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Water Retention and Transmission Characteristics of two Alfisols and an Inceptisol of Orissa

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ABSTRACT

Use efficiency of irrigation water is known to be very low, often less than 30%, in the eastern region of the country. A clear understanding of soil water functional relationship is therefore needed to formulate sound irrigation management strategies there. Soil water functional relationships were studied for two Alfisols, viz. Typic Paleustalf, Typic Haplustalf and an Inceptisol viz. Aeric Haplaquept. In general, the soil was slightly acidic in nature and low in organic carbon content. No salt problem was detected in the soil profile. Available water capacity was low in Typic Paleustalf. The Aeric Haplaquept and Typic Haplustalf are superior in term of available water capacity. At any given suction, retention of water by the soils followed the order: Aeric Haplaquept > Typic Haplustalf > Typic Paleustalf. Available water capacity in 1.0 m soil depth was highest in Aeric Haplaquept (27.4 cm) followed by Typic Haplustalf (15.4 cm) and Typic Paleustalf (12.3 cm). With the help of θ_s, Ks, ψ_e and b, functional relationship between soil water suction, (ψ) and water content (θ), specific water capacity, (C_θ) and water content (θ), hydraulic conductivity, (K) and water content, (θ) and between soil water diffusivity, (D) and water content, (θ) were developed. The relationship can be utilized for estimation of unsaturated hydraulic conductivity or soil water diffusivity. The best fit relationship for describing infiltration in all the three soil groups was: $I = a\,t^b + c$; where I is cumulative infiltration in m, t is time in seconds, and a, b and c are constants. Information generated in the present study shall go a long way to formulate sound water management strategies for these soil groups.

Key words: Alfisols, Water retention, Available water, Hydraulic conductivity, Diffusivity and specific water capacity

Water is a scarce and precious resource in agriculture. Use efficiency of applied irrigation water in eastern region of the country is very low, often 30% or even less (Pande and Reddy 1988). Formulation of sound management strategy to improve water use efficiency will require a clear understanding of soil water functional relationships, i.e. the capacity, intensity and rate variables of moisture availability in the soils and relationships among them. While the capacity variable refers to the content of water in a soil, the intensity variable refers to the force with which water is retained by the soil. The rate variable refers to the rate at which water moves through the soil. Dynamics of water in unsaturated soil systems can be described by various differential equations derived from the combination of Darcy's Law and conservation of mass principle. Derivations of such equations under varying boundary and initial conditions require knowledge of ψ-θ, K-θ, D-θ and C-θ relationships in the soils (where θ is volumetric water content in soil, ψ is suction with which water is retained by the soil, K is the rate at which water flows in the soil, D is soil water diffusivity, and C is the change in soil water content per unit change in suction).

Alfisol and inceptisol are dominant soil groups in the eastern region of India. A thorough understanding of water retention and transmission properties of soils is essential to formulate efficient water management strategies. Information on water retention and infiltration properties of the soils of eastern region in general and that of Orissa state in particular are scanty. Present study was undertaken to generate necessary information for the two major soil groups of Orissa.

Materials and Methods

Profile soil samples were collected, processed and analyzed for various physico-chemical properties using standard methods (Black, 1965; Jackson, 1973). Undisturbed soil cores for each horizon were also collected for estimation of water retention and transmission characteristics. Particle size analyses were carried out by International Pipette method, organic carbon by Walkley & Black method, pH and electrical conductivity (EC) were measured in 1:2 soil water suspension. Saturated water content of the soils was determined by using Keen's box. Available phosphorus (P) was estimated by Olsen extraction and available potash (K) by the normal neutral ammonium acetate extraction method. Soil water retention characteristics (ψ-θ) were determined by using pressure plate apparatus as per the procedure described by Richards (1949) and saturated hydraulic conductivity was determined by constant head method (Klute, 1965). Available water in the soils was computed by subtracting the amount of water held at 1.5 MPa from that at 0.033 MPa. In order to establish ψ-θ, C-θ, K-θ and D-θ relationships of the soils, procedure outlined by Campbell (1974) and subsequently used by Komas et al. (1979), Gupta et al. (1986), Oswal (1993) and Singh et al. (1994 and 1999) was followed. For this, a graph between log ψ and log θ/θ_s (where θ_s = water content at saturation) was plotted for each soil. From the graph, data points corresponding to near saturation were discarded and the remaining data were best fit statistically to the Campbell's equation:

