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Effective organic matter stock management in agricultural practices: modeling and observation

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ZUSAMMENFASSUNG/ SUMMARY

RothC soil carbon dynamic model was used for simulation SOC stocks in 6 Russian long-term fertilization experiments for estimation which agricultural practices lead to soil C accumulation. For all the treatments tested above ground NPP input is sufficient for maintaining constant SOM stocks and additional C gain.

SCHLÜSSELWORTE/ Keywords: Soil organic carbon, Long-term experiments, Fertilization, Modeling

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EINLEITUNG/ INTRODUCTION

Building up soil organic matter (SOM) stock in croplands can greatly help tackle the trilemma faced by world agriculture today - high productivity, low GHG emissions and adaptation to climate change (Smith at al., 2013). However, possibility of effective SOM management have certain limitations including the following constraints: the quantity of C stored in soil is finite, the process is reversible and building up SOC can potentially increase GHG fluxes (Powlson et al., 2011). High uncertainty of the climate effect in agricultural systems connected with a regular removal of harvest biomass and absence of a real equilibrium state. SOC dynamics can be not directly reflecting NPP gradual growth, when organic carbon input from vegetation has increased: this will depend on the history of the plot as well as on carbon – cycle deviations caused by changing pattern of extreme years (Heimann, Reichstein, 2008). The most advanced tools available to predict the interactions between climate change and SOC cycle on timescales from decades to centuries are linked dynamic crop growth and soil carbon models. SOC dynamic models that are designed at the plot or farm scale and use complex functions generally routing the soil C through a number of pools with different residence times (Paustian et al., 1997). These ecosystem models can be run for polygons with a specific combination of soil, land use and climate characteristics (Falloon et al., 1998) and have been extensively validated on long-term experiments (Smith et al., 1997). However, the value of model predictions is not only dependent on the capacity of models to simulate accurately observed SOC dynamics. Validation datasets from long-term trials provide the basis for understanding cropland responses to key natural and management drivers such as climate and productivity, land use changes, soil fertility and greenhouse gas emissions (Romanenkov et al., 2007).

EREBNISSE/ RESULTS

RothC-26.3 model outputs for changes in soil C were compared with those measured in 6 Russian long-term fertilization experiments on podzol, podzoluvisols and chernozem launched in 1948-80 in crop rotations with control, fertilized, manured, fertilized and manured treatments (Table 1). The model gave an acceptable approximation to the measurements for all the 16 treatments tested.

Tab. 1: Russian Long-term experiments with fertilizers used for dynamic modeling ((FB- fodder beet; SW-spring wheat; P-potatoes; O-oats; C-clover,;G-grass+clover; WW-winter wheat; L-lupin; SB- spring barley; WR-winter rye; F-black fallow; FL-flax; S-sunflower, CS- silage corn, CG-corn for grain) (Romanenkov, 2013)

LTE – site, region	DAOS 3, Moscow Region	DAOS 4, Moscow Region
Founded	1937	1933
Crop rotation	FB-SW-P-O	C-WW-P-SB+C
Soil	Albeluvisol, heavy loam	Albeluvisol, heavy loam
Treatments	Control, 2 NPK, NPK, 3NPK+FYM	Control FYM NPK
SOC interval, t /ha	25-38	15-29

LTE – site, region	VNIIOU, Vladimir Region	Perm NIISKH, Experiment 3, Perm Region
Founded	1968	1971
Crop rotation	L-WW-P-SB	F-WR-SW+C-C –C-SB-P-O
Soil	Podzol, loamy sand	Albeluvisol, heavy loam
Treatments	Control, NPK FYM, 1/2 FYM+ 1/2 NPK	NPK FYM, 1/2 FYM+ 1/2 NPK
SOC interval, t /ha	16-26	30-37

LTE – site, region	Flax Institute, Tver Region	Don Zonal Agricultural institute, Rostov Region
Founded	1948	1974
Crop rotation	F-WR+G-G-G-FL-P-SW-O	F-WW-CG-SB-CS-WW-P-WW-S
Soil	Albeluvisol, sandy loam	Haplic chernozem , heavy loam
Treatments	Control FYM+NPK PK	Control, 1 level- NPK+FYM , 2 level - FYM+NPK
SOC interval, t /ha	18-31	82-92

