

Schierhorn, Florian; Faramarzi, Monireh; Prishchepov, Alexander V.; Koch, Friedrich J.; Müller, Daniel

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Quantifying yield gaps in wheat production in Russia

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Supplementary materials for:

Quantifying yield gaps in wheat production in Russia

Florian Schierhorn^{1,*}, Monireh Faramarzi², Alexander V. Prishchepov¹, Friedrich J. Koch¹, Daniel
Müller^{1,3}

¹ Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Theodor-Lieser-Str. 2,
06120 Halle (Saale), Germany

² University of Alberta Water Initiative, University of Alberta, Edmonton, AB T6G 2E9, Canada

³ Department of Geography, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

* Corresponding author (schierhorn@iamo.de; Tel.: +49 (345) 2928 335)

Text A1: Sensitivity analysis

Sensitivity analyses for each of the 28 provinces were conducted to assess the responses of the model to the changes in the input parameters. We pre-selected 28 parameters that are potentially sensitive to wheat yield and pre-defined reasonable parameter ranges based on a literature review, local knowledge, and a one-at-a-time sensitivity analysis using the SWAT Calibration and Uncertainty Program (SWAT-CUP; Abbaspour et al., 2007). The parameters that affected wheat yields in each province were subsequently considered for calibration in the Sequential Uncertainty Fitting Program (SUFI-2).

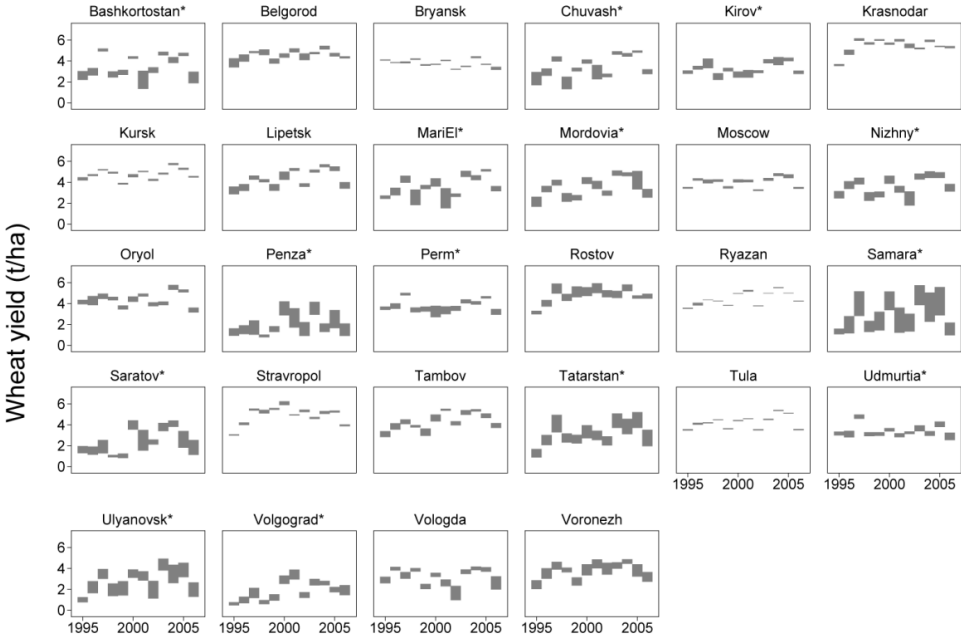
Text A2: Sensitivity results

Parameter sensitivity was reasonably consistent across the provinces (Table A1). As expected, the parameters regulating soil fertility (annual N fertilizer supply (FRT_KG), and organic carbon content (CBN)) were among the most sensitive parameters in almost of the provinces. The wheat yield was sensitive to soil-related parameters, such as bulk density (SOL_BD), the fraction of porosity from which anions are excluded (ANION_EXCL), and the saturated hydraulic conductivity. In addition, wheat the wheat yields were sensitive to the parameters that regulated the surface and sub-surface water flows, such as the SCS runoff curve number for moisture condition II (CN2), the plant uptake compensation factor (EPCO), the soil evaporation factor (ESCO), and the threshold depth of the water in the shallow aquifer for return flow (GWQMN).

The simulation results were insensitive to most of the groundwater-related parameters. This finding suggests that the soil and plant water availability are not decisively regulated by the parameters that are related to groundwater. The yields were highly sensitive to the available water capacity (AWC) and many of the crop-related parameters. However, we were unable to set realistic ranges for the AWC and crop-related parameters in the sensitivity analysis and calibration because the available data were not precise enough. Instead, comparable and more realistic yield potential estimates were generated by excluding the AWC and crop-related parameters from the calibration. Hence, we set the AWC values at 0.15 and 0.1 for the first and second soil layers, respectively, in all of the simulations and used the default parameters in the SWAT crop database.

