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Contribution of Upward Flux From Shallow Ground Water Table to Crop Water Use in Major Soil Groups of Orissa

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ABSTRACT

Steady upward flux of water from shallow water table were evaluated by using solutions of Gardner and Fireman (1958), Anat *et al*. (1965) and Cisler (1969). The soils included in this study were Typic Paleustalf, Typic Haplustalf, Aeric Fluvaquent, Aeric Haplaquept, Aeric Tropaquept, Ultic Haplustalf I, Typic Ustochrept and Ultic Haplustalf II. While Typic Haplustalf , Aeric Fluvaquent, Ultic Haplustalf I and Ultic Haplustalf II were clay in texture, the Aeric Tropaquept was silty clay. The Aeric Haplaquept and Ultic Haplustalf II were sandy clay, the Typic Paleustalf was sandy clay loam in texture. Aeric Fluvaquent was saline, whereas other soil groups were non- saline. Saturated hydraulic conductivity was highest in Typic Paleustalf and the lowest in Aeric Fluvaquent. Water retention characteristics (y-q) were studied for all the studied soils types. At 0.90 cm water table depth, the highest upward flux (18.7 mm.d^{-1}) was observed in Typic Haplustalf and the lowest (5.5 mm.d^{-1}) was observed in Aeric Tropaquept . At 1.2 m depth, the highest flux (10.7 mm.d^{-1}) was observed in the same soil group (Typic Haplustalf) but the lowest (2.8 mm.d^{-1}) was observed in Aeric Fluvaquept. While at 1.5 m water table depth, the highest upward flux was again observed in the same soil group (Typic Haplustalf) but the lowest was observed in Aeric Tropaquept. Comparison of experimentally observed fluxes with the evaluated values indicated superiority of the Gardner estimates over the other two estimates of Cisler and Anat.

Key words: Upward flux, Shallow ground water table, Crop water use, Major soil groups of Orissa

The amount of irrigation water to be supplied to a crop depends on several factors. These factors constitute various components of the water balance equation. In its simple form, the water balance equation can be written as:

$$I + P + Cp = ET + \Delta S + Dp + Rf$$

Where I = water application through irrigation; P = precipitation or rainfall; Cp = capillary rise from ground water; ET = evapotranspiration by crop; i.e. evaporation from soil and transpiration by crop; ΔS = change in soil profile moisture; Dp = deep percolation and Rf = run off. One or more components in this expression can, for a given situation, be negligible e.g. capillary rise, run off losses, deep percolation or rainfall. The soil profile storage (ΔS) can be negative in between two irrigations.

One of the most commonly over looked component is the contribution of the capillary rise to meet the water demands of a crop from medium to shallow water table conditions. The ground water table at many locations is so shallow during the cropping season that it contributes significantly to the water requirements of a crop. Research in different parts of our country have found that water table can supply as much as 50 to 60 percent of water requirement of the crop (Jhorar *et al.*, 1991).

Rise of ground water table is a common phenomenon in all the major irrigation command areas because of seepage from canal distribution network and unjudicious farm water management practices. Use of high water tables reduces irrigation needs, lowers production costs, reduces deep seepage losses, and decreases the volume of drainage water requiring disposal. However, excessive irrigation under shallow water table condition will not only aggravate the problem of decrease in depth of water table and loss of nutrient through leaching, but will also reduce the irrigated area resulting in water logging, salinisation and associated problems. Inadequate information is available on this aspect especially on soils under conditions in Orissa. Keeping this in view, a study was conducted to quantify the ground water contribution towards the evaporation of some of the major soils of Orissa.

Materials and Methods

The soil water retention and transmission properties are key elements in the ability of crops to extract water from the ground water table. Based on soil physical constants, several formulae have been derived for estimating rates of upward flow from a water table to a fallow soil. In case of shallow water table, the upward movement of water under fallow condition can be expressed by the following equation:

$$q = K\left[\frac{d\psi}{(dz-1)}\right] \qquad \ldots(1)$$

On integrating the equation between limits $\psi = 0$ at $z = 0$ to $\psi = \infty$ at $z = z$ (at land surface which is assumed air – dry),

we get

…(2)

where q = steady state upward flux of water, ψ = soil moisture tension, K = capillary conductivity and z = depth of water table.

