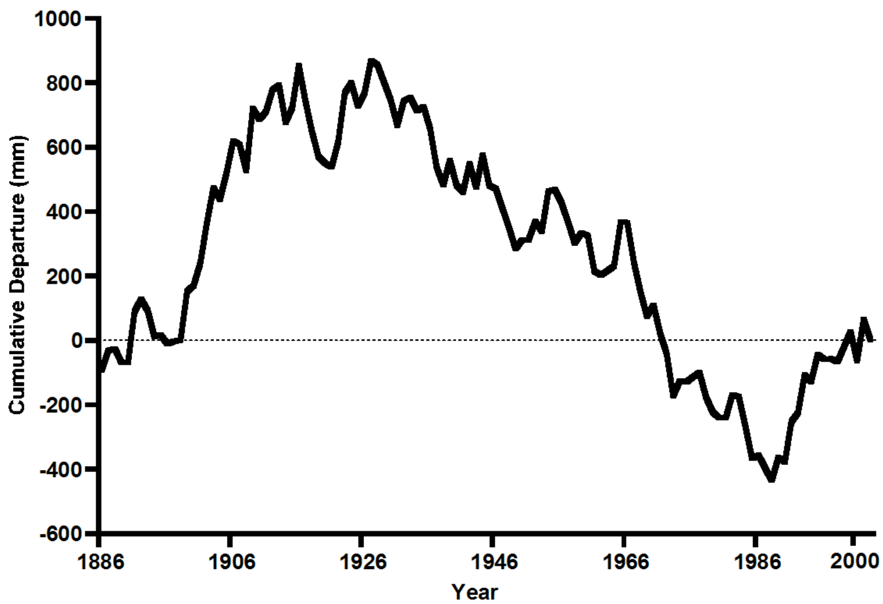


Fig. 2. Accumulated departure from the long-term mean growing season (1 May to 31 August) precipitation at Swift Current for the period 1886 - 2003. (Long-term mean = 211mm). Note: Only slopes are meaningful. Positive slopes denote period of above average precip; negative slopes denote period of drought; zero slope denotes period of average precip.

