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Modeling of wheat (*Triticum aestivum*) yield in relation to soil characteristics and management practices

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ABSTRACT

A study was carried out to evaluate the production potential of soils in Agro-Ecological Sub-Region (AESR) 4.2 of Udaipur district in Rajasthan for wheat (*Triticum aestivum* L. emend. Fiori & Paol.) crop. Grain yield was monitored in farmers' fields consecutively for 3 years during winter season of 2004-05, 2005-06 and 2006-07. Multivariate regression model was developed to relate crop production to the set of four independent variables, viz. soil depth, available water content, irrigation and sowing time, and management. By using the regression equation, yield was predicted in 2005-06 and 2006-07, which was validated with actual yield. The available water capacity strongly affected the crop yield. In shallow sandy-loam soils, due to low available water content, minimum six irrigations were required for obtaining potential yield of 5.5-5.6 t/ha, whereas five irrigations were required in moderately deep to deep sandy clay-loam soils to produce potential yield of 5.7-5.8 t/ha. In deep clay soils four irrigations were sufficient to produce the potential yield. A saving of 15-20% water was achieved through the sprinkler system. The modelling exercise of the response of spatially distributed wheat yield was strongly affected by the soil variability within the study region.

Key words: Crop modeling, Soil suitability, Soil-water availability, Irrigation, Wheat yield

With incessant population growth and diminishing water availability, the agricultural sector is facing a serious challenge to produce more food per unit of this scarce resource. The contribution of wheat in the food basket of India is quite substantial. However, the states like Rajasthan, where it occupies 92% of foodgrain area in winter season (Government of Rajasthan, 2006), the significance of yield-water relationship becomes still more crucial. Prediction of wheat yield in terms of physiological, cultural and meteorologoical variables in this context is of major interest. Early attempts in this context involved statistical analyses of relationships between yield and observational data on precipitation, temperature, radiation etc., and scientific study of the physiological and cultural influences such as simulated phenological stages, variable weather conditions and soil treatments (Kumar and Sharma, 2006). The impact of climatic change on agriculture at regional level will be reduced by the response of individual farms and understanding of the impact of climate at the farm level, requiring investigations at large scale (Wassenaar *et al.*, 1999). However, on a larger scale, the importance of soil variability assumes greater significance in relation to variability in climate. Soil variability can be as high as 0.1 to 10 km, which is likely to affect the potential crop yields significantly. Limited efforts have been made to work out the suitability of soils for various crops at different levels of planning in western part of India, especially in Udaipur region-AESR 4.2 (Giri *et al.*, 1994; Singh *et al.*, 2002). It is therefore essential to evaluate the production potential of available land and to identify the constraints for suggesting proper land use according to its capability or suitability. In view of these facts, the present study was carried out at three sites in Udaipur district to develop yield-prediction model for wheat crop and validation of its performance in farmers' fields.

MATERIALS AND METHODS

The study area lies in Udaipur district of Rajasthan at three sites, viz. Changeri, Vana and Navania. The area represents hot, dry, semi-arid (Aravali East Upland) AESR 4.2 receiving a mean rainfall 500-600 mm, having a potential evapo-transpiration 1,380 mm. The rainfall received in the area during 2004, 2005 and 2006 was 405, 492 and 789 mm respectively. Typifying pedons were exposed and morphological characteristics were described at selected farmers' fields. Horizon-wise samples were collected and processed for laboratory investigation. The soils were

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classified using the latest guidelines given by USDA (Soil Survey Staff, USDA, 2003). The soil-moisture analysis was done by using pressure-plate apparatus. Suitability for wheat was evaluated by matching the soil-site characteristics with crop requirements, using FAO approach and modified suitability criteria by Sys *et al.* (1991) and Jain *et al.* (2000). Limitations were assessed on the basis of productivity at the given level of individual parameters (Verheye, 1996) as suitable (85%), moderately suitable (60%), marginally suitable (40%) and not suitable (<40%). For validation, 10 farmers' fields were selected at the three referred sites with different soil textures, depths (30 to 100 cm) and slope (1-3% to 3-8%). The soil samples were drawn for determining the soil-moisture content at weekly intervals from 0-15, 15-30, 30-50 and 50-80 cm depths of soil in the wheat fields during 2005-06 and 2006-07. The yield was monitored continuously for 3 years during winter season of 2004-05, 2005-06 and 2006-07.