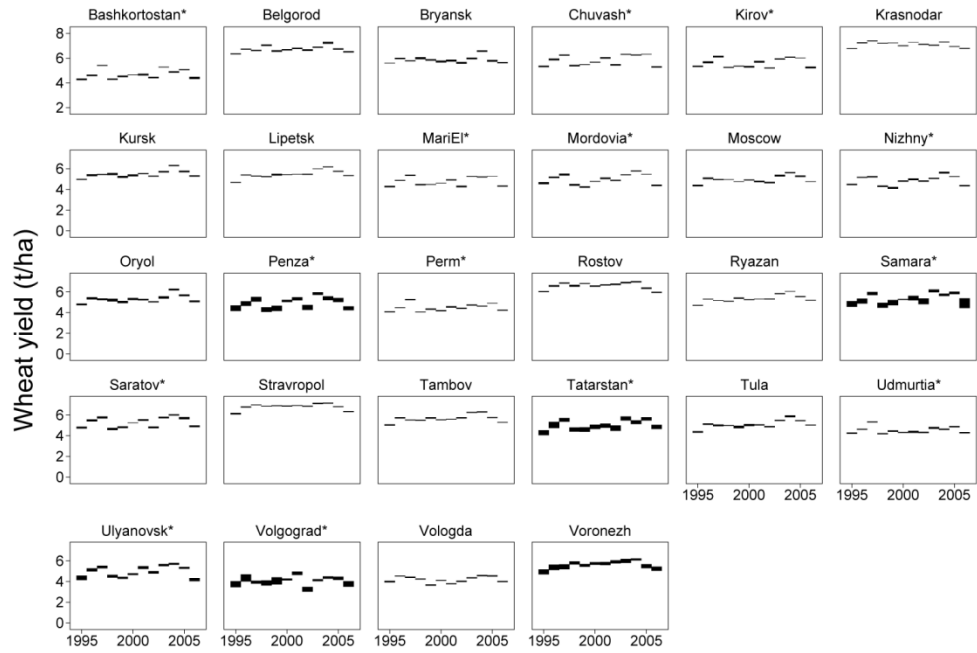
Figure A1. Annual yield potential without nutrient stress (S1) (A) and without nutrient and water stress (S2) (B).

Without nutrient stress (S1):



* Spring wheat

Without nutrient stress and fully irrigated (S2):



* Spring wheat

Table A1. Parameter sensitivity.

