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Buried clay pot irrigation for efficient and controlled water delivery

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This study presents water flow (WF) into soil from several pitchers buried in the soil up to their neck and filled with water, under natural atmospheric conditions for a period of two years. Variation in daily WF into soil indicated a direct correlation with moisture deficit (MD) in atmosphere. WF increases linearly with MD for non rainy days. WF without hydraulic head through all pots varied in the order air>soil>water. Base line flow in water with respect to air was < 5%. WF for pots with hydraulic head was also in the order air>soil>water, but with significant increase in WF. Hydraulic conductivity K_s was in the order air>soil>water. K_s in water was independent of MD, whereas for air and soil, K_s increased with MD. Thus total WF is partially under hydraulic head and partly due to pull effect through capillary pores on pot wall either due to MD in air or prevailing soil water tension in soil.

Keywords: Hydraulic conductivity, Moisture deficit, Pitcher irrigation

Introduction

Water conservation and efficient utilization of water resources are of universal importance. Buried pitcher irrigation, a traditional technology[1-3], is seen to be more economical and water saving[4], and is now emerging as a highly promising method for localized small scale irrigation. It not only conserves water but also provides employment to potters and labour, and does not require external inputs like oil and electricity. It maintains stable soil moisture and enables crops to grow in both normal and saline soils with the use of moderately saline waters[5-9]. Pitcher is a bottle like emitter made of porous baked-clay. When filled with water and buried into soil, it releases water through pores on its wall into surrounding soil. Water diffuses into root zone and is drawn by plant roots. Significant number of studies[7-9] are available but long term studies on release of water to soil under varying moisture deficit (MD) conditions in atmosphere are not available. Earlier studies[10,11] indicated that rate of water flow (WF) correlated reasonably well with atmospheric MD conditions but correlation pattern was different for rainy and non rainy days. Systematic studies on WF through pitcher walls are limited and pertain to release of water into air and into water under hydraulic gradient[12,13]. A recent study[14] has modelled soil moisture profile for irrigation through clay walls with WF under pressure.

This study presents rate of WF through pitchers buried into either water or air or soil under atmospheric pressure as well as under hydraulic head, and analyses flow patterns into soil under natural atmospheric condition.

Experimental Section

Seasonal Flow of Water through Pitchers into Soil

A set of 5 pitchers (labelled A-E), which were almost of the same volume (7.5-8.0 l), surface area, height (30 cm), thickness and porosity, were buried up to neck at a randomly selected plot at IIT, Delhi campus. Pitchers were closed with a tight fitting lid and covered by a plastic film to reduce evaporation from exposed mouth of pot. Water level was kept just below the neck and marked. A distance (1 m) between pitchers ensured that WF from one pitcher does not affect the other. In two contiguous experimental plots, plot I was 8 m away from plot II. In experiments during 2007, plot I housed pitchers A, B and C, while plot II had pitchers D and E (Fig. 1a). Experimental plots did not have any other water source. One sapling, each of plant *Tabernaemontana divaricata* (local name *Chandani*), was planted near (15 cm away from each of) pitchers in January 2007. Amount of water released from each pitcher over a given duration (1-3 d) was noted by measuring volume required to refill pitcher up to marked level at the neck[10].

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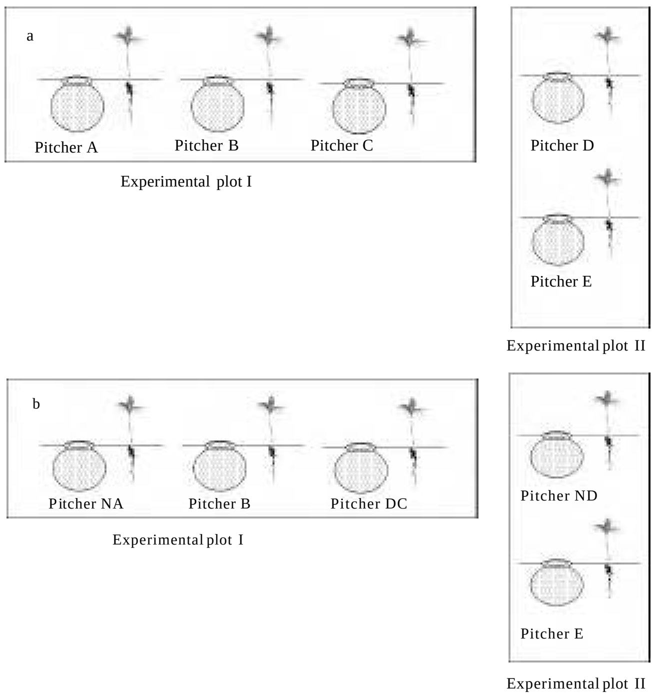