History of the plot can be an important factor of soil C dynamics in the long-term. Possible gains in soil C on light soils are usually connected with accumulation of C in the pool of resistant plant material (RPM) which can be more sustainable under arid weather conditions. For fine-textured soils it was found that if long-term C input was inadequate to maintain SOC it led to a consistent decrease of RPM and microbial biomass pools (Figure 1). These pools can regard as early indicators of sustainability in the tested crop management system. Inputs of 1.0-2.0 and 2.8-2.9 C $m^{-2}yr^{-1}$ were required to maintain soil C on podzoluvisols and chernozem, accordingly (Table 2). For all the control treatments tested above ground NPP input is sufficient for not only maintaining constant SOM stocks but providing additional C gain. These results support findings of Kozlovsky (1998) about the potential for agricultural soils to be a sink for CO2 during the transition to more C-conserving practices. Preferable effect of agronomic practices on active C pools leads to possibility of C sequestration only in a short-term and makes it highly yield-dependent. These results were used to predict SOC stocks changes over time up to 2050 using outputs from HadCM3 climate model and generated changes of climatic extremes pattern. On podzols change in crop rotation system was more important factor for additional C sequestration in comparison with manure application. Soil C annual gain existing under average climate conditions (0.1-0.24 t ha-1) changes to -0.02-0.04 t ha-1 loss for consistent climate extreme years (Table 3). Under consistent favorable years maximum SOC gain can reach 0.26-0.48 t ha-1.

Tab. 2: C balance parameters estimated in the selected long-term experiments for different treatments ([1]NPK+FYM 1 level, [2]NPK+FYM 2 levels) (Romanenkov, 2015)

Site	Parameter annual average, t per ha	Treatments	
		Control	NPK
Vladimir Region, VNIIOU	C input	905	1034
	Δ SOC	-0.022	-0.013
Perm NIISKH, Experiment 3	C input	1263	1322
	Δ SOC	-0.108	0.023
Tver Region, Flax Institute	C input	1759	1992
	Δ SOC	0.069	0.090
Rostov Region, Don Zonal Institute	C input	1783	2814[1]
	Δ SOC	-0.352	-0.020

Site	Parameter annual average, t per ha	Treatment FYM	C input sufficient for sustainable SOC stock
Vladimir Region, VNIIOU	C input	2773	1077
	Δ SOC	0.328	0
Perm NIISKH, Experiment 3	C input	2101	1409
	Δ SOC	0.238	0
Tver Region, Flax Institute	C input	3081	1480
	Δ SOC	0.277	0
Rostov Region, Don Zonal Institute	C input	3142[2]	2870
	Δ SOC	0.089	0

Therefore, in favorable years SOC accumulation demonstrate twofold increase, the highest values are expected for treatments with mineral or organic fertilization. At the same time in the extreme years, the same treatments demonstrate losses of existing SOC stocks that can be as high as annual average gain (mineral fertilization treatment in DAOS 4 experiment). Minimal vulnerability of SOC stocks to climate extremes was found for the control treatments in the both experiments. Thus,

Tab. 3: Simulated values of annual change in the SOC stock (t ha^{-1}) in 2011-2060 for the two long-term field experiments on arable albeluvisols (Romanenkov, 2015)

DAOS 3 experiment, Moscow Region			
Treatment	Average annual C input	25% C input increase	25% C input decrease
Control	0.10	0,26	-0,02
2 NPK	0.16	0,36	-0,04
3 NPK	0.24	0,44	-0,04
3 NPK+FYM	0.19	0,48	-0,02
DAOS 4 experiment, Moscow Region			
Treatment	Average annual C input	25% C input increase	25% C input decrease
Control	0.01	0.24	-0.10
FYM	0.18	0.36	-0.04
NPK equiv.	0.12-0.20	0.28-0.30	-0.10-0.14

Reaching new level of soil fertility needs not less than 10-20 years but it demonstrates further changes after achieving near-equilibrium state