Winter wheat	Moscow		Tula		Ryazan		Bryansk		Orel		Lipetsk		Tambov	
	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value
FRT_KG{4,3}.mgt	18.5	0.0	9.0	0.0	5.1	0.0	8.4	0.0	3.6	0.0	4.9	0.0	1.9	0.1
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FRT_KG{12,3}.mgt	17.5	0.0	1.1	0.3	11.8	0.0	20.2	0.0	2.1	0.0	11.9	0.0	7.6	0.0
FRT_KG{3,3}.mgt	16.5	0.0	11.2	0.0	11.8	0.0	2.3	0.0	12.2	0.0	3.1	0.0	8.2	0.0
EPCO.hru	14.6	0.0	4.9	0.0	4.1	0.0	1.1	0.3	-1.4	0.2	-5.5	0.0	-0.7	0.5
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FRT_KG{10,3}.mgt	14.0	0.0	13.8	0.0	-5.2	0.0	15.1	0.0	-2.4	0.0	-3.5	0.0	-2.9	0.0
FRT_KG{6,3}.mgt	13.1	0.0	9.5	0.0	0.7	0.5	3.2	0.0	-5.8	0.0	0.4	0.7	0.0	1.0
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FRT_KG{14,3}.mgt	12.9	0.0	10.4	0.0	10.7	0.0	12.2	0.0	-2.5	0.0	-3.2	0.0	-5.5	0.0
FRT_KG{7,3}.mgt	11.3	0.0	-0.2	0.8	-2.8	0.0	-2.8	0.0	-7.0	0.0	2.0	0.0	-0.5	0.6
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SOL_CBN(2).sol	10.2	0.0	4.6	0.0	6.2	0.0	11.2	0.0	-0.6	0.6	1.8	0.1	5.9	0.0
FRT_KG{5,3}.mgt	9.5	0.0	1.3	0.2	-8.4	0.0	-3.4	0.0	-4.3	0.0	-1.6	0.1	-2.3	0.0
FRT_KG{9,3}.mgt	7.5	0.0	-2.3	0.0	6.4	0.0	-2.4	0.0	-0.5	0.6	0.6	0.5	-5.4	0.0
FRT_KG{11,3}.mgt	7.3	0.0	8.2	0.0	13.1	0.0	-9.2	0.0	1.1	0.3	3.3	0.0	2.7	0.0
CN2.mgt	8.3	0.0	-0.7	0.5	4.5	0.0	1.3	0.2	2.9	0.0	-5.5	0.0	-9.5	0.0
SOL_BD(2).sol	5.4	0.0	1.4	0.2	1.2	0.2	-2.2	0.0	-1.2	0.2	2.2	0.0	2.7	0.0
SOL_CBN(1).sol	4.9	0.0	2.1	0.0	4.1	0.0	-5.5	0.0	0.0	1.0	-0.3	0.7	2.8	0.0
SOL_BD(1).sol	4.3	0.0	1.5	0.1	1.8	0.1	0.4	0.7	0.8	0.4	2.2	0.0	1.3	0.2
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FRT_KG{13,3}.mgt	3.7	0.0	-0.7	0.5	9.8	0.0	17.6	0.0	1.4	0.2	-8.8	0.0	4.6	0.0
LAT_SED.hru	-2.5	0.0	0.8	0.4	0.5	0.6	1.8	0.1	0.3	0.7	-0.8	0.4	1.4	0.2
DEEPST.gw	1.8	0.1	-0.5	0.6	1.2	0.2	0.3	0.8	-1.5	0.1	1.8	0.1	0.0	1.0
CANMX.hru	-1.7	0.1	-1.4	0.1	0.5	0.6	1.3	0.2	0.8	0.4	0.8	0.4	-1.1	0.3
USLE_K(2).sol	1.6	0.1	-1.1	0.3	-0.1	1.0	0.6	0.5	0.5	0.6	0.6	0.5	0.3	0.7
FRT_KG{8,3}.mgt	1.6	0.1	10.1	0.0	0.1	0.9	0.1	0.9	-2.0	0.0	6.6	0.0	8.9	0.0
FRT_KG{1,3}.mgt	1.3	0.2	-0.5	0.6	0.1	0.9	-0.1	0.9	-0.2	0.8	0.5	0.6	1.4	0.2
FRT_KG{2,3}.mgt	1.2	0.2	-0.5	0.6	2.7	0.0	-0.9	0.4	0.3	0.8	-1.3	0.2	1.7	0.1
GW_SPYLD.gw	-1.1	0.3	-0.1	0.9	-0.7	0.5	-1.3	0.2	0.9	0.4	1.8	0.1	1.0	0.3
GW_DELAY.gw	-1.1	0.3	0.1	1.0	-0.6	0.6	-0.7	0.5	1.0	0.3	-0.5	0.6	1.0	0.3
SOL_ALB(2).sol	-1.0	0.3	-0.8	0.4	0.5	0.6	-0.5	0.6	-0.5	0.6	0.2	0.8	0.2	0.8
ALPHA_BF.gw	-1.0	0.3	-0.6	0.6	1.7	0.1	-1.8	0.1	0.2	0.9	-0.1	0.9	-0.4	0.7
GW_REVAP.gw	-0.9	0.4	-0.2	0.8	1.3	0.2	0.2	0.9	-1.1	0.3	0.1	0.9	0.2	0.8
SHALLST.gw	-0.6	0.5	0.4	0.7	1.1	0.3	-1.4	0.1	0.1	0.9	-1.1	0.3	0.1	0.9
ESCO.hru	-0.6	0.5	-1.3	0.2	-3.9	0.0	-0.5	0.6	-0.7	0.5	3.6	0.0	1.3	0.2
ANION_EXCL.sol	-0.6	0.5	-0.2	0.8	-1.9	0.1	-0.5	0.6	0.1	1.0	2.0	0.0	1.0	0.3
SOL_ALB(1).sol	0.6	0.6	-0.8	0.4	0.0	1.0	0.3	0.8	-0.4	0.7	-2.1	0.0	-0.8	0.4
OV_N.hru	-0.5	0.6	-0.8	0.4	0.3	0.8	2.0	0.0	-0.5	0.6	-1.2	0.2	0.2	0.9
SOL_K(1).sol	-0.5	0.6	0.7	0.5	-2.2	0.0	1.2	0.2	1.2	0.2	1.6	0.1	0.7	0.5
GWSOLP.gw	0.4	0.7	-0.6	0.5	2.1	0.0	-0.6	0.5	1.7	0.1	-0.5	0.6	-1.4	0.2
SOL_CRK.sol	0.4	0.7	-0.1	0.9	0.9	0.4	0.4	0.7	0.5	0.6	-0.2	0.8	0.1	1.0

