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Building and Evaluating Mathematical Model to Predict Available Water in Middle Euphrates in Iraq

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Abstract:

A simple linear and multiple linear regression equation was developed to predict available water in the soils of the Middle Euphrates Governorates from some easily measurable physical and chemical properties. The statistical software SAS was used. The results showed a positive correlation between soil moisture constants (field capacity, permanent wilting point, and available water) and the clay content of the soil. The clay percentage was the most influential factor compared to other properties in the amount of available water. There was a positive correlation between available water and clay and silt content, and a negative correlation between available water and apparent soil density, carbonates, and electrical conductivity. We recommend using the developed prediction model under experimental conditions using the clay fraction, as it yields acceptable results for available water with an error rate of no more than 2%.

Keywords: *available water, forecasting, Middle Euphrates soil, Iraq*

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بناء وتقويم نماذج رياضية للتنبؤ عن الماء الجاهز في ترب محافظات الفرات الاوسط من العراق

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الخلاصة:

تم بناء معادلة انحدار خطي بسيط وانحدار متعدد للتنبؤ عن الماء الجاهز في ترب محافظات الفرات الاوسط من بعض الخصائص الفيزيائية والكيميائية سهلة القياس. استعمل البرنامج الاحصائي SAS. اظهرت النتائج وجود علاقة ارتباط موجبة بين ثوابت رطوبة التربة (السعة الحقلية ونقطة الذبول الدائم والماء الجاهز) ومحتوى التربة من الطين. وان نسبة الطين هي العامل الاكثر تأثيرا من بقية الصفات الاخرى في كمية الماء الجاهز. وعلاقة ارتباط موجبة بين كل من الماء الجاهز ومحتوى الطين والغرين وعلاقة عكسية بين كل الماء الجاهز وكثافة التربة الظاهرية ومعادن الكربونات والايصالية الكهربائية. نوصي بضرورة استعمال النموذج التنبؤ المتحصل عليه تحت ظروف التجربة باعتماد مفصول الطين لانها تعطي نتائج مقبولة بكمية الماء الجاهز بنسبة خطأ لا تتجاوز 2%.

الكلمات المفتاحية: الماء الجاهز، التنبؤ، ترب الفرات الاوسط، العراق.

Introduction

Available water is defined as the portion of water in the soil that is readily available for plant uptake. It is the water held in the soil between the field capacity (the maximum amount of water soil can hold after excess water has drained away) and the permanent wilting point (the point at which plants can no longer extract water from the soil (Brady and Weil, 2008). According to Saxton and Rawls (2006); Abd-Aljabar *et al.*, (2028); Ati (2009) and Alwazzan and Ati (2024), available water capacity is influenced by soil texture, structure, and organic matter content. For instance, soils with higher clay content generally have higher water holding capacity, but not all this water is available to plants due to the strong adhesion forces between water and clay particles. On the other hand, sandy soil drains quickly and thus has lower water holding capacity, but the water present is more readily available to plants.

Available water in the soil is a critical element in agriculture and water resource management. The water content in the soil is influenced by several factors, including the physical and chemical properties of the soil, climatic conditions, and plant type. Using direct methods to estimate the amount of ready water in the soil in the field or laboratory requires considerable time and effort, as well as the presence of spatial variations in soil, which increases the difficulty of obtaining accurate and fast results. Therefore, many researchers resort to indirect methods of estimation, by finding and developing mathematical models that link some soil characteristics with the amount of available water, considering the accuracy and speed of measuring these characteristics on the one hand, and the suitability of these models for application under local conditions on the other hand. This study aims to: Build a mathematical model to predict the available water content in the Middle Euphrates governorates of Iraq (Najaf, Karbala, Babylon, Diwaniyah and Muthanna) based on easy and quick-to-measure soil characteristics

Material and Methods

To anticipate the amount of available water in the soils of the Middle Euphrates based on some of its properties and to create a mathematical model that can be applied to a wide range of soil variations, data were obtained through conducting laboratory analyses on soil samples collected in the field. 100 sites were selected within the study area for soil textures of different textures representing the soils of the Middle Euphrates in Iraq. The physical and chemical properties of the soil were estimated according to the methods mentioned in Black *et al.* (1965) and Al-Ani (2001) (Table 1). Physical properties (soil particles analysis, sand, silt and clay, bulk soil density, volumetric moisture content at tension of 10, 33 and 1500 Kpa). Chemical properties (carbonate minerals, gypsum and electrical conductivity).

Building a mathematical model

The mathematical model construction involves the use of some physical and chemical properties of the soil that included the moisture content held at tension 10, 33 and 1500 kPa, soil texture, bulk density, carbonate minerals, gypsum and soil salinity as explanatory variables, while ready-made water values were counted as response variables.