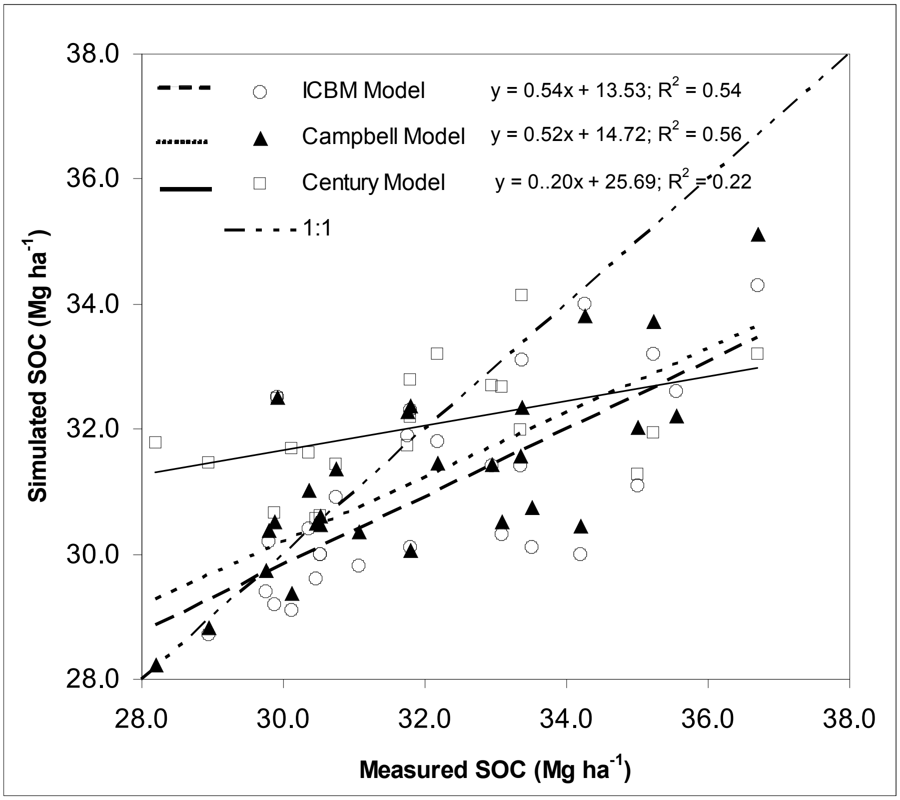
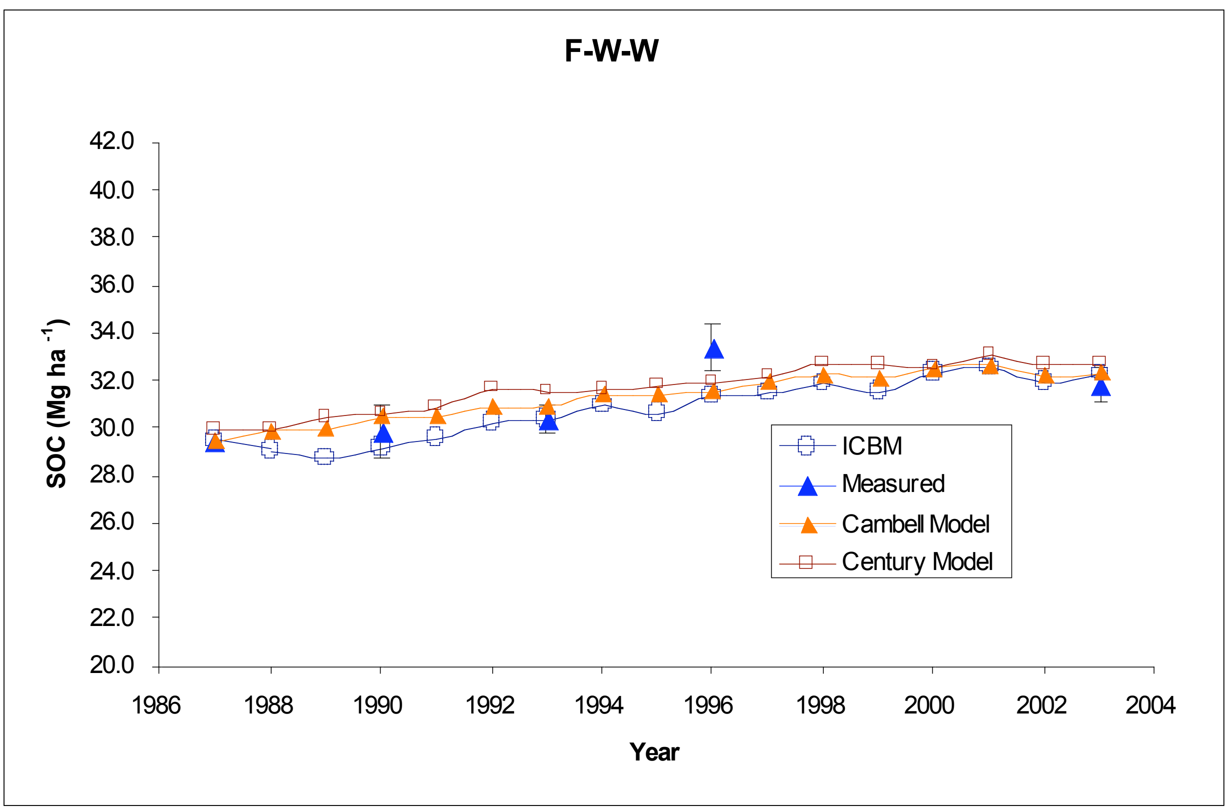
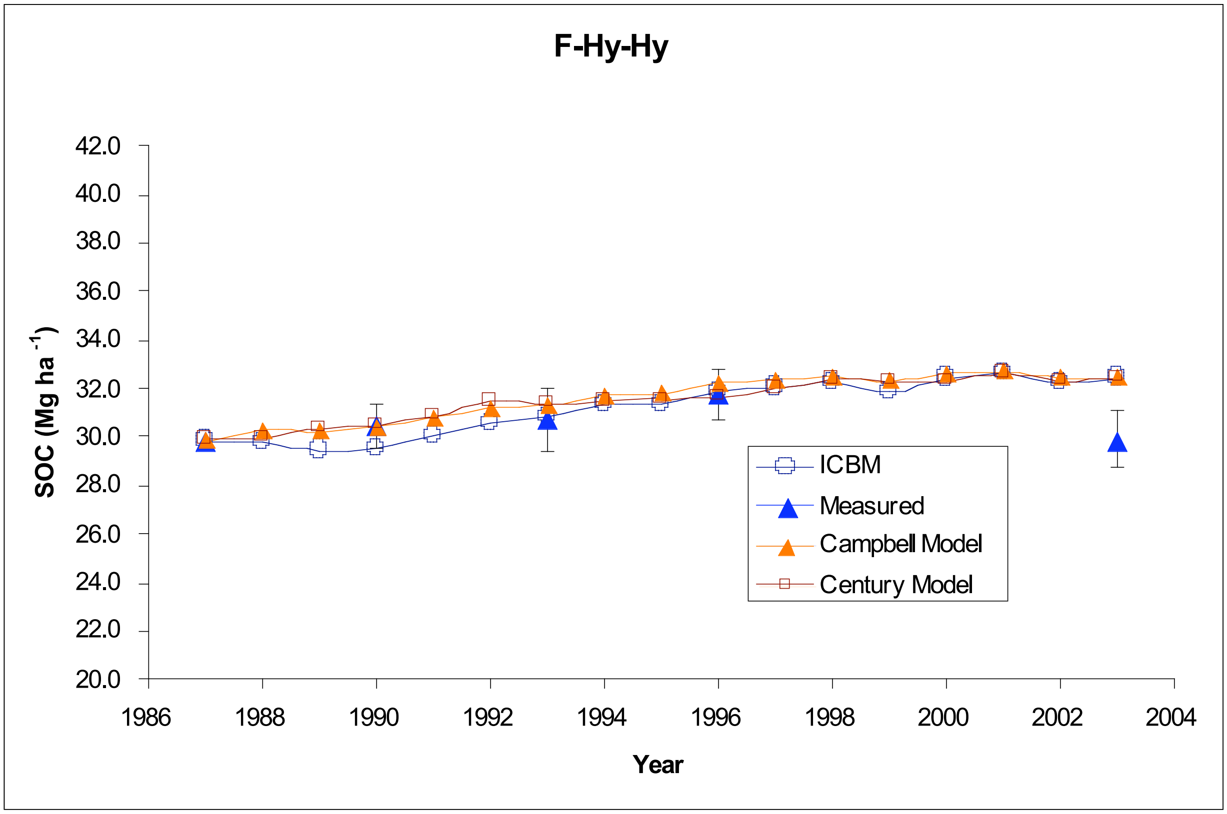