$$\psi/\psi_e = (\theta/\theta_s)^{-b}$$

where, ψ_e = air entry suction, which refer to negative pressure of the soil water when air at the atmospheric pressure enters the soil with a continuous water phase (Bouwer, 1966) and 'b' is a soil parameter. Parameters ψ_e and b were evaluated by measuring slope and intercept of the best-fit equation, respectively. The capillary variable $d\theta/d\psi$ was obtained by taking reciprocal of the first derivative of the above equation:

$$d\theta/d\psi = \theta^{b+1}/b.\ \psi_e.\ \theta_s^{\,b}$$

From the knowledge of Ks, θ_s and b, capillary conductivity (K) was functionally related to water content by using the Campbell's equation:

$$K_\theta/Ks = (\theta/\theta_s)^{2b+3}$$

Soil water diffusivity D(θ) was computed by putting the value of Ks, b and ψ_e in the equation, as described by Komas et al. (1979):

$$D(\theta) - b.\psi_e K_s \left(\frac{\theta^{b+2}}{\theta^{b+3}}\right)$$

Infiltration was measured by using double ring infiltrometers, maintaining a constant head of 5-cm water. Observations on infiltration were recorded initially at 1-minute interval and subsequently at 2, 3, 5, 10, 20 and 30-minute intervals until the rate became constant.

Results and Discussion

Physico-chemical properties of the soil profiles are given in Table 1. Texture of the Typic Paleustalf varied from sandy loam to clay loam. Clay content in the 0-15 cm soil layer was 12.0 per cent, in the 15-30-soil layer 22 per cent, while in the 30 to 150 cm soil layer it varied from 27 to 34 per cent. Clay content increased as the soil depth increased but sand and silt content decreased with soil depth. Bulk density of the soil varied between 1.49 and 1.50 g/cm^3. pH of the soil varied from 5.6 to 6.6 and EC from 0.13 to 0.28 dS/m. Organic carbon content in the soils varied between 0.04 and 0.40 per cent, available phosphorus (Olsen P) between <1.0 and 7.4 mg/kg soil and available potassium (K) from 35 to 105 mg/kg soil. In general, soil was moderately acidic to slightly acidic in nature, low in organic carbon and low to medium in available P and K content. Currently the soils have no salt problem. While texture of Typic Haplustalf varied from sandy clay loam to clay loam to clay and the clay content varied between 21 and 40 per cent. Higher clay content was observed in deeper soil layers i.e. below 90 cm depth. Bulk density of the soil varied from 1.44 to 1.50 g/cc. The bulk density increased with soil depth. pH of the soil varied from 5.7 to 8.3 and EC from 0.25 to 1.23

Table 1. Physico-chemical properties of the soil profiles included in the study

Soil depth (cm)	Sand %	Silt %	Clay %	Textural class	Org. C %	EC_2 (dS/m)	pH_2	Bulk density (g/cc)
				Typic Paleustalf				
0-15	58.0	30.0	12.0	sl	0.40	0.23	5.6	1.51
15-30	52.2	25.8	22.0	scl	0.33	0.18	5.6	1.52
30-45	46.0	25.0	29.0	scl	0.25	0.18	5.8	1.49
45-60	45.6	27.4	27.0	scl	0.20	0.20	5.6	1.55
60-90	43.6	22.4	34.0	cl	0.13	0.13	6.1	1.53
90-120	42.6	23.6	33.0	cl	0.07	0.23	6.5	1.54
				Typic Haplustalf				
0-15	68.0	8.5	23.5	sacl	0.66	0.04	4.9	1.23
15-30	67.2	5.0	27.8	sacl	0.43	0.04	4.9	1.54
30-45	49.0	21.0	30.0	sacl	0.22	0.03	4.9	1.74
45-60	59.4	10.1	30.5	sacl	0.22	0.03	4.9	1.61
60-90	42.6	29.4	28.0	cl	0.18	0.02	5.1	1.47
90-120	48.7	30.6	20.7	l	0.19	0.02	5.3	1.81
				Aeric Haplaquept				
0-15	63.0	16.0	21.0	scl	0.70	0.25	5.7	1.44
15-30	49.6	37.4	13.0	sl	0.38	0.50	6.7	1.45
30-45	37.7	32.3	30.0	cl	0.36	0.43	6.8	1.46
45-60	30.0	40.0	30.0	cl	0.32	0.33	6.9	1.48
60-90	33.5	30.0	36.5	cl	0.31	0.25	6.3	1.49
90-120	32.3	27.7	40.0	c	0.28	0.38	6.5	1.50