Fig. 1—Relative location of the pitchers (a) 2007 and (b) 2008

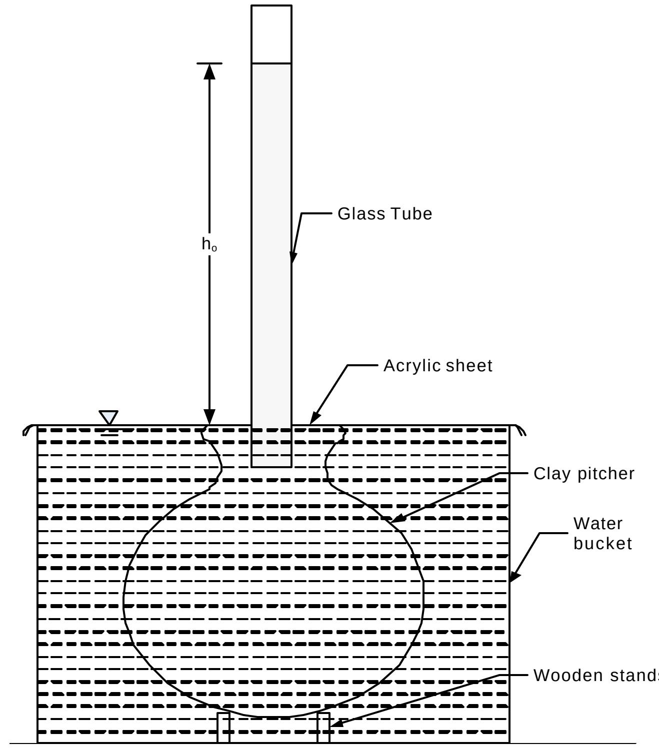

Fig. 2—Falling head method[13] for calculating hydraulic conductivity in water

In 2008 also, experiments were repeated in the same manner. However, in second year, to see the effect of surrounding soil and pitcher parameters on WF from pitchers, position of some of the pitchers were changed (Fig. 1b). Positions of pitchers B and E were left unchanged. Pot D was put in place of C and labelled as DC. Original Pot C broke. A new pot was kept in place of D and named ND. A new pot was kept in place of A and named NA (Fig. 1b). For all days, average day temperature (T) and average relative humidity (RH) for day were obtained from metrological records. From these data, saturation vapour pressure (p_o) and actual vapour pressure (p_a) were obtained from the tables. WF was correlated with MD in air, which was related to RH as

$$MD\,(bars)\ is\ proportional\ to\ (r_o - r_a) = r_o(1 - r_a / r_o) = r_o(1 - RH) \quad \ldots(1)$$

In another set of experiments, WF through 4 pots (P, Q, R and S) was measured in air, soil and water without hydraulic head. For studies in the soil, 4 pots were set up in a site without any vegetation around to eliminate transpiration effect due to plant. Pot S was further selected for studying WF under a hydraulic head. This was done by sealing neck of the pot and inserting a graduated glass tube through acrylic sheet into water in pitcher with an air tight seal (Fig. 2). Hydraulic conductivity in water at saturation of pitchers was measured by falling head method[12]. Whole pitcher was initially saturated for 72 h before measurements. After that, pitcher full of water was submerged to its neck in a water bucket, in which water level was kept constant by an overflow. Tube was filled with water thus creating a hydraulic head, across the wall of pitcher, equal to the height of water level in tube above water surface (≈ 90 cm) in bucket. Rate of fall in head (h) was observed. Similar experiments were done while keeping pitcher in air, and burying it up to the neck in soil. Falling head level was noted every 20 min for ≈2 h.

Calculation of Hydraulic Conductivity[12, 13]

If $h(t)$ is height of water column at time t, rate of flow, $Q = -a\,dh/dt$ and hydraulic conductivity (K_S) can be obtained from Eq. (2) as

$$\ln\left(\frac{h}{h_0}\right) = \frac{-AK_S\,t}{aL} \quad \ldots(2)$$

where, h_0 = initial height of water column in access tube, A = surface area of pot, a = cross sectional area of tube, and L = average wall thickness of pitcher.

