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Sensitivity of tile drainage flow and crop yield on measured and calibrated soil hydraulic properties

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Abstract

Process-based agricultural system models require detailed description of soil hydraulic properties that are usually not available. The objectives of this study were to evaluate the sensitivity of model simulation results to variability in measured soil hydraulic properties and to compare simulation results using measured and default soil parameters. To do so, we measured soil water retention curves and saturated soil hydraulic conductivity (K_{sat}) from intact soil cores taken from a long-term experimental field near Nashua, Iowa for the Kenyon–Clyde–Floyd–Readlyn soil association. The soil water retention curves could be well described using the pore size distribution index (λ). Measured λ values from undisturbed soil cores ranged from 0.04 to 0.12 and the measured K_{sat} values ranged from 1.8 to 14.5 cm/h. These hydraulic properties were then used to calibrate the Root Zone Water Quality Model (RZWQM) for simulating soil water content, water table, tile drain flow, and crop yield (corn and soybean) by optimizing the lateral K_{sat} (LK_{sat}) and hydraulic gradient (HG) for subsurface lateral flow. The measured soil parameters provided better simulations of soil water storage, water table, and N loss in tile flow than using the default soil parameters based on soil texture classes in RZWQM. Sensitivity analyses were conducted for λ, K_{sat}, saturated soil water content (θ_s) or drainable porosity, LK_{sat}, and HG using the Latin Hypercubic Sampling (LHS) and for LK_{sat} and HG also using a single variable analysis. Results of sensitivity analyses showed that RZWQM-simulated yield and biomass were not sensitive to soil hydraulic properties. Simulated tile flow and N losses in tile flow were not sensitive to λ and K_{sat} either, but they were sensitive to LK_{sat} and HG. Further sensitivity analyses using a single variable showed that LK_{sat} in the tile layer was a more sensitive parameter compared to LK_{sat} in other soil layers, and HG was the most sensitive parameter for tile flow under the experimental soil and weather conditions.

Keywords: Subsurface drainage; N loading; Tile flow; Agricultural systems modeling; Water table; Water balance; Nitrogen balance

1. Introduction

Agricultural system models require input of soil properties, weather data, plant parameters, and management practices, for all of which uncertainty has been a major concern. The more complex a model, the more parameters it requires and the more sensitive its simulation results are to uncertainty in input parameters. Among the major requirements for a process-based model are detailed soil hydraulic properties (e.g. soil water retention curve, hydraulic conductivity) for the study site. As a result, estimating soil hydraulic properties has been a significant subject of study for soil physicists and agricultural engineers. Rawls et al. (1982) compiled soil hydraulic properties for 11 soil texture classes, which was used as default soil database in the Root Zone Water Quality Model (RZWQM). Later, they refined these estimates based on a series of regression equations from soil texture, soil organic carbon, soil porosity, and soil bulk density (Rawls and Brakensiek, 1985), which were used to estimate soil hydraulic properties in GPFARM (Great Plains Framework for Agricultural Resources Management) (Andales et al., 2003).

Ahuja and Williams (1991) and Williams and Ahuja (2003) found that the soil water retention curves as described by the