dS/m. Organic carbon content in the soil varied from 0.26 to 0.46 per cent, available phosphorus (Olsen P) from <1.0 to 7.5 mg/kg soil and potassium (K) content 30 to 100 mg/kg soil. In general, soil was slightly acidic up to 120 cm from and slightly alkaline in lower depths i.e. below 120 cm soil depth. Slight salt accumulation in the deeper soil layer was observed. The soil was low in organic carbon, low to medium in both available phosphorus and potash content. Texture of Aeric Haplaquept varied from sandy loam to clay loam with clay content varying from 20 to 35 per cent. No definite trend of clay distribution in the layers was observed in the soil profile. Bulk density of soil varied between 1.45 and 1.55 g/cm^3 and it increased with soil depth. pH of the soil varied from 6.0 to 6.2 and EC from 0.13to 0.28 dS/m. Organic carbon content of the soil varied from 0.27 to 0.47 per cent. Available phosphorus (Olsen P) and potash (K) content varied from <1.0 to 4.6 and 50 to105 mg/kg soil, respectively. In general, the soil was slightly acidic in nature, low in organic carbon, low to medium in available phosphorus and potash content in the soil profile. No salt problem was detected in the soil profile.

Water Retention (ψ-θ relationship) Characteristics of the Soils

The values of water content at saturation, θ_s, water content at 0.01, 0.033 and 1.5 MPa and available water content, are presented in Table 2. Saturated water content (θ_s) varied from 0.334 to 0.391 cm^3/cm^3 in Typic Paleustalf, while it varied from 0.451 to 0.529 cm^3/cm^3 in Aeric Haplaquept and from 0.467 to 0.535 cm^3/cm^3 in Typic Haplustalf. At 0.01 MPa, the highest water was retained by Typic Haplustalf (0.373 to 0.446 cm^3/cm^3) followed by Aeric Haplaquept (0.330 to 0.434 cm^3/cm^3). The lowest water was retained by Typic Paleustalf (0.213 to 0.281 cm^3/cm^3). Similarly at 0.033 and 1.5 MPa, the highest amount of water was retained by Typic Haplustalf (0.292 to 0.357 and 0.113 to 0.151 cm^3/cm^3) and the lowest in Typic Paleustalf (0.160 to 0.216 and 0.052 to 0.078 cm^3/cm^3). Available water capacity of the soils varied from 0.108 to 0.138 cm^3/cm^3 in

Table 2. Water retention properties of the soils

Soil depth (cm)	θs (cm^3/cm^3)	θ (cm^3/cm^3) at 0.01 Mpa	θ (cm^3/cm^3) at 0.033 MPa	θ (cm^3/cm^3) at 1.5 MPa	Availablewater content (cm^3/cm^3)
			Typic Paleustalf		
0-15	0.334	0.213	0.160	0.052	0.108
15-30	0.344	0.223	0.167	0.053	0.114
30-45	0.388	0.274	0.209	0.073	0.136
45-60	0.391	0.281	0.216	0.078	0.138
60-90	0.371	0.261	0.201	0.071	0.130
90-120	0.351	0.239	0.181	0.060	0.121
120-150	0.339	0.225	0.169	0.055	0.114
			Typic Haplustalf		
0-15	0.467	0.373	0.292	0.113	0.179
15-30	0.483	0.389	0.306	0.120	0.186
30-45	0.508	0.413	0.327	0.131	0.196
45-60	0.501	0.415	0.331	0.138	0.193
60-90	0.491	0.409	0.316	0.127	0.189
90-120	0.520	0.432	0.345	0.144	0.201
120-150	0.535	0.446	0.357	0.151	0.206
			Aeric Haplaquept		
0-15	0.451	0.330	0.250	0.084	0.166
15-30	0.472	0.350	0.268	0.093	0.175
30-45	0.491	0.386	0.298	0.109	0.189
45-60	0.506	0.403	0.315	0.119	0.196
60-90	0.493	0.393	0.306	0.116	0.190
90-120	0.517	0.416	0.341	0.126	0.215
120-150	0.529	0.434	0.345	0.140	0.205

Typic Paleustalf, while it varied from 0.166 to 0.215 cm^3/cm^3 in Aeric Haplaquept and from 0.179 to 0.206 cm^3/cm^3 in Typic Haplustalf. Available water capacity was low in Typic Paleustalf. The Aeric Haplaquept and Typic Haplustalf are, therefore, superior in term of available water capacity. At any given suction, retention of water by the soils followed the order: Aeric Haplaquept > Typic Haplustalf > Typic Paleustalf. Available water capacity in 1.0 m soil depth was highest in Aeric Haplaquept (27.4 cm) followed by Typic Haplustalf (15.4 cm) and Typic Paleustalf (12.3 cm).