For pot S, A=0.1503 m^2, L=0.006757 m, and a =0.00189 m^2. By measuring h as function of time, K_S

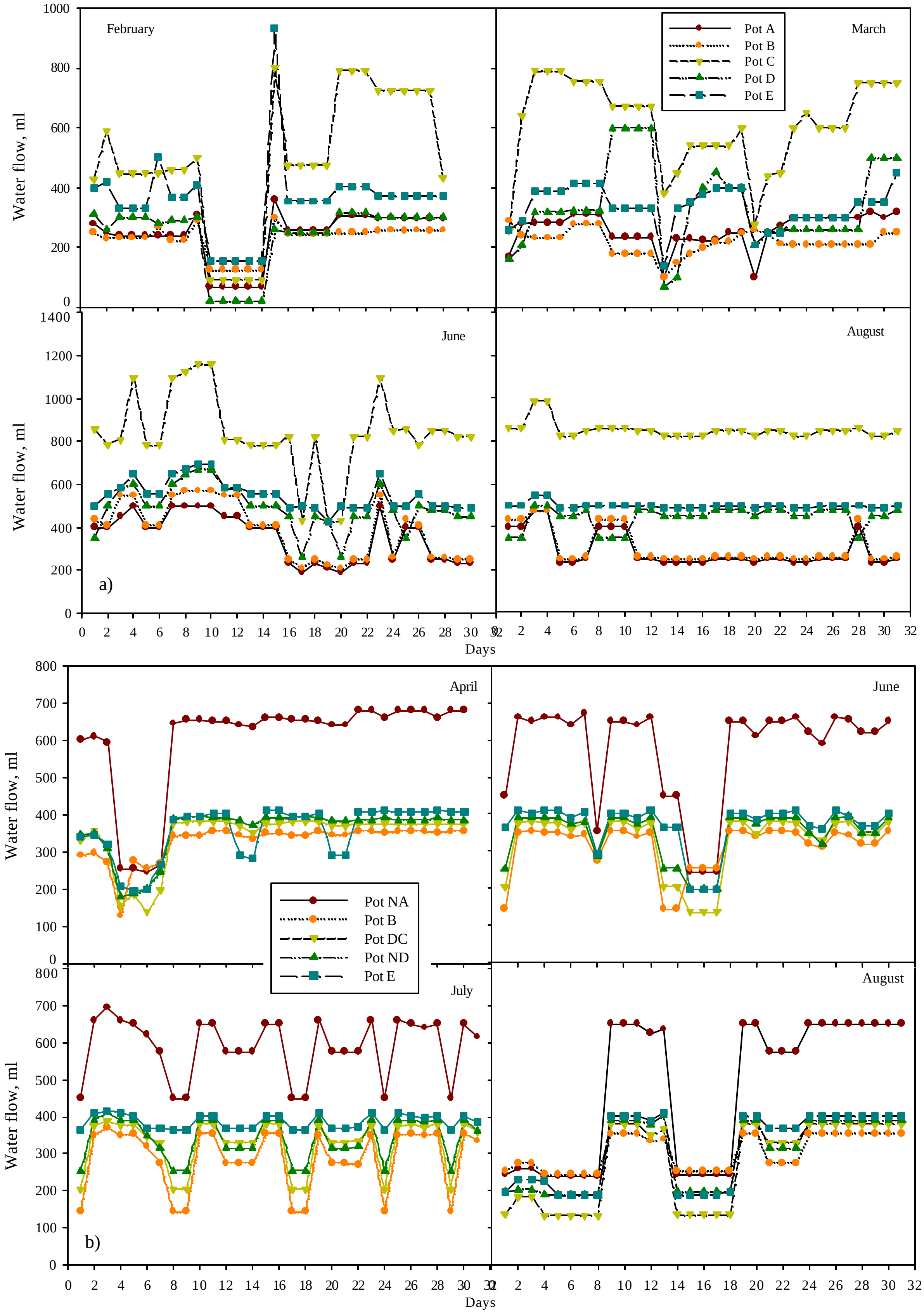

Fig. 3—Daily water flow over different months for a) 2007; b) 2008

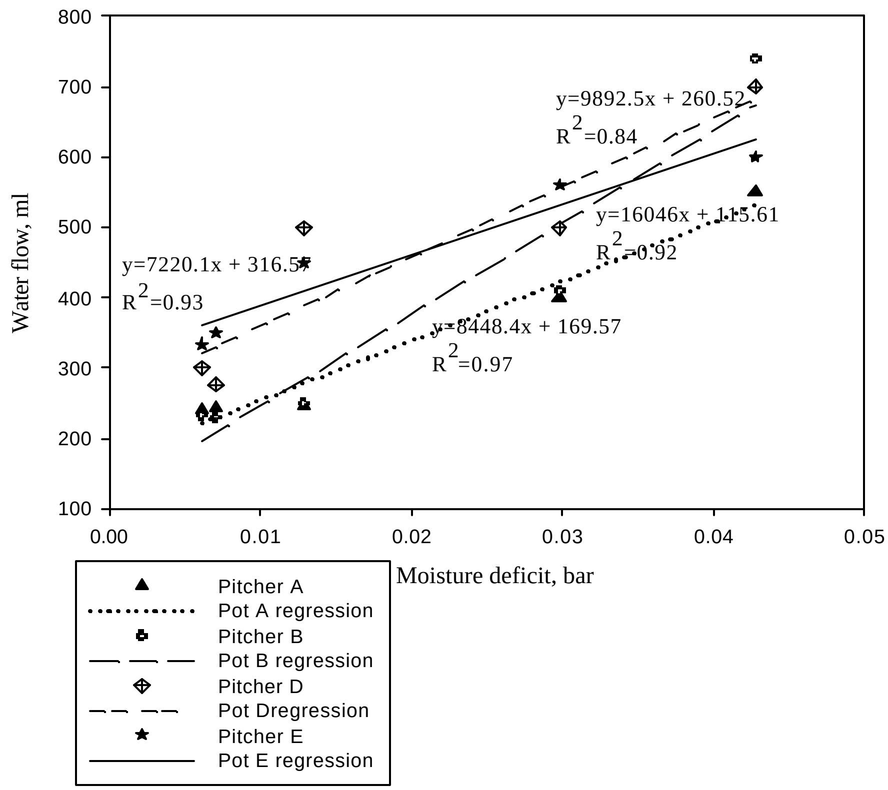

Fig. 4—Daily WF *vs* MD for different pitchers during non rainy days in 2007

(mm/day) was determined from slope of the graph of ln(*h*) *vs* time.

Calculation of Moisture Deficit (MD)

Temperatures of wet and dry bulb thermometers kept in vicinity of experimental site were noted. These readings were used to calculate mixing ratio (g/kg), which is the ratio of mass of water vapour to mass of dry air. RH and mixing ratio were obtained from tables shown in web[15], which used wet and dry bulb temperatures as inputs. Average MD in air (g/kg) was obtained in absolute terms using Eq. (3) as

$$\text{Air bearing capacity} = \left(\frac{\text{Maximum water content}}{\text{Unit mass of air}}\right) = \left(\frac{\text{Mixing ratio}}{\text{Relative humidity}}\right)$$

$$\text{Moisture Deficit} = \text{Air bearing capacity} - \text{mixing ratio}$$

$$= \text{mixing ratio}\left(\frac{1}{\text{RH}} - 1\right) \qquad \ldots(3)$$

Results and Discussion

Day to day variation in WF volume through pitchers (A - E) is shown for different months of 2007 (Fig. 3a), and same data for pitchers (A, NA, B, C, D, ND and E) is shown for different months of 2008 (Fig. 3b). It was observed (Fig. 3) that day to day variations in WF through pitchers follow remarkably the same pattern for all pots, and clearly showing dip in flow during rain events. Trends were same in all months over two years. WF over all days and seasons in 2007 (Fig. 3a) was in the order A & B < D & E< C. Possibly pitcher C was slightly more porous as it broke at the end of September 2007. WF in 2008 (Fig. 3b) was seen to be in the order pot B < pot DC, pot ND and pot E < pot NA. In all cases during rain events, WF through pitchers came down. Water evaporation from soil is expected to increase with increase in temperature and decrease with increase in RH. Combined effect of temperature and pressure is reflected in MD in air, which was calculated using Eq. (1). WF would also be influenced by the degree, to which surrounding soil is saturated. This in turn would depend on atmospheric MD. It was seen that for non rainy days, when WF varied almost linearly with MD (Fig. 4).