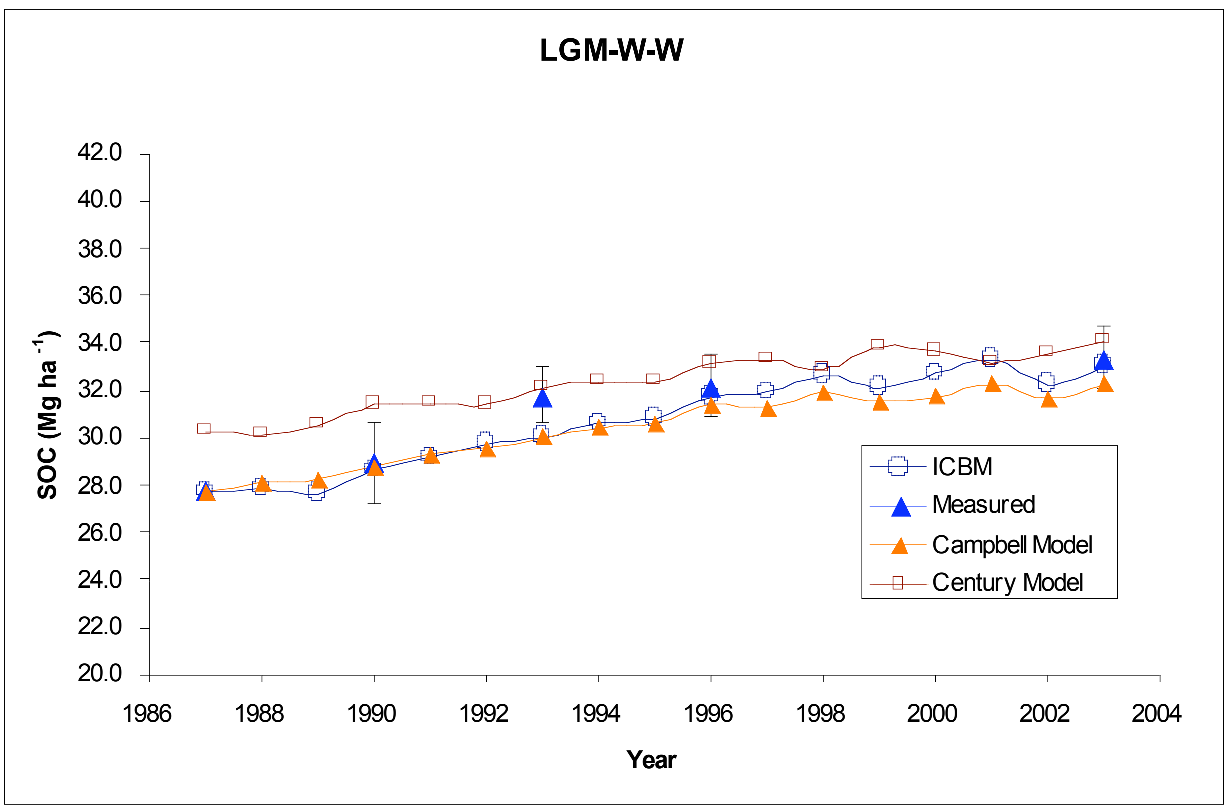
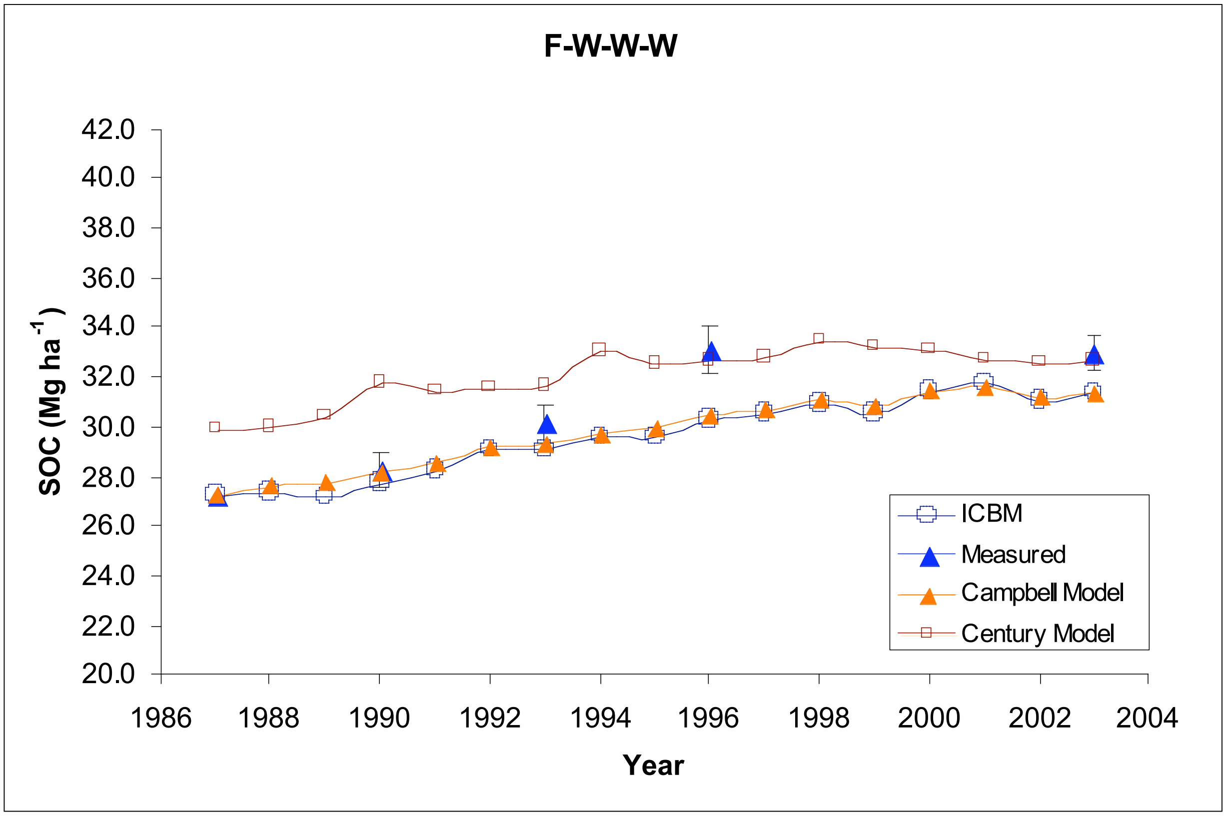