For developing the regression model, weightage was assigned (0.10 to 0.80) for variables affecting the wheat yield (Sys *et al.*, 1991). The highest numerical value was assigned for maximum wheat production by each factor. Similarly, the lowest value was assigned for the lowest yield obtained by each factor (Table 1).

A multi-linear regression model was developed for predicting the wheat yield in semi-arid region of AESR 4.2 in Udaipur district. Factors having significant correlation with wheat yield such as soil depth, available water content (AWC), irrigation and sowing time, and management were chosen for regression model. These were individually significant at 5% level of significance. These factors account for 99% variations in wheat yield.

Predicted yield of wheat

Wheat yield (t/ha) = 2.00 – 1.23 (soil depth, mm) + 2.70 (AWC) + 2.24 (irrigation) + 1.28 (Sowing time and management); $R^2 = 0.99$

Table 1. Soil-suitability ratings for wheat during winter season 2004

Depth	Texture	Available water content	Irrigation	Sowing time and management	Field leveling
			Changeri		
0.40	0.60	0.35	0.70	0.70	0.60
0.60	0.60	0.60	0.40	0.70	0.50
0.70	0.65	0.70	0.40	0.50	0.50
0.75	0.60	0.70	0.80	0.75	0.75
0.75	0.60	0.70	0.60	0.75	0.75
			Vana		
0.40	0.70	0.40	0.80	0.75	0.70
0.60	0.70	0.65	0.75	0.75	0.75
			Navania		
0.75	0.75	0.75	0.80	0.75	0.75
0.75	0.75	0.75	0.75	0.75	0.75
0.75	0.75	0.75	0.40	0.60	0.40

The performance of the model was tested with soil-suitability ratings during 2005-06 and 2006-07 in actual field conditions and the yield was predicted. It was then compared with actual yield observed at farmers' fields.

RESULTS AND DISCUSSION

Soils and soil-moisture availability

It was observed that soil-moisture content was associated with clay content of the soils (Table 2). At Changeri the clay content in shallow, moderately deep and deep soils was 17.65-17.26, 20.21-35.25 and 22.35-27.20% respectively. In shallow soils, where the clay content was only 17.26-17.65%, the soil-moisture was 12.20-12.94% at 1/3 bar to 4.99-5.01% at 15 bar soil-moisture tension. In moderately deep soils with clay content 20.21-31.0%, the soil moisture was 15.12-24.11% at 1/3 bar to 6.60-10.66% at 15 bar soil-moisture tension. In deep soils with clay content 22.35-27.20%, the soil moisture was 17.46-21.86% at 1/3 bar to 6.37-9.97% at 15 bar soil-moisture tension. Hence in shallow soils for obtaining the potential wheat yield, minimum six irrigations were required, whereas in moderately deep to deep soils five irrigations were sufficient. At Navania, where the clay content in shallow soils was 21.81-25.81%, the soil moisture was 24.75-25.58% (1/3 bar) to 11.28-11.67% (15 bar). Hence in these deep clay soils only four irrigations were required.