Plot of WF *vs* MD for rainy days was quite different (Fig. 5). In all the cases at low MD, WF was small and constant, it jumped to a higher value (0.005-0.01 MD), and became constant at higher MD. In some cases

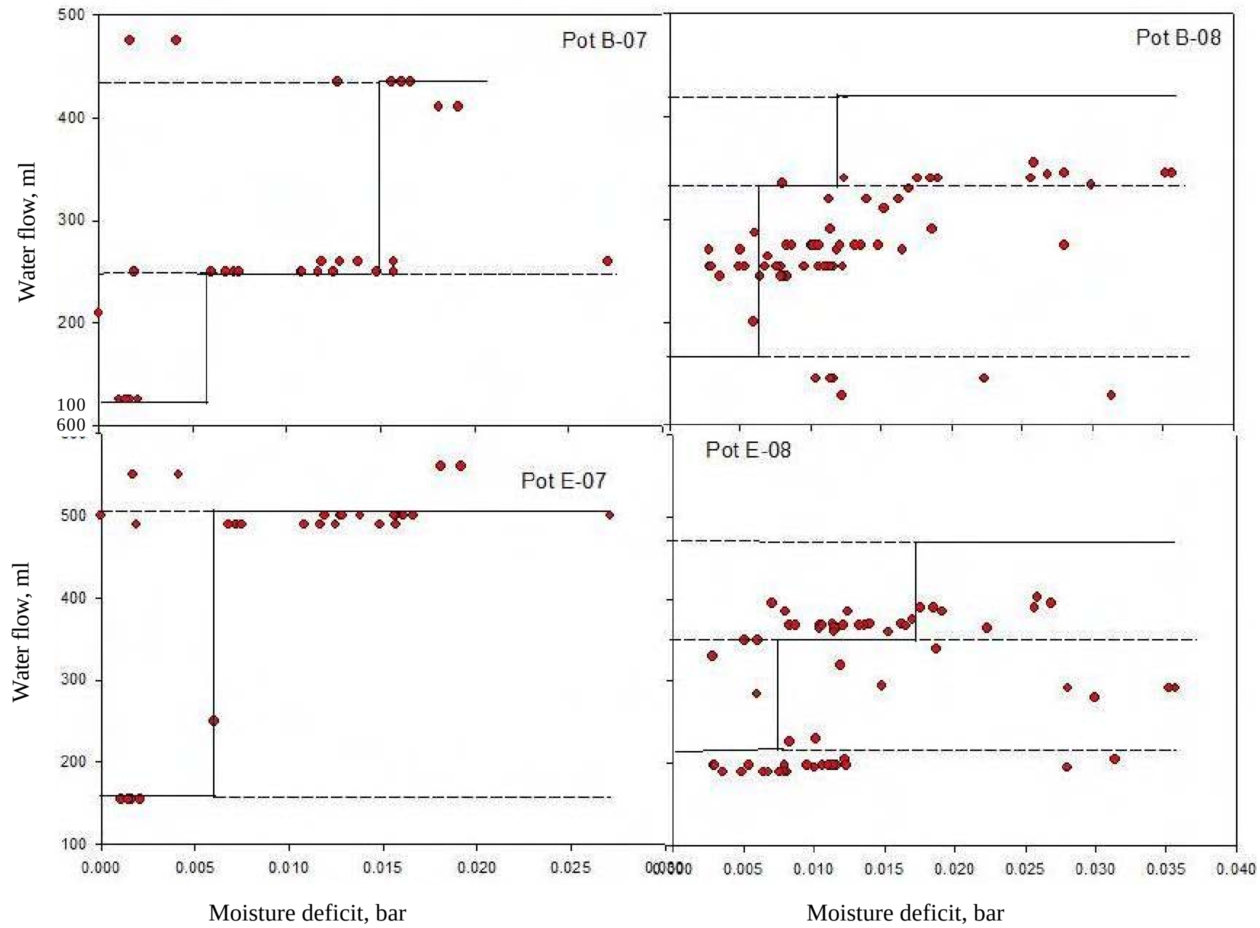

Fig. 5—Daily Water flow through Pots B and E during rainy days

Table 1—Water flow (WF) through different pitchers at different moisture deficit (MD)