Fig. 3. Relationship between simulated SOC in 0-15 cm depth and measured SOC for the Campbell, ICBM and Century models.




F-Hy-Hy
42.0
40.0
38.0
36.0
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
SOC (Mg ha -1)
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
Year
ICBM
Measured
Campbell Model
Century Model


LGM-W-W
42.0
40.0
38.0
36.0
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
SOC (Mg ha -1)
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
Year
ICBM
Measured
Campbell Model
Century Model


F-W-W-W
SOC (Mg ha^{-1})
42.0
40.0
38.0
36.0
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
1986
1988
1990
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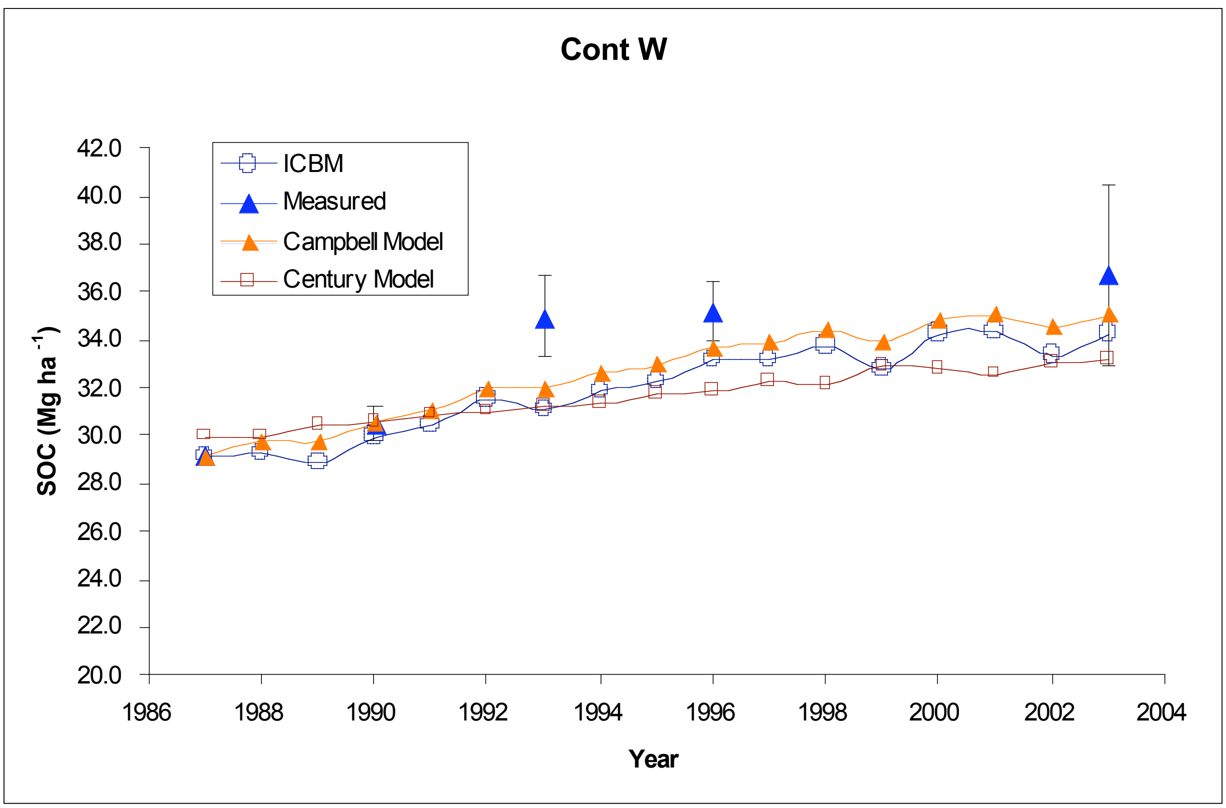
2004
Year
ICBM
Measured
Campbell Model
Century Model