Soil-moisture availability

The soil moisture played a very important role in attaining potential crop yield. The availability of soil moisture was affected by the number of irrigations applied and water-holding capacity of different soils. In shallow sandy-loam soils of Changeri, during 2005-06 with six irrigations, in most of the growing period the availability of soil moisture was 9.4-19.5% at 1/3 bar, except in 1 week coinciding with the time of flowering when the soil moisture availability was within 7.1-7.4% at 3-5 bar tension (Fig. 1). However, during 2006-07, when only five irrigations were applied, the availability of moisture at critical grain-filling stage was reduced to 5-10 bar soil-moisture tension; hence in shallow soils minimum six irrigations were required to get the potential yield. Conjointly in shallow and medium soils the ground-water availability was lower because these soils were mostly situated on upper part of the watershed; hence by the time the crop reached maturity, farmers were not able to give irrigation at crucial grain-development stage due to shortage of water. In moderately deep (65-70 cm) sandy clay-loam soils, during 2005-06 (Fig. 2) with three irrigations at flower initia-

Table 2. Soils and soil-moisture availability of study area

Soil horizon (cm)	Total depth (cm)	Clay (%)	Soil-moisture tension (bar) at soil moisture (%)					
			1/3	1	3	5	10	15
				Changeri				
0-15	35-40	17.65	12.20	8.42	7.17	6.49	5.70	4.99
15-30		17.26	12.94	9.31	7.89	7.08	5.74	5.01
0-15	65-70	20.21	15.12	11.24	9.12	8.32	7.86	6.60
15-30		22.06	16.84	11.50	10.18	8.94	8.02	7.13
30-50		26.49	22.66	15.59	12.54	10.94	10.36	9.46
50-70		31.10	24.11	17.96	14.16	12.65	11.65	10.66
0-15	100	22.35	17.46	11.91	9.59	8.49	7.49	6.37
15-30		24.77	18.79	13.66	11.68	10.50	9.06	7.78
30-50		26.87	21.80	16.32	14.15	12.70	11.16	9.91
50-80		27.20	21.86	16.35	14.25	12.78	11.26	9.97
				Vana				
0-15	35-40	21.81	24.75	17.42	14.91	13.38	11.61	11.28
15-30		25.81	25.58	18.13	16.10	14.23	12.51	11.67
				Navania				
0-15	>100	40.63	30.19	24.23	22.74	21.18	17.94	16.55
15-30		40.80	30.29	24.33	22.49	21.27	18.09	16.80
30-50		42.54	31.05	25.34	23.26	22.18	19.12	18.22
50-80		42.49	31.15	25.48	23.32	22.19	19.29	18.32