Solution of above equation requires functional relationship between capillary conductivity 'K' and soil moisture tension 'ψ'. Gardner and Fireman (1958) established the following functional relationship between 'K' and 'ψ', which fits many soils.

$$K = a/(b+\psi^n) \qquad \ldots(3)$$

where, 'a', 'b' and 'n' are soil constants.

Disregarding the constant 'b' (since $b << y^n$ for n>1), the above equation becomes

$$K = a\,\psi^{-n} \qquad \ldots(4)$$

For the 'K - ψ' relation, Gardner and Fireman (1958) gave the following solution for the steady flux of water for integer values of 'n' up to 4.0.

$$q = Aa/Z^n \qquad \ldots(5)$$

The value of 'A' was evaluated to be $\frac{\pi^2}{4}$,

and for n = 2, 3 and 4 respectively .

Cisler (1969) solved the equation for any value of 'n' and obtained the solution of 'b' = 0 in equation (3).

$$q = a[z(n/\pi)\ .\ \sin(\pi/n)]^{-n} \qquad \ldots(6)$$

Anat *et al.* (1965) describe the solution as:

$$q = a\,[1+ 1.886/(1+n^2)]\ z^{-n} \qquad \ldots(7)$$

Evaluation of 'q' by the above equations requires pre-determined values of 'A' and 'n'. This calls for establishing a functional relationship between 'K– ψ'. For this purpose, soil water retention (ψ-θ relationship) was determined using pressure-plate apparatus, as per the procedure described by Richards (1949). Saturated hydraulic conductivity was determined following constant head method of Klute (1965). The obtained ψ-θ values were best fitted to the empirical relationship given by Campbell (1974):

…(8)

where ψ, is soil-water suction (cm); θ and θ_s, are soil-water content at suction ψ and saturation (cm^3/cm^3) respectively; b, is a constant; and ψ_e, is air-entry suction, which refers to negative pressure of the soil water when the air at the atmospheric pressure enters the soil with a continuous water phase (Bouwer, 1966).

The constants ψ_e and b were calculated by plotting ψ against θ/θ_s on log-log scale. The values of ψ_e and b are presented in Table 2. The unsaturated hydraulic conductivity was calculated using the relationship:

…(9)

where n= 2+3/b; K, unsaturated hydraulic conductivity; and Ks, saturated hydraulic conductivity.

Comparing equation (3) with equation (9) we get

$$a = K_s\,\psi_e^{\,n}$$

The value of 'a' and 'n' determined for different soils were used to evaluate the steady upward flux of water by using the three methods given by Gardner and Fireman (1958), Cisler (1969) and Anat *et al*. (1965). These values of the flux were compared statistically with the experimentally determined values from PVC column (1.5 m height and 0.11 m) in a net house.

Profile soil samples were collected from 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm depth and filled the same into PVC columns and water table were maintained at 1.5, 1.2, and 0.9 cm depth in a net house. Composite soil samples as well as core soil samples (6.0 cm height and 4.2 cm diameter) were also collected, respectively from the following predominant soils of Orissa: Typic Paleustalf, Typic Haplustalf, Aeric Fluvaquent, Aeric Haplaquept, Aeric Tropoquept, Ultic Haplustalf, Typic Ustochrept and Ultic Haplustulf. The disturbed samples were used for determining soil texture and other physico-chemical characteristics of the soil. The core samples were used to generate 'ψ-θ' and saturated hydraulic conductivity (Ks) data.

$$K = K_s\left(\frac{\psi_e}{\psi}\right)^n$$

Result and Discussion

Physico-chemical properties of the soils are presented in Table 1. The texture was clay for Typic Haplustalf, Aeric Fluvaquent, Ultic Haplustalf I and Ultic Haplustalf II, while the Aeric Tropaquept came under silty clay having clay content more than 40%. The Aeric Haplaquept and Ultic Haplustalf II were sandy clay in texture with clay content more than 30% while Typic Paleustalf was sandy clay loam having clay contents less than 30%. Aeric Fluvaquent was saline whereas the other soil groups were non-saline in nature. pH_2 of Aeric Tropaquept, Typic Ustochrept and Ultic Haplustalf II varied from 7.02 to 7.38, while in other soil groups it ranged between 5.85 and 6.12. All soils were invariably low in their organic matter content.