	Water		Air		Soil	
	MD	WF, ml	MD	WF, ml	MD	WF, ml
Pot P	0.0105	50	0.0124	780	0.0108	210
	0.0105	50	0.0139	820	0.0137	260
	0.0115	50	0.0161	885	0.0143	245
	0.0089	50	0.0163	950	0.0146	290
Pot Q	0.0146	10	0.0070	440	0.0124	220
	0.0143	10	0.0089	470	0.0139	260
	0.0137	10	0.0105	503	0.0163	280
	0.0108	10	0.0115	503	0.0161	265
Pot R	0.0124	30	0.0108	470	0.007	220
	0.0139	30	0.0137	584	0.0089	275
	0.0163	30	0.0143	570	0.0105	283
	0.0161	30	0.0146	575	0.0115	283
Pot S	0.006363	10	0.00509	320	0.009	250
	0.004242	10	0.00520	330	0.011	300
	0.000672	10	0.00561	340	0.013	440
	0.002402	10	0.00594	370	0.015	480

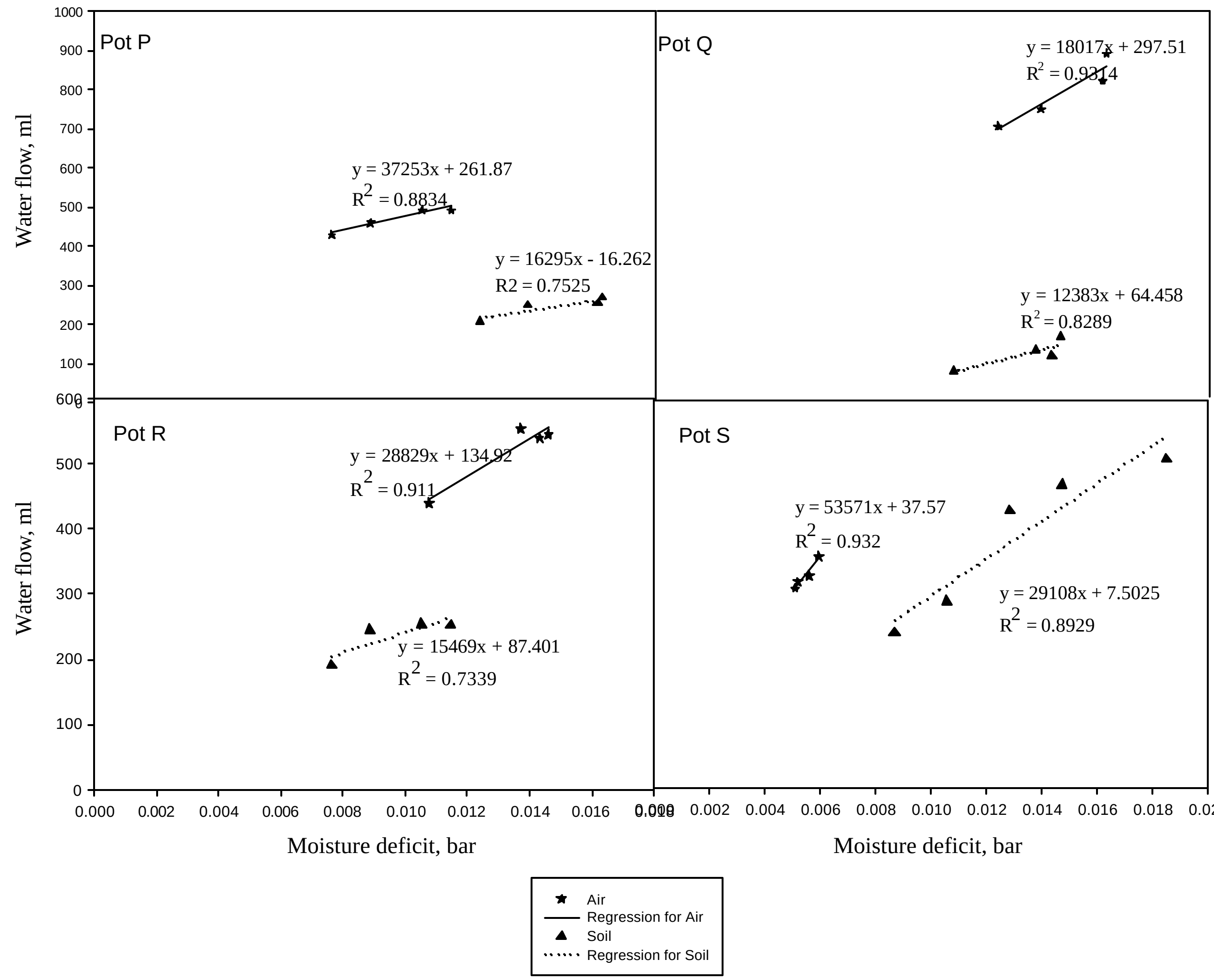

Fig. 6—WF Vs MD for pots P, Q, R, S in air and soil

(pot B), two such jumps were noted. During rainy days, top soil layer will remain saturated. Essentially flow from clay pot will be due to soil tension at lower layers as they get dried. Once soil layers lateral to pot have been saturated, larger amounts of water would be drawn upwards because there is continuity of moist region, which leads to a sharp increase in WF. In these studies, WF was subjected to not only soil water tension but also water suction by plant roots. Plants grew well without any external irrigation except from the pot, or rain water, under natural conditions. This shows feasibility of clay pot irrigation for auto regulated water delivery correlated to soil dryness. To eliminate contribution in water uptake by plants, experiments were done in a new site under selected conditions without any vegetation around.