Water Transmission Characteristics of the Soils

Saturated hydraulic conductivity (Ks) of the soils varied from 0.92 to 1.78 cm/hr in Typic Paleustalf, from 0.55 to 1.42 cm/hr in Aeric Haplaquept, and from 0.40 to 1.14 cm/hr in Typic Haplustalf. Saturated hydraulic conductivity (Ks) of the soils was highest in Typic Paleustalf and the lowest in Typic Haplustalf. Saturated hydraulic conductivity decreases as the depth increases in all the soils Table 1. The values of air entry suction, ψ_e and soil parameter b are presented in Table 3. The highest values of air entry suction (39.9 cm to 43.9 cm) were observed in Typic Haplustalf followed by that Aeric Haplaquept (32.7 to 42.7 cm) and the lowest (20.8 to 28.0 cm) in Typic Paleustalf. Similarly the highest value of b (4.20 to 4.63) was observed in Typic Haplustalf and the lowest (3.51 to 3.92) in Aeric Haplaquept.

With the help of θ_s, K_s, ψ_e and b, functional relationship between soil water suction, (ψ) and water content (θ), specific water capacity, (C_θ) and water content (θ), hydraulic conductivity, (K) and water content, (θ) and between soil water diffusivity, (D) and water content, (θ) were developed. The relationships can be utilized for estimation of unsaturated hydraulic conductivity or soil water diffusivity. These relationships are

Table 3. The values of air entry suction (Ψe) and soil parameter b

Soil depth(cm)	Typic Paleustalf		Typic Haplustalf		Aeric Haplaquept	
	Ψe(cm)	b	Ψe(cm)	b	Ψe(cm)	b
0-15	20.81	3.55	32.74	3.65	39.90	4.20
15-30	22.31	3.51	33.22	3.78	40.48	4.27
30-45	27.29	3.80	39.41	3.97	41.53	4.36
45-60	28.00	3.92	40.27	4.11	43.50	4.54
60-90	26.71	3.85	40.32	4.10	41.64	4.36
90-120	25.32	3.64	40.81	4.21	43.80	4.55
120-150	23.37	3.58	42.71	4.43	43.92	4.63

Table 4. Functional relationships between suction Ψ and θ

Soil depth(cm)	Typic Paleustalf	Typic Haplustalf	Aeric Haplaquept
0-15	$20.81(\theta/0.334)^{-3.55}$	$39.90(\theta/0.467)^{-4.20}$	$32.74(\theta/0.451)^{-3.65}$
15-30	$22.31(\theta/0.344)^{-3.51}$	$40.48(\theta/0.483)^{-4.27}$	$33.22(\theta/0.472)^{-3.78}$
30-45	$27.29(\theta/0.388)^{-3.80}$	$41.53(\theta/0.508)^{-4.36}$	$39.41(\theta/0.491)^{-3.97}$
45-60	$28.00(\theta/0.391)^{-3.92}$	$43.50(\theta/0.501)^{-4.54}$	$40.27(\theta/0.506)^{-4.11}$
60-90	$26.71(\theta/0.371)^{-3.85}$	$41.64(\theta/0.491)^{-4.36}$	$40.32(\theta/0.493)^{-4.10}$
90-120	$25.32(\theta/0.351)^{-3.64}$	$43.80(\theta/0.520)^{-4.55}$	$40.81(\theta/0.517)^{-4.21}$
120-150	$23.37(\theta/0.339)^{-3.58}$	$43.92(\theta/0.535)^{-4.63}$	$42.71(\theta/0.529)^{-4.43}$