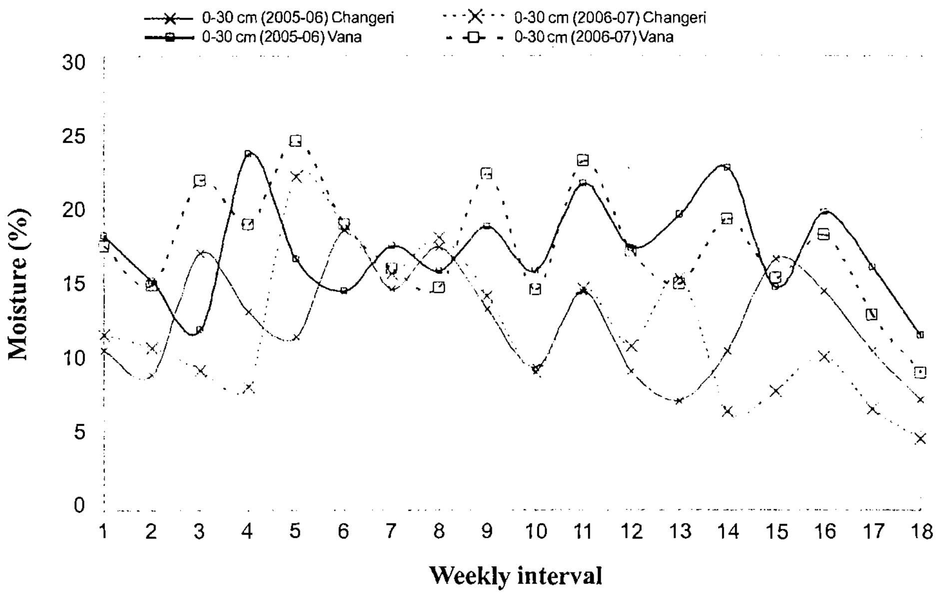

Fig. 1. Soil-moisture availability in shallow soils at Changeri and Vana

tion and grain-filling stages the soil-moisture availability was within 5-10 bar tension range in 0-30 cm soil horizon. It was observed that crop-root penetration in these soils was only up to 20-25 cm. Therefore due to less availability of water in the root zone, potential crop yield was not obtained. However, when five irrigations were given throughout the cropping season of 2006-07, soil-moisture availability in the whole horizon hovered around 1-3 bar tension, which resulted in achieving the potential wheat yield. Similar trend was observed in deep (100 cm) soils, where the soil-moisture availability in the whole horizon was in the range of 1-3 bar soil-moisture tension during the 3 years on applying five irrigations.

Contrarily, the application of seven irrigations on shallow sandy-clay loam soils of Vana resulted in excess soil water, which could be attributed to crop-lodging during 2005-06. But when six irrigations were applied in 2006-07, the soil-moisture availability remained in the 3-5 bar tension range with no lodging. In moderately deep sandy clay-loam soils, where three irrigations were applied, soil-

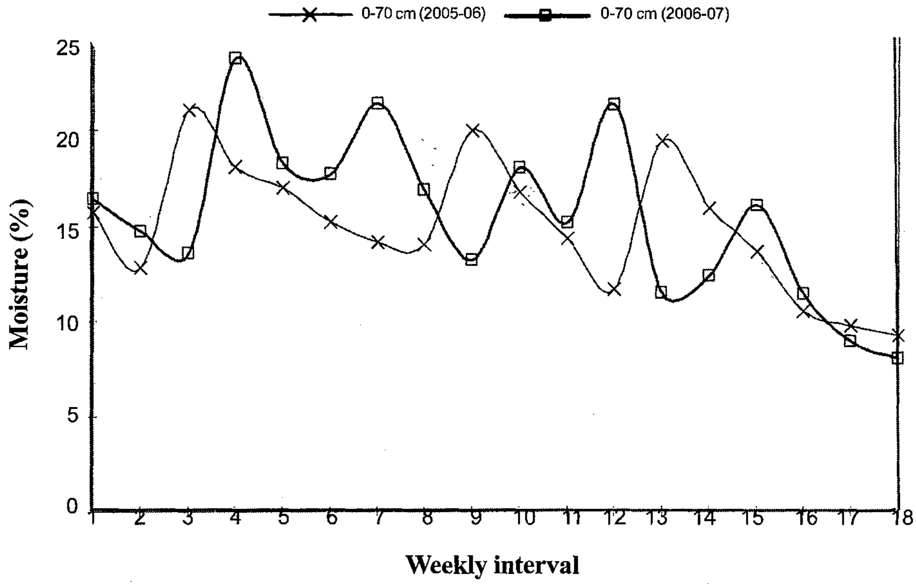

Fig. 2. Soil-moisture availability in moderately deep (65-70 cm) soils at Changeri

moisture availability in 0-30 cm horizon at tillering and flowering stages was in the tension range of 5-10 bar, but at the time of grain filling the moisture availability remained around 10-15 bar range, which resulted in poor yield (Fig. 1).

In very deep (> 100 cm) clay soils of Navania, when three irrigation (2005-06) were applied soil-moisture availability in 0-30 cm horizon at tillering, milk and dough stages was in the range of 5-10 bar tension. However, when four irrigations were applied throughout the cropping season during 2006-07, the soil-moisture availability was in the range of 1-5 bars tension. In these deep clay soils when irrigations were applied by sprinkler system, there was saving of 15-20% water, and with five irrigations in 2005-06 and four irrigations in 2006-07 throughout the cropping season, though whole of the soil horizon never attained the field capacity, 15-50 cm horizon, remained in the range of 1-5 bar moisture tension for most of the time (Fig. 3). Studies in these soils showed that maximum root penetration was up to 22-30 cm depth, due to which the deeper layer of soil never required more moisture. These results corroborate the findings of Panda *et al.* (2003), who reported that plants extracted most of the soil moisture from 0 to 45 cm soil layer. Hence only 0-