FRT_KG{2,3}.mgt	2.2	0.0	3.0	0.0	0.5	0.6	-0.2	0.9	-0.7	0.5	-0.5	0.6		
GW_SPYLD.gw	-1.0	0.3	0.1	0.9	2.1	0.0	2.0	0.0	1.0	0.3	0.1	1.0		
GW_DELAY.gw	0.0	1.0	0.2	0.9	0.4	0.7	-0.5	0.6	1.1	0.3	0.3	0.8		
SOL_ALB(2).sol	-0.6	0.5	1.9	0.1	0.7	0.5	0.3	0.8	1.4	0.1	-1.0	0.3		
ALPHA_BF.gw	0.1	0.9	-1.6	0.1	-0.2	0.8	0.1	0.9	1.0	0.3	1.0	0.3		
GW_REVAP.gw	-0.5	0.6	0.7	0.5	-0.7	0.5	-0.4	0.7	0.9	0.4	0.8	0.4		
SHALLST.gw	-0.7	0.5	1.4	0.2	-0.1	0.9	-0.3	0.8	2.4	0.0	-0.4	0.7		
ESCO.hru	2.4	0.0	3.2	0.0	7.3	0.0	-2.5	0.0	0.8	0.4	11.4	0.0		
ANION_EXCL.sol	1.0	0.3	-2.1	0.0	0.2	0.9	1.0	0.3	6.8	0.0	-1.4	0.2		
SOL_ALB(1).sol	0.2	0.9	-1.1	0.3	1.1	0.3	-0.5	0.6	1.8	0.1	1.0	0.3		
OV_N.hru	-0.1	1.0	1.4	0.2	1.0	0.3	-1.6	0.1	-0.5	0.6	0.8	0.5		
SOL_K(1).sol	-1.7	0.1	-1.4	0.2	-4.9	0.0	3.6	0.0	-0.8	0.4	7.8	0.0		
GWSOLP.gw	0.2	0.9	1.6	0.1	-1.2	0.2	-0.7	0.5	0.2	0.8	-0.7	0.5		
SOL_CRK.sol	0.9	0.4	0.0	1.0	-0.3	0.8	-0.8	0.4	-0.3	0.8	0.3	0.7		
SOL_K(2).sol	-1.1	0.3	-0.1	0.9	0.6	0.6	-0.2	0.8	0.9	0.4	-1.0	0.3		
RCHRG_DP.gw	0.1	0.9	0.0	1.0	-1.2	0.2	1.3	0.2	0.6	0.5	0.7	0.5		
HLIFE_NGW.gw	0.4	0.7	-0.4	0.7	2.5	0.0	-1.6	0.1	-1.1	0.3	0.2	0.9		
SOL_EC(2).sol	2.1	0.0	-0.9	0.4	-0.6	0.5	0.2	0.9	0.7	0.5	-1.4	0.2		
USLE_K(1).sol	-0.2	0.8	0.5	0.6	0.0	1.0	1.1	0.3	1.4	0.2	0.3	0.8		
SHALLST_N.gw	-0.8	0.4	-0.9	0.3	0.5	0.6	-0.8	0.4	0.6	0.5	1.6	0.1		
GWHT.gw	-0.3	0.8	-1.1	0.3	-0.2	0.8	0.2	0.9	0.0	1.0	1.0	0.3		
SOL_EC(1).sol	-0.9	0.4	0.0	1.0	1.3	0.2	-0.9	0.3	-0.5	0.6	0.1	0.9		
GWQMN.gw	1.5	0.1	-0.6	0.6	-0.4	0.7	-0.1	0.9	-0.9	0.4	-0.3	0.8		
LAT_TTIME.hru	1.1	0.3	0.2	0.9	-0.7	0.5	1.2	0.2	-0.6	0.6	0.6	0.5		
Spring wheat														
	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value
Parameter														
ESCO.hru	-8.2	0.0	-8.2	0.0	19.2	0.0	24.8	0.0	15.2	0.0	16.9	0.0	-7.5	0.0
FRT_KG{10,3}.mgt	12.0	0.0	10.3	0.0	-4.9	0.0	-7.6	0.0	10.6	0.0	12.5	0.0	20.3	0.0
FRT_KG{11,3}.mgt	11.0	0.0	-6.2	0.0	1.2	0.2	-5.4	0.0	-1.3	0.2	12.2	0.0	17.4	0.0
FRT_KG{15,3}.mgt	21.5	0.0	4.1	0.0	6.1	0.0	-2.5	0.0	-1.2	0.2	12.6	0.0	20.8	0.0
FRT_KG{4,3}.mgt	11.5	0.0	9.9	0.0	-2.3	0.0	-1.5	0.1	6.8	0.0	6.2	0.0	-2.0	0.0
FRT_KG{7,3}.mgt	13.1	0.0	18.7	0.0	4.7	0.0	7.9	0.0	14.5	0.0	15.2	0.0	-2.9	0.0
CN2.mgt	11.0	0.0	17.4	0.0	8.2	0.0	11.3	0.0	19.5	0.0	19.9	0.0	-8.2	0.0
SOL_CBN(2).sol	-6.2	0.0	31.2	0.0	5.9	0.0	-6.4	0.0	7.5	0.0	1.3	0.2	25.1	0.0
FRT_KG{12,3}.mgt	-5.2	0.0	-	0.0	-0.3	0.7	-3.2	0.0	-1.7	0.1	-	0.0	-	0.0