WF (ml) data through P, Q, R, S pots without hydraulic head in water, air and soil and MD showed that WF through all pots varied in the order air>soil> water (Table 1). Base line of flow in water with respect to air was < 5%. WF in air and soil less the base flow in water is plotted against MD (Fig. 6), and plots were found linear with ratio of slopes for air and soil for pots P (2.29), Q (1.45), R (1.86) and S (1.84). Since these experiments were without hydraulic head, this clearly brings out that MD in surrounding atmosphere results in drawing out water through capillary pores on pot. Variations in WF *vs* MD for different pots may be attributed to differences in pore size and pore distribution on pot wall.

For experiments with pot S under hydraulic head, fall in height was plotted (Fig. 7) against time as per Eq. (2) for different days in air (A_1, A_2 and A_3), soil

Table 2—Variation of Ks with moisture deficit (MD) for pot S when placed in water, air and soil

		MD	Hydraulic conductivity (Ks) mm/d	Residual hydraulic conductivity (Kr)
Air	A1	8.3	0.0497	0.0357
	A2	7.8	0.0405	0.0265
	A3	6.2	0.0307	0.0167
Soil	S1	6.8	0.0376	0.0236
	S2	6.5	0.0294	0.0154
	S3	6.3	0.0264	0.0124
Water	W1	6.5	0.014	0
	W2	6.3	0.014	0
	W3	5.4	0.014	0