Cont W
SOC (Mg ha^{-1})
42.0
40.0
38.0
36.0
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
1986
1988
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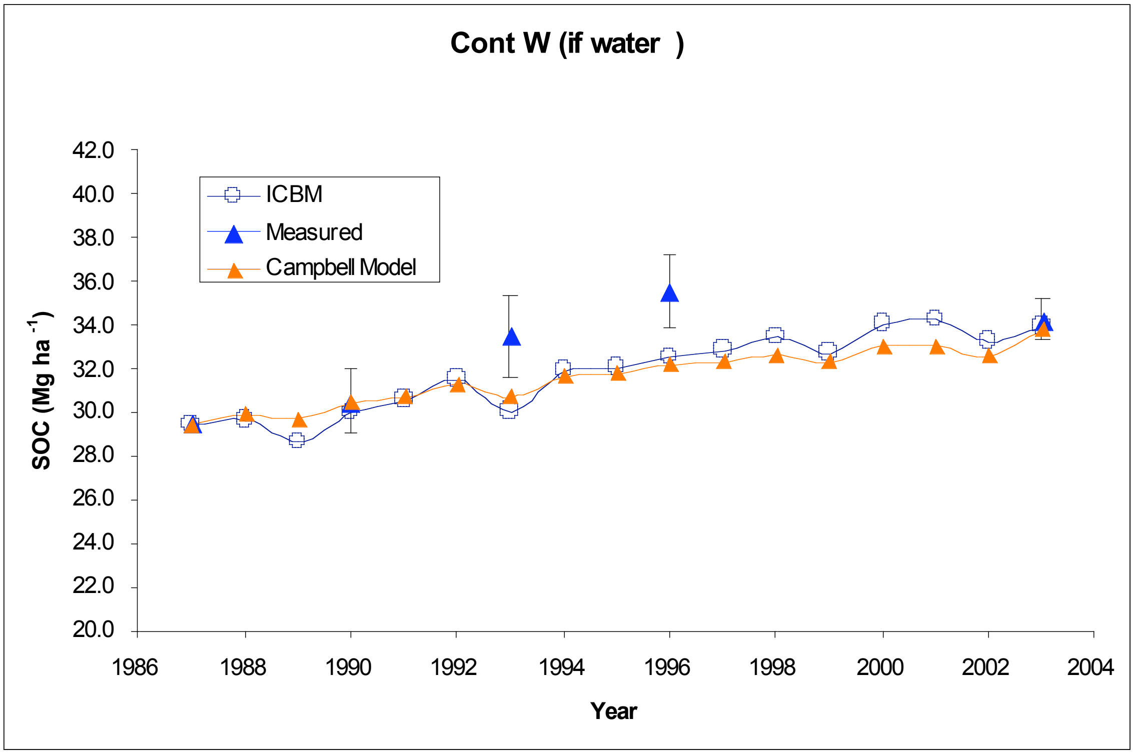
2004
Year
ICBM
Measured
Campbell Model
Century Model