			10.6								10.1		13.1	
FRT_KG{6,3}.mgt	4.8	0.0	11.9	0.0	-6.8	0.0	-3.5	0.0	0.1	1.0	16.6	0.0	17.4	0.0
FRT_KG{14,3}.mgt	-4.1	0.0	8.4	0.0	2.6	0.0	-2.1	0.0	-1.7	0.1	8.2	0.0	21.8	0.0
FRT_KG{13,3}.mgt	-3.8	0.0	4.4	0.0	1.2	0.2	-0.7	0.5	-4.2	0.0	-8.9	0.0	14.7	0.0
SOL_CBN(1).sol	-2.1	0.0	12.9	0.0	4.5	0.0	-3.7	0.0	4.3	0.0	1.2	0.2	11.1	0.0
SHALLST_N.gw	-2.1	0.0	0.3	0.8	1.0	0.3	0.9	0.4	-0.3	0.8	1.7	0.1	-1.1	0.3
SOL_BD(2).sol	1.8	0.1	3.7	0.0	-0.5	0.6	-1.6	0.1	0.7	0.5	2.1	0.0	-0.1	0.9
CANMX.hru	1.7	0.1	1.0	0.3	-0.6	0.5	4.5	0.0	-1.4	0.2	4.7	0.0	4.7	0.0
SOL_BD(1).sol	-1.7	0.1	6.6	0.0	0.9	0.4	-1.7	0.1	-0.2	0.8	0.8	0.4	-3.9	0.0
SOL_ALB(2).sol	1.4	0.2	-0.3	0.8	0.5	0.6	0.5	0.6	0.3	0.8	-0.6	0.6	0.6	0.6
GWQMN.gw	-1.2	0.2	0.8	0.4	1.3	0.2	-0.2	0.8	-1.2	0.2	0.2	0.8	-0.9	0.4
SOL_ALB(1).sol	-1.2	0.2	-0.2	0.9	-0.2	0.9	-0.7	0.5	-1.4	0.2	-0.6	0.6	-0.3	0.8
FRT_KG{9,3}.mgt	1.1	0.3	29.3	0.0	2.8	0.0	2.6	0.0	15.9	0.0	28.7	0.0	-7.5	0.0
FRT_KG{2,3}.mgt	1.1	0.3	0.0	1.0	-1.2	0.2	-2.0	0.0	0.7	0.5	1.3	0.2	-0.3	0.7
LAT_TTIME.hru	1.0	0.3	0.4	0.7	-0.6	0.5	0.8	0.4	0.1	0.9	-1.0	0.3	0.2	0.8
GWSOLP.gw	-0.9	0.3	0.6	0.5	0.0	1.0	-0.3	0.8	0.8	0.4	-2.2	0.0	-1.0	0.3
SOL_EC(1).sol	0.9	0.3	-1.2	0.2	-0.9	0.4	-0.2	0.8	0.3	0.8	-0.4	0.7	0.4	0.7
FRT_KG{3,3}.mgt	0.9	0.4	2.5	0.0	-0.2	0.9	1.2	0.2	1.1	0.3	1.4	0.2	0.5	0.6
ANION_EXCL.sol	0.9	0.4	11.8	0.0	-1.1	0.3	1.6	0.1	-6.1	0.0	-2.0	0.0	12.1	0.0
USLE_K(2).sol	-0.9	0.4	-1.6	0.1	-1.0	0.3	-0.9	0.3	-0.4	0.7	-1.2	0.2	-0.3	0.8
FRT_KG{1,3}.mgt	0.9	0.4	0.7	0.5	0.7	0.5	-0.4	0.7	-1.1	0.3	0.1	0.9	1.2	0.2
FRT_KG{8,3}.mgt	0.7	0.5	19.5	0.0	8.6	0.0	9.3	0.0	20.0	0.0	13.0	0.0	5.7	0.0
GWHT.gw	-0.7	0.5	0.3	0.7	-1.0	0.3	-0.5	0.6	-0.8	0.4	1.3	0.2	0.7	0.5
RCHRG_DP.gw	0.7	0.5	0.0	1.0	-0.1	0.9	-0.9	0.4	-0.3	0.8	-0.4	0.7	-1.2	0.2
SHALLST.gw	0.6	0.5	-0.3	0.7	-0.1	0.9	0.9	0.4	-1.4	0.2	-0.9	0.4	-0.1	1.0
GW_DELAY.gw	0.6	0.5	0.1	0.9	-0.2	0.8	1.1	0.3	1.4	0.2	0.0	1.0	0.8	0.4
SOL_CRK.sol	-0.5	0.6	-0.3	0.8	-0.2	0.9	-2.8	0.0	-0.2	0.9	-0.3	0.8	0.5	0.6
EPCO.hru	0.5	0.6	-1.9	0.1	2.5	0.0	-2.2	0.0	-8.4	0.0	6.7	0.0	12.0	0.0
SOL_EC(2).sol	-0.4	0.7	0.9	0.3	0.1	0.9	-1.8	0.1	-0.8	0.4	0.1	0.9	0.6	0.5
LAT_SED.hru	0.3	0.7	-0.7	0.5	2.8	0.0	-1.2	0.2	0.6	0.6	-0.8	0.4	-1.0	0.3
GW_SPYLD.gw	-0.3	0.8	0.2	0.8	-0.7	0.5	1.0	0.3	0.4	0.7	0.9	0.4	1.8	0.1
SOL_K(2).sol	-0.3	0.8	-0.6	0.6	0.6	0.5	2.4	0.0	-1.2	0.2	1.1	0.3	-0.8	0.4
DEEPST.gw	-0.3	0.8	1.0	0.3	0.4	0.7	0.4	0.7	0.2	0.9	-0.6	0.5	-2.4	0.0
OV_N.hru	-0.3	0.8	0.0	1.0	-1.5	0.1	0.7	0.5	0.3	0.8	1.4	0.2	1.1	0.3
SOL_K(1).sol	-0.2	0.8	-0.4	0.7	1.1	0.3	1.8	0.1	1.1	0.3	0.4	0.7	-0.9	0.4
ALPHA_BF.gw	-0.2	0.9	-0.1	0.9	-0.5	0.6	-0.8	0.4	0.5	0.6	0.6	0.5	-0.4	0.7
FRT_KG{5,3}.mgt	0.2	0.9	1.1	0.3	-2.0	0.0	-5.2	0.0	-3.2	0.0	2.2	0.0	12.2	0.0
HLIFE_NGW.gw	-0.1	0.9	0.4	0.7	0.3	0.8	0.4	0.7	-1.3	0.2	1.6	0.1	0.3	0.8
GW_REVAP.gw	0.1	0.9	-0.9	0.4	2.5	0.0	0.6	0.6	0.5	0.6	1.0	0.3	0.3	0.7
USLE_K(1).sol	0.1	0.9	-0.9	0.4	-1.9	0.1	-0.5	0.6	0.1	0.9	-1.3	0.2	0.4	0.7
	Tatarstan		Mordovia		Samara		Orenburg		Penza		Saratov		Wolgograd	