Table 5. Functional relationships between specific water capacity,(C_θ)and θ

Soil depth(cm)	Typic Paleustalf	Typic Haplustalf	Aeric Haplaquept
0-15	$0.014(\theta^{4.55}/2.04´10^{-2})$	$0.006(\theta^{5.20}/4.08´10^{-2})$	$0.008(\theta^{4.67}/5.46´10^{-2})$
15-30	$0.013(\theta^{4.51}/2.36´10^{-2})$	$0.006(\theta^{5.27}/4.47´10^{-2})$	$0.008(\theta^{4.78}/5.86´10^{-2})$
30-45	$0.010(\theta^{4.80}/2.74´10^{-2})$	$0.006(\theta^{5.36}/5.22´10^{-2})$	$0.006(\theta^{4.97}/5.94´10^{-2})$
45-60	$0.009(\theta^{4.92}/2.52´10^{-2})$	$0.005(\theta^{5.54}/4.34´10^{-2})$	$0.006(\theta^{5.11}/6.08´10^{-2})$
60-90	$0.009(\theta^{4.85}/2.20´10^{-2})$	$0.006(\theta^{5.36}/4.50´10^{-2})$	$0.006(\theta^{5.10}/5.50´10^{-2})$
90-120	$0.011(\theta^{4.64}/2.21´10^{-2})$	$0.005(\theta^{5.55}/5.10´10^{-2})$	$0.006(\theta^{5.21}/6.20´10^{-2})$
120-150	$0.012(\theta^{4.58}/2.08´10^{-2})$	$0.005(\theta^{5.63}/5.52´10^{-2})$	$0.005(\theta^{5.43}/5.96´10^{-2})$

Table 6. Functional relationships between K and θ

Soil depth (cm)	Typic Paleustalf	Typic Haplustalf	Aeric Haplaquept
0-15	$1.78(\theta/0.334)^{10.10}$	$1.14(\theta/0.467)^{11.40}$	$1.42(\theta/0.451)^{10.30}$
15-30	$1.75(\theta/0.344)^{10.02}$	$0.97(\theta/0.483)^{11.54}$	$1.24(\theta/0.472)^{10.56}$
30-45	$1.66(\theta/0.388)^{10.60}$	$0.89(\theta/0.508)^{12.08}$	$1.04(\theta/0.491)^{10.94}$
45-60	$1.04(\theta/0.390)^{10.84}$	$0.65(\theta/0.501)^{12.08}$	$0.76(\theta/0.506)^{11.22}$
60-90	$0.92(\theta/0.371)^{10.70}$	$0.55(\theta/0.491)^{11.72}$	$0.67(\theta/0.493)^{11.20}$
90-120	$1.05(\theta/0.351)^{10.28}$	$0.52(\theta/0.520)^{12.10}$	$0.58(\theta/0.517)^{11.42}$
120-150	$1.14(\theta/0.339)^{10.16}$	$0.40(\theta/0.535)^{12.26}$	$0.55(\theta/0.529)^{11.86}$

Table 7. Functional relationships between D and θ

Soil depth(cm)	Typic Paleustalf	Typic Haplustalf	Aeric Haplaquept
0-15	131.289($\theta^{5.55}$/7.59´10^{-4})	191.21($\theta^{6.20}$/4.16´10^{-3})	169.8($\theta^{5.65}$/5.02´10^{-3})
15-30	136.80($\theta^{5.51}$/9.62´10^{-4})	167.66($\theta^{6.27}$/5.04´10^{-3})	155.71($\theta^{5.78}$/6.16´10^{-3})
30-45	171.73($\theta^{5.80}$/1.60´10^{-3})	157.26($\theta^{6.36}$/6.84´10^{-3})	161.93($\theta^{5.97}$/7.03´10^{-3})
45-60	113.71($\theta^{5.92}$/1.51´10^{-3})	128.37($\theta^{6.54}$/5.45´10^{-3})	126.28($\theta^{6.11}$/7.88´10^{-3})
60-90	98.26($\theta^{5.85}$/1.12´10^{-3})	99.853($\theta^{6.36}$/5.33´10^{-3})	111.42($\theta^{6.10}$/6.59´10^{-3})
90-120	96.59($\theta^{5.64}$/9.57´10^{-4})	104.03($\theta^{6.55}$/7.18´10^{-3})	98.96($\theta^{6.21}$/8.60´10^{-3})
120-150	94.88($\theta^{5.58}$/1.16´10^{-3})	81.54($\theta^{6.63}$/8.46´10^{-3})	104.06($\theta^{6.43}$/8.82´10^{-3})

presented in Tables 4, 5, 6 and 7. ψ-θ relationships of the three soil profiles, each one-averaged over six soil layers, were established as:

$\psi = 0.571\ \theta^{-3.699}$ (R^2=0.99) for Typic Paleustalf,

$\psi = 2.301\ \theta^{-3.581}$ (R^2=0.96) for Typic Haplustalf, and

$\psi = 2.064\ \theta^{-4.447}$ (R^2=0.99) for Aeric Haplaquept.