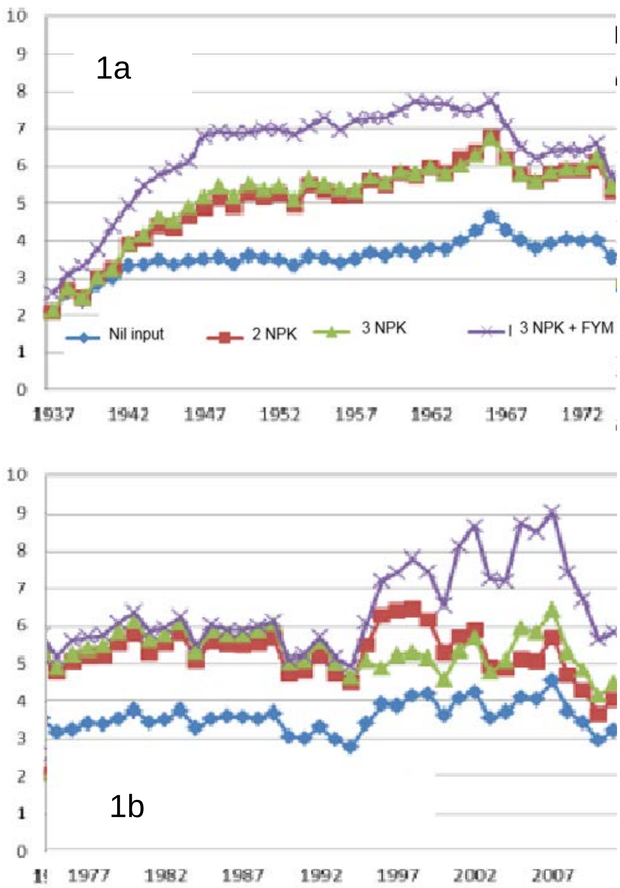

Fig. 1: Dynamics of C in resistant plant material pool in DAOS 3 (1937-1972, 1a) (1972-2011, 1b) long-term experiment

The changes in the observed trends for different fields with the same treatments are related to the initial level of soil fertility and different crop-climatic year combinations.

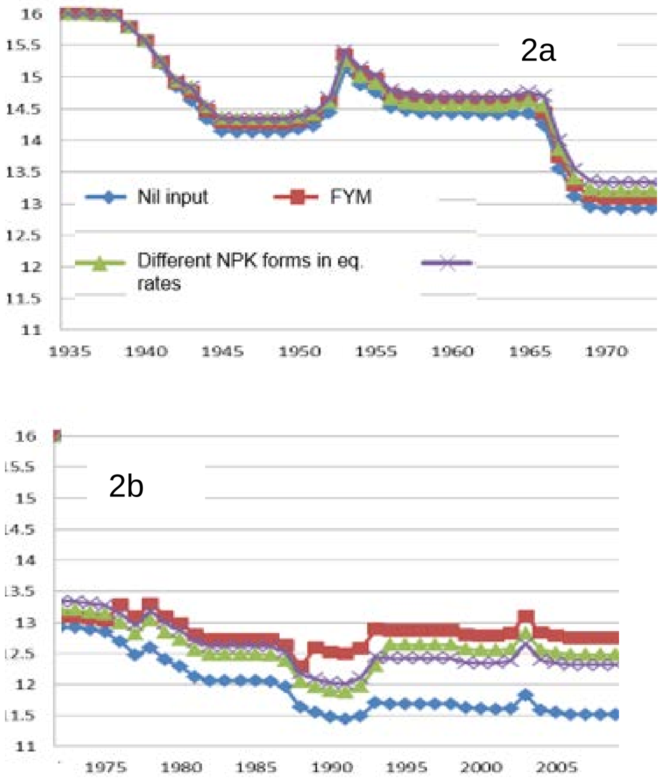

Fig. 2: Dynamics of C in resistant plant material pool in DAOS 4 (1933-1972, 2a) (1972-2011, 2b) long-term experiment

SCHLUSSFOLGERUNGEN/ CONCLUSION

- For all the experiments and treatments tested in the long-term experiments with fertilizers above ground NPP input is sufficient for maintaining constant SOM stocks and providing additional C gain.
- Annual average inputs of 1.4-2.0 and 2.8-2.9 C t per ha were required to maintain soil C on podzoluvisols and chernozem.
- Preferable effect of agronomic practices on active C pools leads to possibility of C sequestration only in a short-term as it highly yield-dependent.
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