Parameter														
	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value	t-Stat	P-Value
ESCO.hru	-	0.0	-5.6	0.0	-0.3	0.8	33.2	0.0	-1.6	0.1	11.8	0.0	17.8	0.0
FRT_KG{10,3}.mgt	-0.9	0.4	11.9	0.0	-9.8	0.0	-2.6	0.0	-3.5	0.0	-1.3	0.2	8.3	0.0
FRT_KG{11,3}.mgt	7.3	0.0	20.3	0.0	-9.4	0.0	-1.2	0.2	16.2	0.0	-4.6	0.0	-4.6	0.0
FRT_KG{15,3}.mgt	2.6	0.0	13.4	0.0	-2.3	0.0	0.1	0.9	-6.6	0.0	-9.5	0.0	-2.8	0.0
FRT_KG{4,3}.mgt	1.9	0.1	10.8	0.0	-0.4	0.7	-1.0	0.3	4.4	0.0	11.2	0.0	4.1	0.0
FRT_KG{7,3}.mgt	4.3	0.0	20.3	0.0	15.8	0.0	-1.4	0.2	-0.1	0.9	8.1	0.0	8.2	0.0
CN2.mgt	14.0	0.0	-7.2	0.0	5.4	0.0	11.7	0.0	-3.2	0.0	5.9	0.0	-6.7	0.0
SOL_CBN(2).sol	7.4	0.0	19.2	0.0	4.0	0.0	50.9	0.0	-8.3	0.0	4.6	0.0	6.4	0.0
FRT_KG{12,3}.mgt	11.4	0.0	19.6	0.0	4.6	0.0	1.5	0.1	28.3	0.0	10.5	0.0	19.0	0.0
FRT_KG{6,3}.mgt	4.3	0.0	24.0	0.0	16.5	0.0	-2.4	0.0	11.2	0.0	10.1	0.0	3.4	0.0
FRT_KG{14,3}.mgt	26.8	0.0	-9.2	0.0	18.5	0.0	-1.4	0.2	-3.8	0.0	-5.6	0.0	2.5	0.0
FRT_KG{13,3}.mgt	16.4	0.0	6.3	0.0	10.9	0.0	-0.6	0.6	10.0	0.0	5.6	0.0	3.2	0.0
SOL_CBN(1).sol	4.5	0.0	-7.8	0.0	2.5	0.0	32.5	0.0	-5.0	0.0	1.5	0.1	3.9	0.0
SHALLST_N.gw	-2.4	0.0	1.8	0.1	0.4	0.7	0.2	0.8	0.1	1.0	0.2	0.9	-1.1	0.3
SOL_BD(2).sol	-3.3	0.0	0.1	0.9	1.5	0.1	12.7	0.0	-0.9	0.4	0.8	0.4	3.9	0.0
CANMX.hru	3.9	0.0	1.4	0.2	-0.1	1.0	1.5	0.1	2.0	0.0	3.2	0.0	-0.2	0.8
SOL_BD(1).sol	-0.7	0.5	-3.7	0.0	-1.0	0.3	-9.2	0.0	1.8	0.1	1.7	0.1	-0.5	0.6
SOL_ALB(2).sol	-1.2	0.2	-0.3	0.8	0.0	1.0	0.1	0.9	1.0	0.3	-1.6	0.1	0.5	0.6
GWQMN.gw	-2.3	0.0	-0.7	0.5	0.8	0.4	-1.6	0.1	-2.0	0.0	0.7	0.5	-0.6	0.6
SOL_ALB(1).sol	0.8	0.4	-0.5	0.6	0.3	0.7	1.7	0.1	-0.2	0.9	-0.1	0.9	0.9	0.4
FRT_KG{9,3}.mgt	3.7	0.0	-3.0	0.0	19.0	0.0	-1.5	0.1	16.5	0.0	29.9	0.0	17.7	0.0
FRT_KG{2,3}.mgt	0.9	0.4	-1.6	0.1	-1.5	0.1	0.0	1.0	-1.4	0.2	0.4	0.7	0.2	0.8
LAT_TTIME.hru	-2.9	0.0	0.2	0.8	0.4	0.7	-1.7	0.1	1.3	0.2	-0.7	0.5	-0.2	0.8
GWSOLP.gw	2.0	0.1	-1.6	0.1	-0.8	0.4	1.9	0.1	1.7	0.1	-2.0	0.0	-0.3	0.7
SOL_EC(1).sol	1.8	0.1	-1.5	0.1	1.5	0.1	0.6	0.6	0.0	1.0	1.2	0.2	1.1	0.3
FRT_KG{3,3}.mgt	1.9	0.1	-1.1	0.3	-2.0	0.0	-0.9	0.4	0.1	0.9	1.4	0.2	1.5	0.1
ANION_EXCL.sol	15.4	0.0	7.3	0.0	-1.4	0.2	5.8	0.0	3.0	0.0	-0.8	0.4	-2.6	0.0
USLE_K(2).sol	0.3	0.8	0.1	0.9	0.4	0.7	-0.1	0.9	-0.2	0.9	-0.9	0.4	0.3	0.7
FRT_KG{1,3}.mgt	0.7	0.5	-0.5	0.6	-0.3	0.8	-1.3	0.2	1.9	0.1	0.7	0.5	1.0	0.3
FRT_KG{8,3}.mgt	3.7	0.0	20.3	0.0	13.2	0.0	-0.9	0.4	2.2	0.0	14.1	0.0	12.7	0.0
GWHT.gw	1.0	0.3	0.3	0.8	2.1	0.0	0.1	0.9	1.0	0.3	0.1	0.9	-1.8	0.1
RCHRG_DP.gw	0.8	0.4	0.9	0.4	0.0	1.0	1.0	0.3	-1.0	0.3	-0.7	0.5	0.5	0.6
SHALLST.gw	0.6	0.6	0.7	0.5	-0.8	0.4	0.3	0.8	-0.9	0.4	0.3	0.8	0.0	1.0
GW_DELAY.gw	0.4	0.7	0.8	0.4	-0.2	0.8	0.5	0.6	0.1	0.9	-0.1	0.9	0.6	0.6