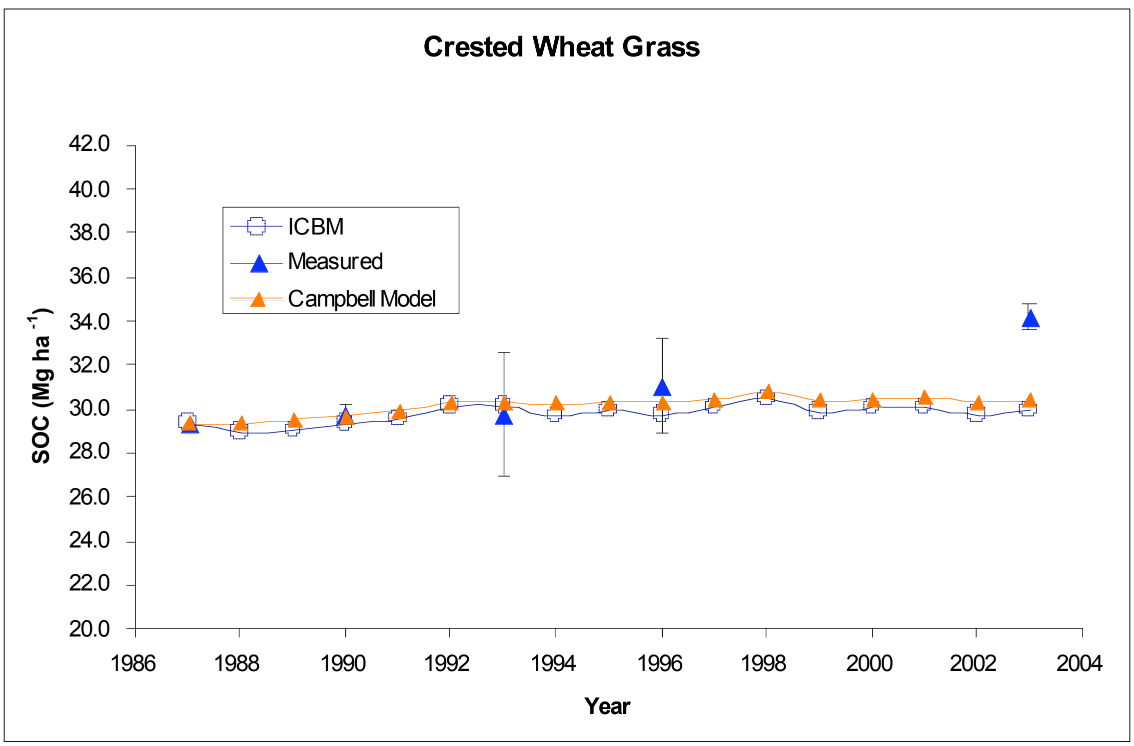
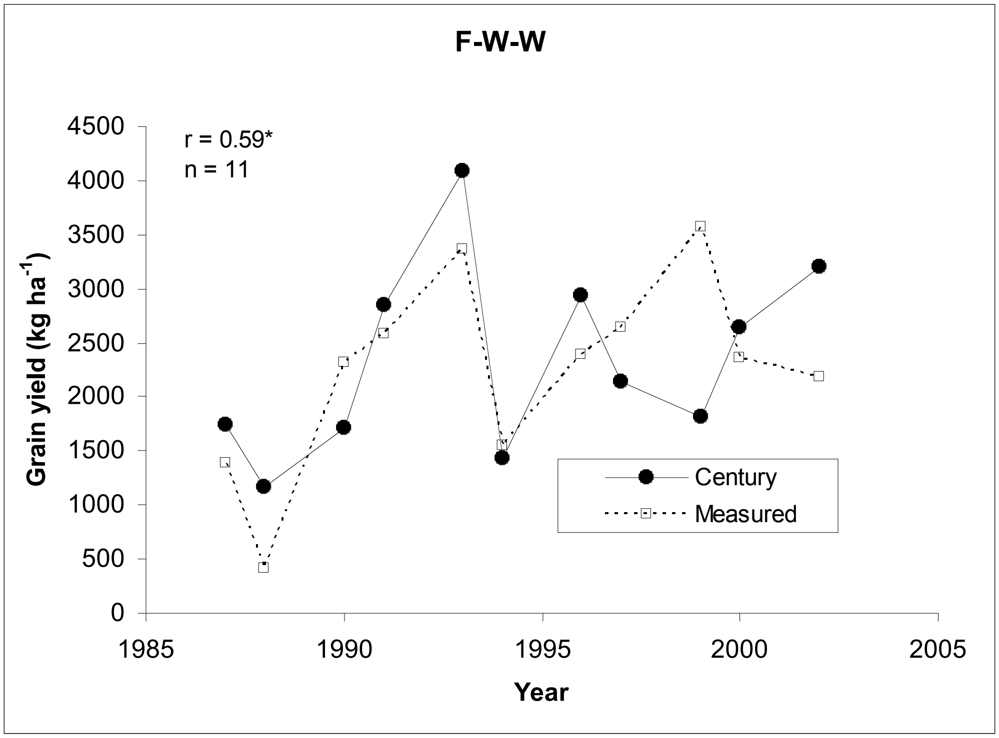
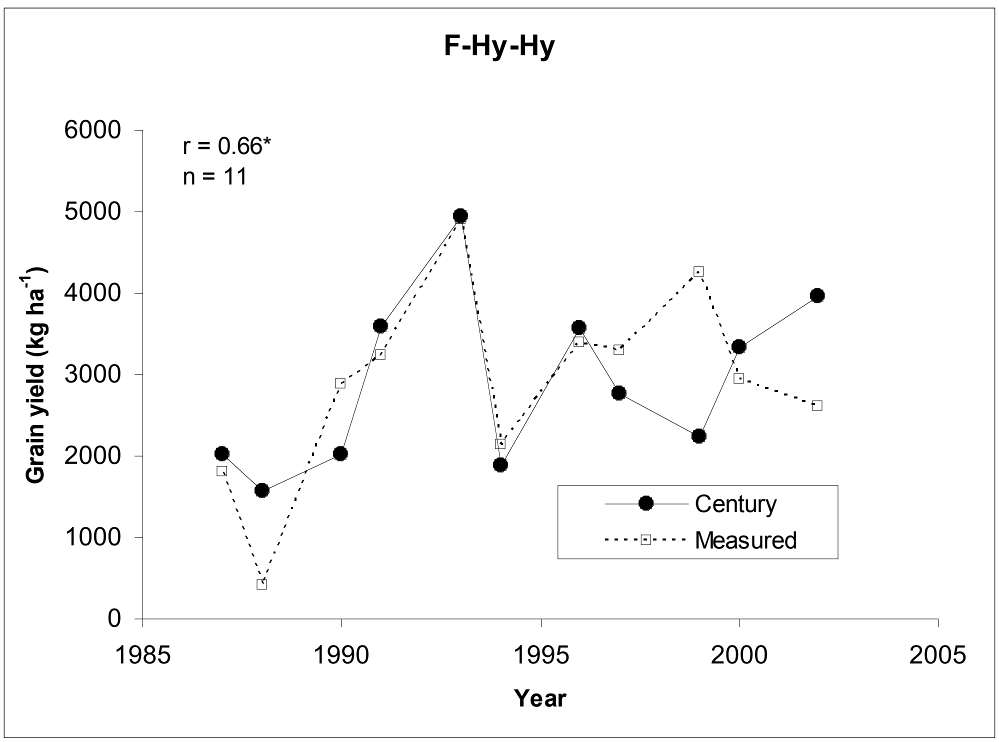