The slope of the ψ-θ relationship, b, was 4.447 for Aeric Haplaquept, 3.706 for Typic Paleustalf, and 3.581 for Typic Haplustalf. In general, Typic Paleustalfare low in moisture retention as well as water transmission in unsaturated condition than Aeric Haplaquept and Typic Haplustalf.

With the help of b and ψ_e, hydraulic conductivity, diffusivity and specific capacity of the soils were predicted from the following equations:

for Aeric Haplaquept,

$$K(\theta) = 0.66\ (\theta/0.505)^{11.90}$$

$$D(\theta) = 125.557\ \theta^{6.45}/12.20 \times 10^{-3}$$

$$C(\theta) = -0.005\ \theta^{5.45}/4.78 \times 10^{-2}$$

for Typic Paleustalf,

$$K(\theta) = 1.243\ (\theta/0.358)^{10.42}$$

$$D(\theta) = 114.914\ \theta^{5.71}/2.84 \times 10^{-3}$$

$$C(\theta) = -0.011\ \theta^{4.71}/2.21 \times 10^{-2}$$, and

for Typic Haplustalf,

$$K(\theta) = 4.25\ (\theta/0.439)^{10.16}$$

$$D(\theta) = 634.161\ \theta^{5.58}/1.012 \times 10^{-2}$$

$$C(\theta) = -0.007\ \theta^{4.58}/5.24 \times 10^{-2}$$

Infiltration Characteristics of the Soils

Initial infiltration rate was quite high in the soils of Typic Haplustalf (1.89×10^{-4}m/s) followed by Typic Paleustalf (1.405×10^{-4} m/s) and Aeric Haplaquept (1.362×10^{-4} m/s). After 48 seconds of infiltration, the infiltration rates were 3.13×10^{-5}, 1.937×10^{-5} and 1.61×10^{-5} m/s, respectively, in soils of Typic Paleustalf, Aeric Haplaquept and Typic Haplustalf. The steady state infiltration rate was 1.87 x 10^{-3} m/s in Typic Paleustalf reached 14880 seconds after initiation of the infiltration process. It was 1.22 x 10^{-3} m/s in Aeric Haplaquept reached 12600 seconds and 1.48 x 10^{-2} m/s in Typic Haplustalf reached 17100 seconds after initiation of the infiltration process. Steady state infiltration rate of Typic Haplustalf was 12.1 and cumulative infiltration 8.1 times that of Aeric Haplaquept. Again, steady state infiltration rate and cumulative infiltration of Typic Paleustalf were 1.6 and 1.9 times respectively that of Aeric Haplaquept.

Five different empirical relationships were evaluated for their suitability to describe infiltration in the soil groups. The functional relationships, coefficients and R^2 values are presented in Table 8. The best-fit relationship for describing infiltration in all the three soil groups was: $I = a\ t^b + c$; where I is cumulative infiltration in m, t is time in seconds, and a, b and c are constants. It is hoped that the information generated in the present study shall go a long way to formulate sound water management strategies for these soil groups, dominant in the eastern regions of India and Orissa.

Table 8. Functional relationships tested to describe infiltration characteristics of the soils

Type of relationship	Values of constants and R^2 for different soil groups		
	Typic Paleustalf	Aeric Haplaquept	Typic Haplustalf
$I = a + bt$	a = 0.036 b = 6.078×10^{-6} R^2 = 0.83	a = 0.019 b = 3.027×10^{-6} R^2 = 0.93	a = 0.026 b = 0.003×10^{-2} R^2 = 0.96
$I = a + b \ln t$	a = -0.076 b = 0.019 R^2 = 0.95	a = 0.022 b = 0.008 R^2 = 0.94	a = -0.525 b = 0.094 R^2 = 0.80
$I = at^b$	a = 0.003 b = 0.403 R^2 = 0.95	a = 0.004 b = 0.263 R^2 = 0.96	a = 0.003 b = 0.771 R^2 = 0.96
$I = ae^{bt}$	a = 0.033 b = 1.0×10^{-4} R^2 = 0.57	a = 0.019 b = 1.0×10^{-4} R^2 = 0.81	a = 0.085 b = 2.1×10^{-4} R^2 = 0.75
$I = at^b + c$	a = 0.021 b = 0.203 c = -0.038 R^2 = 0.98	a = 0.004 b = 0.280 c = 0.001 R^2 = 0.98	a = 2.61×10^{-4} b = 0.786 c = 0.001 R^2 = 0.99

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