Moisture retention data for all the soils at different suctions were measured and the following ψ-θ functional relationships were established;

$\psi = 22.5\ (\theta/0.484)^{-3.713}$ (For Typic Paleustalf)

$\psi = 31.5\ (\theta/0.556)^{-5.254}$ (For Typic Haplustalf)

$\psi = 111.7\ (\theta/0.605)^{-5.317}$ (For Aeric Fluvaquent)

$\psi = 53.0\ (\theta/0.561)^{-3.341}$ (For Aeric Haplaquept)

$\psi = 71.2\ (\theta/0.610)^{-4.836}$ (For Aeric Tropaquept)

$\psi = 28.0\ (\theta/0.527)^{-3.567}$ (For Ultic Haplustalf I)

$\psi = 92.2\ (\theta/0.663)^{-7.461}$ (For Typic Ustochrept)

$\psi = 39.6\ (\theta/0.576)^{-3.720}$ (For Ultic Haplustalf II)

The experimentally determined values of Ks and evaluated values of 'b' and ψ_e along with those of 'n' and 'A' are reported in Table 2. Saturated hydraulic conductivity (Ks) was the

Table 1. Physico-chemical characteristics of predominant soils of Orissa used for the experimental purpose

Name of the soil subgroup	Particle size analysis				Textural class	EC_2 (dS/m)	pH_2	OC (%)
	Clay	Silt	Fine sand	Course sand (%)				
Typic Paleustalf	27.67	10.33	13.79	48.20	scl	0.07	5.85	0.22
Typic Haplustalf	47.63	14.66	16.23	21.47	c	0.07	6.01	0.29
Aeric Fluvaquent	44.91	26.87	8.74	19.46	c	2.49	6.92	0.25
Aeric Haplaquept	34.16	15.28	10.73	39.69	sc	0.108	6.23	0.262
Aeric Tropaquept	46.34	43.23	6.35	4.07	sic	0.259	7.02	0.152
Ultic Haplustalf I	40.95	14.31	28.15	16.57	c	0.076	6.74	0.313
Typic Ustochrept	54.53	30.84	7.33	6.95	c	0.428	7.38	0.368
Ultic Haplustalf II	35.74	15.92	13.96	34.38	sc	0.322	7.21	0.342

Table 2. Average values of air entry suction, saturation hydraulic conductivity and soil parameter

Name of the soil subgroup	Air entry suction (kPa)	Saturated hydraulic conductivity (md^{-1})	Soil parameter		
			b	n	A
Typic Paleustalf	2.25	0.283	3.713	2.808	1.768
Typic Haplustalf	3.15	0.274	5.252	2.571	1.768
Aeric Fluvaquent	11.12	0.002	5.317	2.564	1.768
Aeric Haplaquept	5.30	0.065	3.341	2.898	1.768
Aeric Tropoquept	7.12	0.004	4.836	2.620	1.768
Ultic Haplustalf	2.80	0.209	3.567	2.841	1.768
Typic Ustochrept	9.22	0.005	7.461	2.402	2.462
Ultic Haplustalf	3.96	0.118	3.72	2.806	1.768

highest (0.283 md^{-1}) in Typic Paleustalf, followed by Typic Haplustalf (0.274 md^{-1}), Ultic Haplustalf I (0.209 md^{-1}) and Ultic Haplustalf II (0.118 md^{-1}) and low to very low in Aeric Haplaquept (0.065 md^{-1}), Typic Ustochrept (0.005 md^{-1}), Aeric Tropaquept (0.004 md^{-1}) and Aeric Fluvaquent (0.002 md^{-1}). Similarly, the highest air entry suction (11.12 kPa) was observed in Aeric Fluvaquent and lowest (2.25 kPa) in Typic Paleustalf soil group. The value of ‘ b’ varied from 3.341 to 7.461 and values of ‘n’ varied from 2.402 to 2.898. The value of ‘A’ was (1.768) same for all the soil groups except for Typic Ustochrept where it was 2.462. Using these values, the steady state flux corresponding to water table depth of 0.90, 1.2 and 1.5 m was evaluated by each of the methods. The evaluated results of the steady flux along with the experimentally determined data from net house columns are presented in Table 3.