Fig. 4. Trends in SOC in 0-15 cm depth 1987-2003, as measured and modeled by ICBM, Campbell and Century. Vertical bars on measured points are standard error of mean.


F-W-W
r = 0.59*
n = 11
Grain yield (kg ha-1)
Year
Century
Measured


F-Hy-Hy
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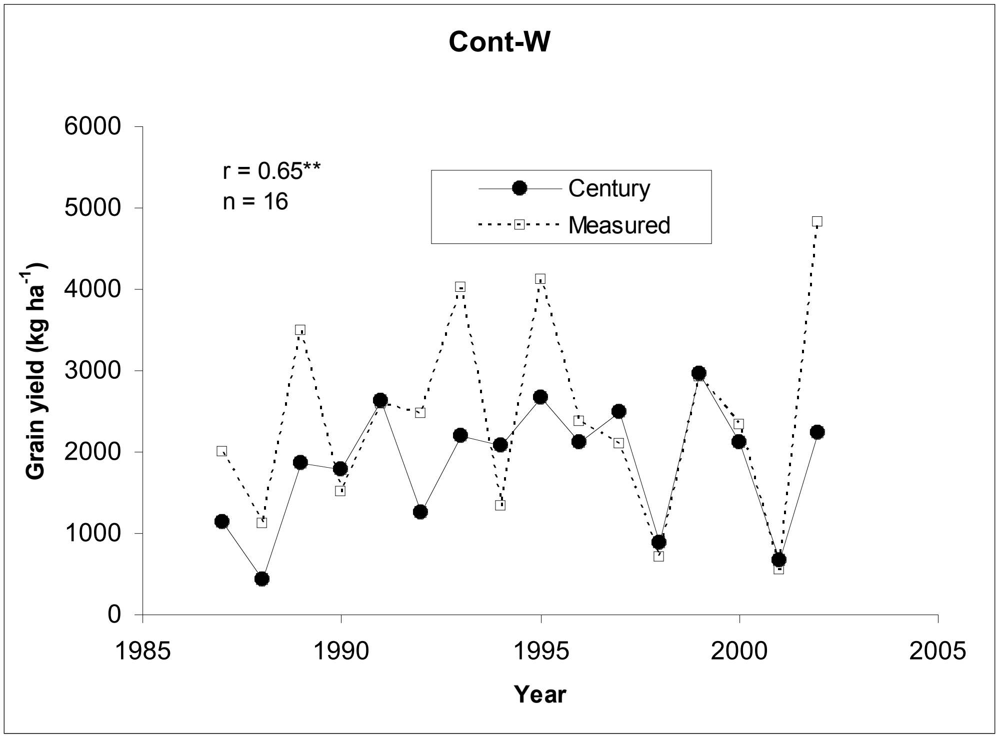
n = 11
Grain yield (kg ha-1)
Year
Century
Measured