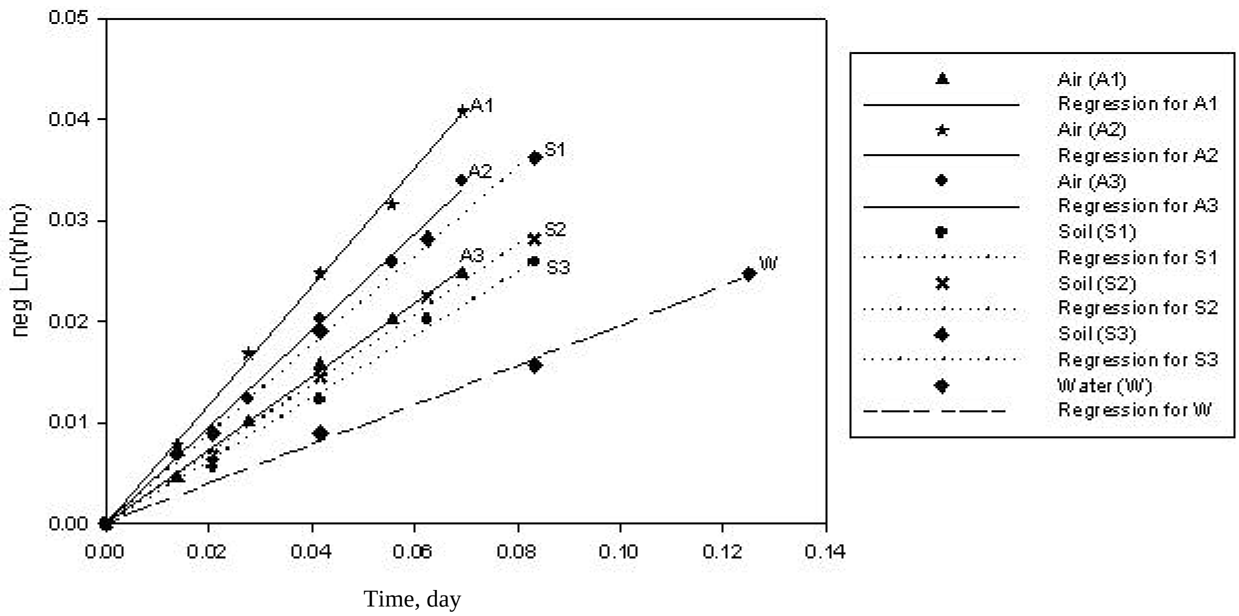

Fig. 7—Correlation between the falling head and time for pot S

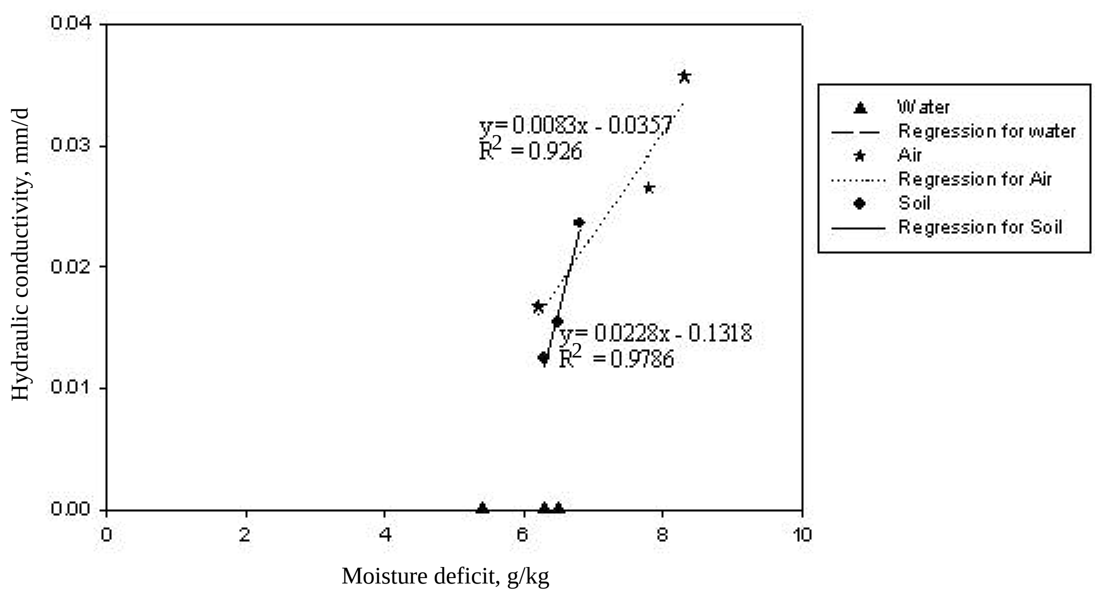

Fig. 8—Correlation of K_r in soil and water with MD

(S_1,S_2 and S_3) and water (W_1, W_2 and W_3). Plots were linear for all the cases with K_s varying as air> soil>water. K_s in water medium is independent of MD (Table 2), indicating that under hydraulic head certain large pores on pot wall allow WF but this flow is not influenced by pull due to MD in external medium. Subtracting K_s in water from total K_s, remaining K_r in air and soil is obtained. K_r is essentially due to suction (pull effect) generated by MD in air or soil, correlated linearly with MD (Fig. 8), and would depend on pore size and distribution on pot walls.

Conclusions

WF through walls of a buried clay pot was directly regulated by MD in air and soil over all seasons of the year. Capillary pores on the pot respond to soil water tension and MD in the air through a pull effect. WF can be said to be regulated by atmospheric MD when soil is dry as in the case during non rainy days. Pattern was different under full saturation of the soil top layer during rainy days, due to changes in conductivity of top soil layer as well as layers below with varying levels of saturation with moisture. Amount of WF from pot into water medium was low under atmospheric pressure, indicating that pots are not leaky. However, there was a significant increase in WF into water under hydraulic head and hydraulic conductivity in water was independent of MD. Thus WF in water is essentially due to flow through capillary pores under pressure head. When WF was measured in air and soil, it was very much higher than that in water both with and without hydraulic head. Hydraulic conductivity in air and water were also higher than that for water, and vary with MD. This conclusively indicates pull effect from medium (air/soil), which thus leads to auto regulated WF.

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