Irrespective of the soil types, the values of upward flux decreased with increase in water table depth (Table 3). At lower water table level, i.e. 0.90 m depth, the highest upward flux was observed (18.7 mmd^{-1}) in Typic Haplustalf followed by Ultic Haplustalf II (14.6 mmd^{-1}), Aeric Haplaquept (13.8 mmd^{-1}), and Ultic Haplustalf I (13.8 mmd^{-1}), and the lowest upward flux (5.5 mmd^{-1}) was observed in Aeric Tropaquept. The upward flux in Typic Paleustalf, Aeric Fluvaquent and Typic Ustochrept was found to be 10.5, 8.0 and 8.7 mmd^{-1}, respectively. As the water table depth receded from 0.90 m to 1.20 m depth, the highest upward flux was observed in Typic Haplustalf (10.7 mmd^{-1}) followed by Ultic Haplustalf II (9.0 mmd^{-1}) and the lowest was observed in Aeric Fluvaquent (2.8 mmd^{-1}). In case of 1.5 m water table depth, the highest upward flux was observed in the same soil group as in 0.90 and 1.2 m water table depth but the lowest upward flux was observed in Aeric Tropaquept (Table 3).

As the water table receded from 0.90 m to 1.20 m the upward flux reduced by 2.28, 1.7, 2.86, 1.73, 2.12, 2.51, 1.50 and 1.62 times and when it receded to 1.50 m, the upward flux reduced by 3.75, 2.34, 4.45, 3.07, 6.68, 5.11, 2.42 and 3.25 times, respectively in Typic Paleustalf, Typic Haplustalf, Aeric Fluvaquent, Aeric Haplaquept, Aeric Tropaquept, Ultic Haplustalf I, Typic Ustochrept and Ultic Haplustalf II. In the present investigation, Gardner values were found to be more close to the observed values. The Anat estimates were also close to the observed values but not as close as Gardner. The Cisler estimates were, however, higher for all the water table depths. Statistical analysis by t test (Table 3) also supports these observations. The t test indicated superiority of Gardner method over Cisler and Anat methods. Thus Gardner method could be used for estimating upward flux of these type of soils.

The results indicated that under shallow and medium water table depth condition significant amount of ground water was contributed to crop

Table 3. Calculated and observed upward fluxes (mmd^{-1}) of water from eight soil subgroups of Orissa having water table at different depths

Name of the soil group / soil depth	Calculated flux (mmd^{-1})											
	Gardner and Fireman			Cisler			Anat *et al.*			Observed		
	0.90 m	1.20 m	1.50 m	0.90 m	1.20 m	1.50 m	0.90 m	1.20 m	1.50 m	0.90 m	1.20 m	1.50 m
Typic Paleustalf	11.0	5.0	3.0	7.0	3.0	2.0	10.0	5.0	2.4	10.5	4.6	2.8
Typic Haplustalf	18.0	10.0	7.0	16.0	8.0	4.0	17.0	11.0	7.0	18.7	10.70	8.0
Aeric Fluvaquent	7.0	3.0	2.0	4.0	2.0	1.0	6.0	3.0	2.0	8.0	2.8	1.8
Aeric Haplaquept	15.0	11.0	6.0	14.0	7.0	4.0	15.0	11.0	6.0	13.8	8.0	4.5
Aeric Tropaquept	4.0	2.0	1.0	3.0	1.0	0.7	4.0	2.0	1.0	5.5	2.6	0.8
Ultic Haplustalf I	14.0	6.0	3.0	9.0	4.0	2.0	13.0	6.0	3.0	13.8	5.5	2.7
Typic Ustochrept	11.0	6.0	3.0	2.0	0.70	0.40	11.0	7.0	4.0	8.7	5.8	3.6
Ultic Haplustalf II	13.0	10.0	5.0	12.0	6.0	3.0	14.0	9.0	5.0	14.6	9.0	4.5
Students t value(0.05)	-0.154	1.224	0.619	-4.696	-4.340	-2.931	-0.855	1.63	0.839	-	-	-
	NS	NS	NS	S	S	S	NS	NS	NS	-	-	-

NS = Non significant and S = Significant at P = 0.05

use. To avoid future problems of soil salinization, water logging and others associated problems; ground water contribution must be considered for proper planning especially long term planning for management of soil and water resources under different canal command areas in Orissa.

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