SOL_CRK.sol	-0.4	0.7	1.4	0.2	0.6	0.6	-1.4	0.2	-1.4	0.2	0.0	1.0	0.1	0.9
EPCO.hru	20.4	0.0	3.3	0.0	-2.2	0.0	1.3	0.2	-7.3	0.0	-3.0	0.0	2.6	0.0
SOL_EC(2).sol	2.1	0.0	0.8	0.4	-1.6	0.1	-0.6	0.6	-0.4	0.7	0.1	0.9	-0.5	0.6
LAT_SED.hru	0.8	0.4	2.2	0.0	1.9	0.1	-1.6	0.1	0.0	1.0	0.2	0.9	-1.6	0.1
GW_SPYLD.gw	-0.1	1.0	0.5	0.6	-0.5	0.6	-1.4	0.2	-0.2	0.9	-0.9	0.4	-0.4	0.7
SOL_K(2).sol	0.5	0.6	-1.5	0.1	2.1	0.0	0.3	0.8	-1.9	0.1	-0.2	0.8	-1.0	0.3
DEEPST.gw	0.9	0.3	0.4	0.7	1.9	0.1	0.6	0.5	0.1	0.9	3.2	0.0	-0.9	0.4
OV_N.hru	0.0	1.0	-0.3	0.8	0.9	0.4	-1.9	0.1	-0.7	0.5	0.1	0.9	-0.9	0.4
SOL_K(1).sol	-1.3	0.2	1.8	0.1	-1.1	0.3	7.1	0.0	3.9	0.0	2.3	0.0	-5.5	0.0
ALPHA_BF.gw	-0.7	0.5	-0.9	0.4	-0.8	0.4	-0.4	0.7	0.1	0.9	1.9	0.1	-0.6	0.6
FRT_KG{5,3}.mgt	2.1	0.0	-8.4	0.0	-6.2	0.0	-3.1	0.0	0.6	0.5	-3.6	0.0	7.9	0.0
HLIFE_NGW.gw	1.0	0.3	0.9	0.4	0.1	1.0	-0.5	0.6	-1.0	0.3	0.5	0.6	0.5	0.6
GW_REVAP.gw	-0.2	0.8	1.9	0.1	-1.4	0.2	0.3	0.7	-1.2	0.2	-0.4	0.7	-0.7	0.5
USLE_K(1).sol	-1.6	0.1	-1.2	0.2	-0.3	0.8	-0.6	0.6	0.8	0.4	-0.4	0.7	0.4	0.7

Table A2. Initial parameter ranges for sensitivity analysis and calibration.