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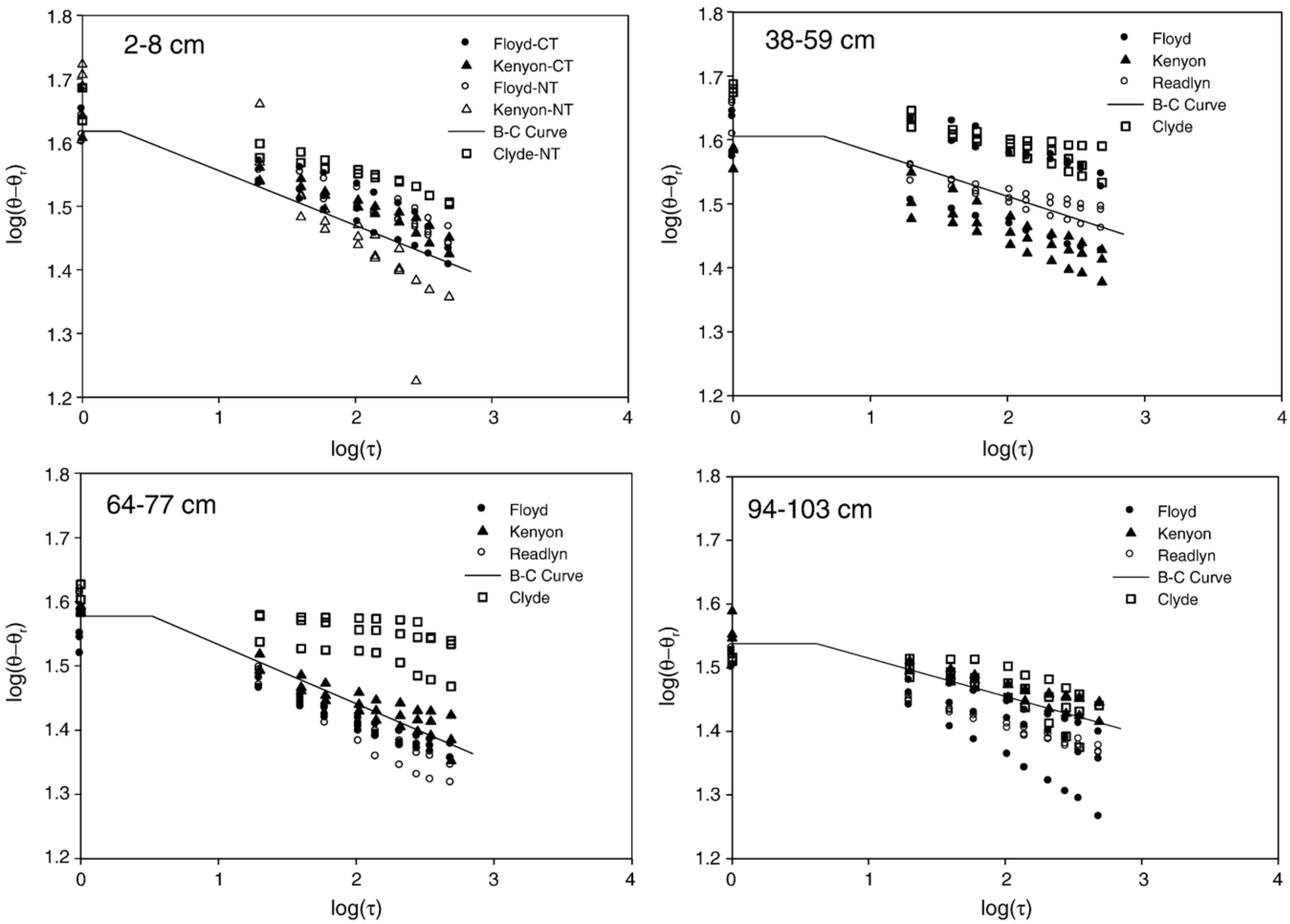

Fig. 1. Measured soil water retention curves for all the four soils and the lines are average Brooks–Corey curves for the Floyd, Kenyon, and Readlyn soils.

Brooks–Corey equations could be simply described by the pore size distribution index (λ). In other words, if the value for λ is known for a soil, the soil water retention curve for the soil can be estimated with good confidence. For saturated soil hydraulic conductivity (K_{sat}), Ahuja et al. (1984) found that it could be estimated as a power function of effective porosity. In RZWQM, users can either use K_{sat} based on soil texture class given in Rawls et al. (1982) or estimate K_{sat} from effective

Table 1
Measured soil hydraulic properties of Clyde, Floyd, Kenyon, and Readlyn soils

Soil or tillage	Depth (cm)	θ (cm/cm)	λ*	K_{sat}* (cm/h)	Bulk density (g/cm^3)	Particle density (g/cm^3)	Sand (g/kg)	Silt (g/kg)	Clay (g/ka)
NT (C)	0–8	0.49	0.063	0.83	1.36	2.58	215	493	292
NT (K, F)	0–8	0.44	0.080	3.58	1.42	2.60	312	434	254
CT (K, F)	0–8	0.51	0.119	3.65	1.26	2.61			
Clyde	38–59	0.51	0.047	0.00079	1.30	2.64	257	412	331
Clyde	64–77	0.43	0.040	0.00064	1.55	2.72	304	405	291
Clyde	94–103	0.35	0.083	0.095	1.74	2.69	496	245	259
Floyd	38–59	0.44	0.063	28.92	1.50	2.69	252	442	306
Floyd	64–77	0.37	0.071	27.84	1.69	2.69	466	285	249
Floyd	94–103	0.36	0.082	1.17	1.71	2.66	472	308	220
Kenyon	38–59	0.40	0.078	6.89	1.62	2.71	447	295	258
Kenyon	64–77	0.41	0.062	12.97	1.58	2.69	340	326	334
Kenyon	94–103	0.39	0.048	0.704	1.65	2.71	320	304	376
Readlyn	38–59	0.47	0.043	4.71	1.43	2.67	395	336	269
Readlyn	64–77	0.47	0.103	8.15	1.50	2.68	469	242	289
Readlyn	94–103	0.36	0.056	3.84	1.71	2.65	449	254	297
Average F, K, R	0–8	0.442	0.086	3.60	1.45	2.60	312	434	254
Average F, K, R	38–59	0.430	0.070	8.05	1.51	2.65	365	357	278
Average F, K, R	64–77	0.405	0.092	14.50	1.60	2.69	425	285	290
Average F, K, R	94–103	0.372	0.060	1.80	1.69	2.69	413	289	298

*Geometric means were taken for λ and K_{sat}. C: Clyde; F: Floyd; K: Kenyon; R: Readlyn.