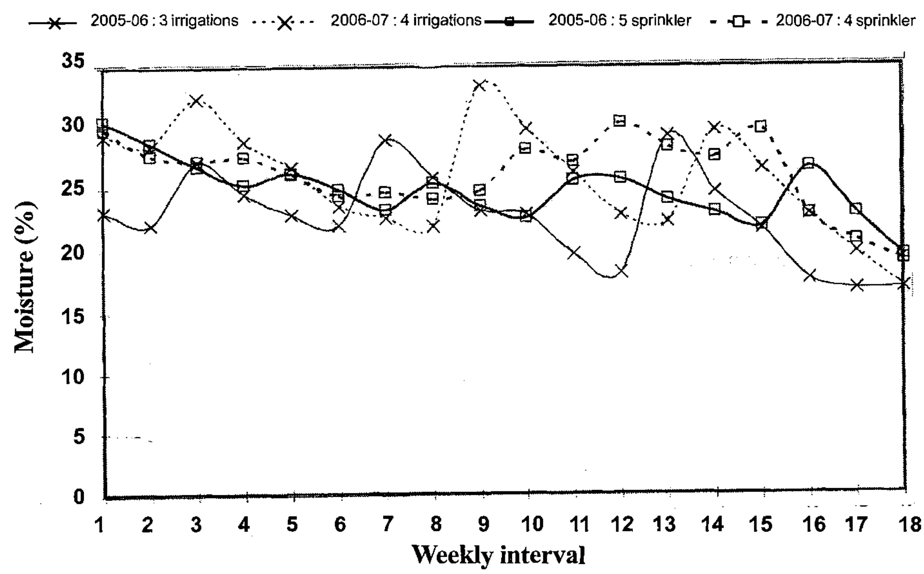

Fig. 3. Soil-moisture availability in very deep clay soils at Navania by normal and sprinkler systems

Table 3. Grain yield of wheat at three sites

Soil depth (cm)	2004-05		2005-06		2006-07	
	No. of irrigations	Grain yield (t/ha)	No. of irrigations	Grain yield (t/ha)	No. of irrigations	Grain yield (t/ha)
			Changeri			
35-40	5	4.90	6	5.31	5	4.99
65-70	3	4.69	3	4.75	5	5.62
85-90	3	4.55	3	4.67	4	4.88
100	5	5.67	5	5.70	5	5.78
100	4	5.25	5	5.60	5	5.75
			Vana			
35-40	6	5.41	7	5.00	6	5.63
65-70	5	5.56	3	4.69	3	4.90
			Navania			
>100	4	5.94	3	5.25	4	5.94
100	4 (sprinkler)	5.78	5 (sprinkler)	5.99	4 (sprinkler)	5.74
>100	2	4.80	2	4.68	3	5.14

45 cm soil layer should be considered for scheduling irrigation of wheat grown in sandy loam soils in the subtropical regions under water-scarcity conditions.

Effect of irrigation

It was observed that on shallow sandy loam soils of Changeri and Vana, minimum six irrigations were required to overcome the limitations of soil depth and water-holding capacity. At Changeri, with five irrigations 4.99 t/ha yield was obtained due to lower availability of moisture (5-10 bar) at crucial grain-filling stage. Similarly, at Vana even with seven irrigations during 2005-06 only 5.0 t/ha yield was obtained due to crop lodging. In moderately deep to deep sandy loam soils for obtaining potential yield of 5.6-5.8 t/ha, five irrigations were required (Table 3).

In moderately deep sandy clay-loam soils at Changeri and Vana, an increasing number of irrigations from three to five increased the crop yield, because with three irrigations the soil-moisture availability at crucial grain-development stage remained in the range of 10-15 bar tension, which resulted in poor observed and predicted yield. Plot leveling also played an important role, because poor leveling in mostly shallow soils resulted in lower yield. Even on deep soils, where leveling was not proper and 2 or 3 irrigations were given, poor yield of 4.6-5.1 t/ha was obtained.