Definition	Parameter	Initial range*
Soil evaporation factor	v_ESCO.hru	0.01-1
Plant uptake compensation factor	v_EPCO.hru	0.01-1
Manning's n value for overland flow	v_OV_N.hru	0.01-0.8
Lateral flow travel time (days)	v_LAT_TTIME.hru	0-180
Sediment concentration in lateral and groundwater flow (mg/L)	v_LAT_SED.hru	0-5000
Maximum canopy storage (mm H ₂ O)	v_CANMX.hru	0-1
Soil bulk density in layer 1 of soil profile (g/cm ³)	v_SOL_BD(1).sol	1.1-1.7
Soil bulk density in layer 2 of soil profile (g/cm ³)	v_SOL_BD(2).sol	1.1-1.7
Organic carbon content in layer 1 of soil profile (% soil weight)	v_SOL_CBN(1).sol	1-3
Organic carbon content in layer 2 of soil profile (% soil weight)	v_SOL_CBN(2).sol	0-2
Moist soil albedo in layer 1 of soil profile	v_SOL_ALB(1).sol	0-0.25
Moist soil albedo in layer 2 of soil profile	v_SOL_ALB(2).sol	0-0.25
Fraction of porosity from which anions are excluded	v_ANION_EXCL.sol	0.2-0.8
Saturated hydraulic conductivity in layer 1 of soil profile (mm/hr)	v_SOL_K(1).sol	0-2000
Conductivity in layer 2 of soil profile(mm/hr)	v_SOL_K(2).sol	0-2000
Potential or maximum crack volume of the soil profile	v_SOL_CRK.sol	0-1
SCS runoff curve number for moisture condition II	v_CN2.mgt	65-90
USLE equation soil erodibility (K) factor in layer 1 of soil profile	v_USLE_K(1).sol	0-0.65
USLE equation soil erodibility (K) factor in layer 2 of soil profile	v_USLE_K(2).sol	0-0.65
Electrical conductivity in layer 1 of soil profile (dS/m)	v_SOL_EC(1).sol	0-100
Electrical conductivity in layer 2 of soil profile (dS/m)	v_SOL_EC(2).sol	0-100
Initial depth of water in the shallow aquifer (mm H ₂ O)	v_SHALLST.gw	0-1000

Initial depth of water in the deep aquifer (mm H ₂ O)	v__DEEPST.gw	0-1290
Groundwater delay time (days)	v__GW_DELAY.gw	0-500
Base flow alpha factor (days)	v__ALPHA_BF.gw	0-1
Threshold depth of water in shallow aquifer required for return flow to occur (mm)	v__GWQMN.gw	0-5000
Groundwater revap. coefficient	v__GW_REVAP.gw	0.02-02
Deep aquifer percolation fraction	v__RCHRG_DP.gw	0-1.1
Initial groundwater height (m)	v__GWHT.gw	0-25
Specific yield of the shallow aquifer (m ³ /m ³)	v__GW_SPYLD.gw	0-0.4
Initial concentration of nitrate in shallow aquifer (mg N/L or ppm)	v__SHALLST_N.gw	0-10
Concentration of soluble phosphorus in groundwater (mg N/L or ppm)	v__GWSOLP.gw	0-1000
Half-life of nitrate in the shallow aquifer (days)	v__HLIFE_NGW.gw	0-365
Amount of fertilizer applied (kg/ha)	r__FRT_KG.mgt	0.3-0.3

* Minimum and maximum values of the parameter range over 28 provinces.

Table A3. Calibration and validation statistics for all of the provinces.

1. Spring wheat

Province	Period*	P-factor	R-factor	RMSE
Vologda	C	1	1.74	0.0061
	V	0.75	0.59	
Udmurtia	C	0.75	0.94	0.0232
	V	1	1.9	
Kirov	C	0.75	0.94	0.0171
	V	1	1.9	
Perm	C	1	1.81	0.0233
	V	0.75	0.93	
Chuvash	C	0.92	1.02	0.0488
	V	1	1.66	
Mari El	C	0.67	1.07	0.0569
	V	0.75	1.54	
Bashkortostan	C	0.92	1.42	0.0532
	V	0.5	1.56	
Nizhny	C	0.58	1.01	0.0922
	V	1	1.49	
Tatarstan	C	0.75	1.55	0.1599
	V	0.75	1.76	

Mordovia	C	0.92	2.07	0.0337
	V	1	1.37	
Ulyanovsk	C	0.75	1.51	0.0661
	V	0.5	4.79	
Samara	C	0.75	1.4	0.0401
	V	1	0.91	
Penza	C	0.75	1.3	0.0407
	V	0.75	1.53	
Saratov	C	0.92	1.26	0.0557
	V	0.75	0.91	
Volgograd	C	0.92	1.09	0.0191
	V	0.75	0.87	
Average	C	0.82	1.34	
	V	0.82	1.58	

* C: calibration period (1995–2006); V: validation period (1992–1995); RMSE: root mean squared error

2. Winter wheat

Province	Period*	P-factor	R-factor	RMSE
Moscow	C	0.58	0.58	0.0078
	V	1	0.96	
Tula	C	0.92	0.73	0.0369
	V	1	0.87	
Ryazan	C	0.67	0.49	0.0529
	V	0.75	0.78	
Bryansk	C	0.42	0.52	0.0682
	V	0.75	0.76	
Oryol	C	0.92	0.71	0.0512
	V	1	1.2	
Lipetsk	C	0.75	0.51	0.1313
	V	1	1.35	
Tambov	C	0.67	0.7	0.0941
	V	1	1.18	
Kursk	C	0.75	0.72	0.0687
	V	1	1.22	
Belgorod	C	0.75	0.57	0.0883
	V	0.75	0.88	
Voronezh	C	0.92	1.02	0.0568

	V	0.5	0.64	
Rostov	C	0.92	0.55	0.0332
	V	1	1.55	
Krasnodar	C	1	0.7	0.0479
	V	1	1.35	
Stravropol	C	0.83	0.58	0.0817
	V	1	1.01	
Average	C	0.78	0.64	
	V	0.9	1.06	

* C: calibration period (1995–2006); V: validation period (1992–1995); RMSE: root mean squared error