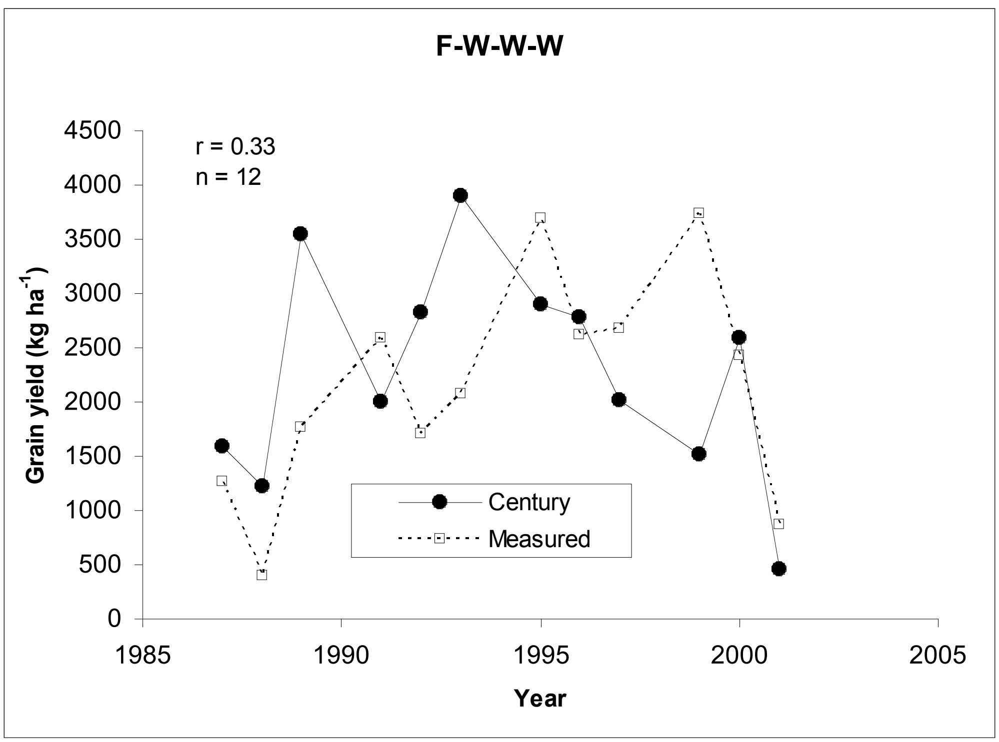


Fig. 5. Measured and estimated wheat yields by Century model (Only two phases of rotation simulated for fallow-containing systems).

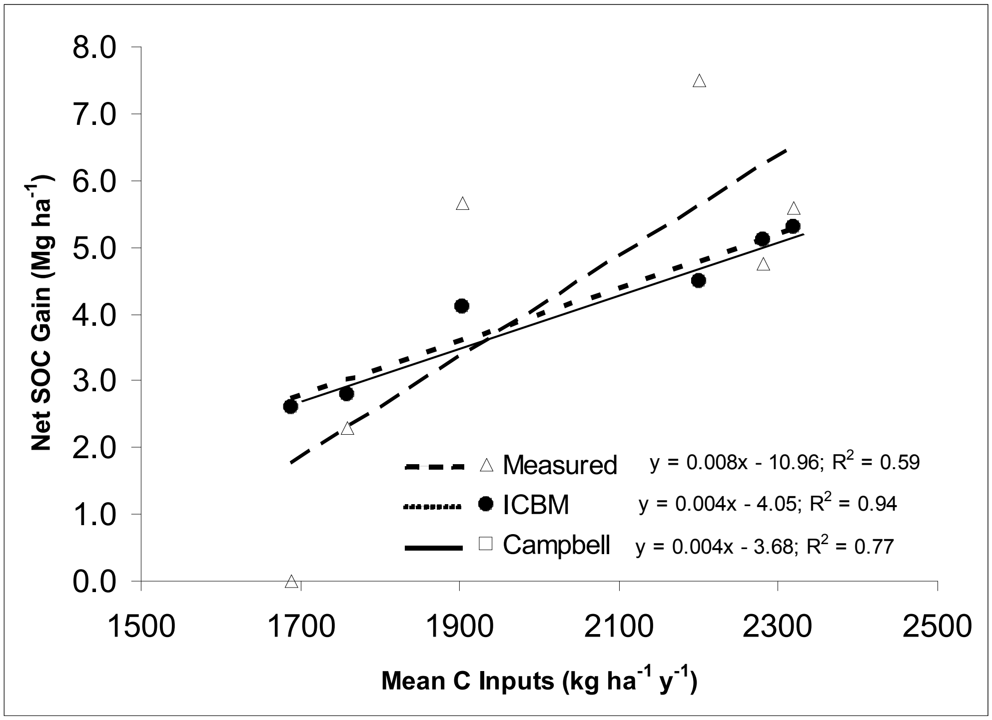


Fig. 6. Relationship between net SOC gain in 0-15 cm depth (measured and modeled) between 1987 and 2003 and C inputs.