For obtaining the yield of 5.7-5.9 t/ha, four irrigations were required on deep clay loam-clay soils due to their higher capacity of soil-moisture holding and higher organic carbon content. However, in clay soils the use of sprinkler system saved 15-20% water and produced maximum yield of 5.99 t/ha with five irrigations. Bhaskar *et al.* (1996) also reported significant positive correlation between depth, clay, cation-exchange capacity (CEC), AWC and organic carbon with wheat yield.

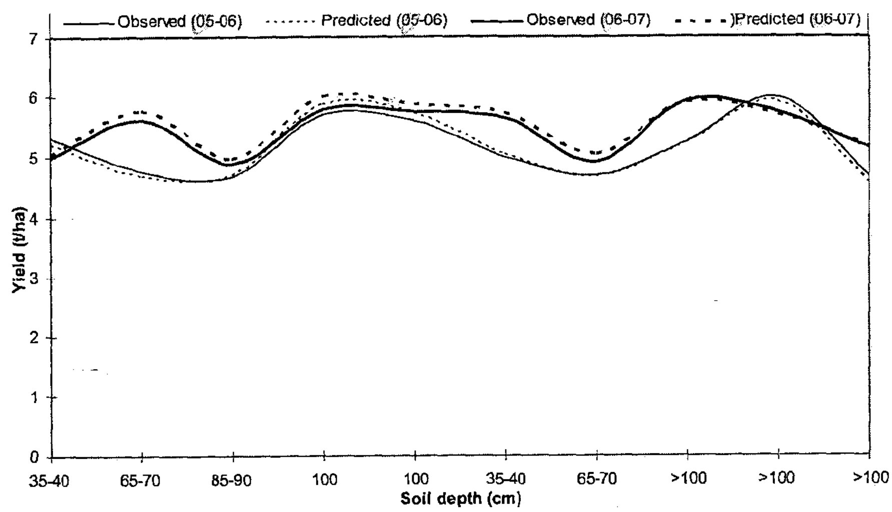

Fig. 4. Observed and predicted grain yield of wheat in different soils

Simulation of wheat yield

Based on the yield data of 2004-05, a regression model was developed. The fitted model agreed well for wheat crop. The predicted yield values in individual years were within acceptable limits, with more or less even distribution of difference from observed crop yield (Fig. 4) and governing of crop yield largely by variables considered in the model. In the present study, good relationship was found with climate-specific regressions between soil indicator and average yields. The selected soil indicator was the available water capacity (AWC). The AWC was observed up to 0.80 m depth, since this corresponds to the maximum depth at which annual plant roots can go. The AWC approximates the amount of water that can be absorbed by the plant roots. In our study a strong relationship existed between AWC, soil texture, number of irrigations, sowing dates and field leveling with crop yield. Wassenaar *et al.* (1999) also came across strong relationship between average wheat yield and AWC over the period 1977-1984. The correlation coefficients were very high, indicating that wheat yields can be estimated from the AWC under known climatic conditions. In another study Kumar and Sharma (2006) in CERES wheat model had also successfully simulated phenological stages and yield of wheat varieties, and recommended its use in the framework of decision support system for predicting the yield under variable weather conditions for strategic and tactical decision making for crop management and improving the resource-use efficiency.

The AWC affected the crop yield in all the 3 years. In shallow sandy-loam soils with low AWC, minimum six irrigations were required for obtaiing the potential yield of 5.5-5.6 t/ha. In moderately deep to deep sandy-clay loam soils, five irrigations were required to produce the potential yield of 5.7-5.8 t/ha. In deep clay soils five irrigations were required to produce the potential yield, and by the use of sprinkler system there was saving of 15-20% water. The modeling exercise of the response of spatially distributed wheat yields was strongly affected by the soil variability within the study region for simulating the yields.

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