Statistical Analysis

The Statistical Analysis System, User's Guide (2018) program was used to Estimate of Regression coefficient-b (Prediction equations: $Y^{\wedge} = a + bx$, Simple and multiple linear regression) and Correlation coefficient between variables in this study.

Table 1. Some physical and chemical properties for study soil

NO.	Clay	Silt	Sand	Bulk density	Soil Moisture (cm ³ cm ⁻³)		CaCO ₃	CaSO ₄	EC
	g kg ⁻¹			μg m ⁻³	FC	PWP	g kg ⁻¹		dSm ₁
1	447.9	469.4	82.7	1.43	0.32	0.16	274.7	9.22	11.25
2	275.2	502.9	221.9	1.5	0.27	0.15	280.2	8.92	6.77
3	286.2	388.4	325.4	1.5	0.28	0.153	299.7	7.88	4.03
4	327.1	422.5	250.4	1.4	0.29	0.16	302.9	11.67	24.41
5	391.4	332.6	276	1.51	0.31	0.15	297.4	13.85	2.97
6	420.7	421.7	157.6	1.46	0.33	0.14	280.2	9.55	3.41
7	394.4	418	187.6	1.44	0.33	0.13	286.5	10.77	1.95
8	343.9	415.2	221.6	1.35	0.31	0.12	357.7	7.68	28.38
9	230	426	344	1.42	0.25	0.12	254.6	18.91	7.4
10	140	496	364	1.38	0.25	0.14	236.9	20.33	1.06
11	250	306	444	1.57	0.26	0.141	258.7	10.12	7
12	270	332	397	1.22	0.25	0.16	254.6	13.11	7.87
13	234	333	431	1.29	0.21	0.13	293.3	8.55	20.57
14	320	320	360	1.04	0.26	0.17	329.2	7.12	2.97
15	238	283	475	1.28	0.2	0.14	320	7.13	10.93
16	243	302	453	1.93	0.24	0.16	254.6	6.76	7.85
17	230	346	424	1.31	0.21	0.14	114.1	6.97	31.8
18	240	276	484	1.12	0.22	0.15	240.1	14.11	26.6
19	229	304	465	1.31	0.21	0.14	304.4	6.88	20.76
20	331.8	167	501.2	1.46	0.18	0.092	234.2	4.67	1.51
21	194	246	529	1.4	0.17	0.09	246.32	2.34	7.22
22	185	351	464	1.25	0.19	0.09	240.59	6.82	4.42
23	360	464	150	1.31	0.25	0.16	456	1.4	17.4
24	260	600	120	1.34	0.34	0.16	298	18	8.4
25	400	572	28	1.37	0.38	0.2	274	3	3.8
26	290	530	150	1.31	0.32	0.16	416	2	13.9
27	342	552	100	1.32	0.31	0.18	442	6	10.8
28	105	496	398	1.48	0.28	0.16	200	7.07	3.5
29	539	382	178	1.33	0.31	0.18	218.4	16.34	2.8
30	320	504	179	1.44	0.3	0.14	227.1	8.23	2.3
31	124	527	347	1.48	0.27	0.13	215.6	7.81	4
32	417	408	174	1.38	0.31	0.13	176	17.92	4.3
33	312	459	227	1.34	0.28	0.12	311.6	10.26	1.7
34	215	528	256	1.46	0.33	0.16	218	6.4	6.9
35	76	618	305	1.35	0.25	0.09	207.1	37.44	13.3
36	159	460	381	1.51	0.29	0.1	235.4	17.39	5
37	281	435	284	1.4	0.28	0.13	245.4	13.52	3.9
38	92	489	420	1.68	0.14	0.06	197.5	15.67	4.3

39	98	488	412	1.66	0.22	0.08	312	6.73	3.8
40	213	260	527	1.5	0.28	0.11	171.9	16.47	2.6
41	436	221	342	1.34	0.25	0.09	264.1	38.18	7
42	231	295	473	1.52	0.15	0.06	154.2	8.74	5.3
43	95.8	406	498	1.42	0.27	0.12	210.7	7.52	2.8
44	241	320	438	1.34	0.26	0.09	205.3	13.09	2.9
45	150	527	322	1.35	0.29	0.13	204.3	24.18	9.2
46	64	552	382	1.42	0.3	0.12	202.5	18.03	2.7
47	69	547	3384	1.35	0.31	0.13	251.3	6.2	2
48	420	440	140	1.43	0.35	0.18	248	15.2	18.22
49	430	469	110	1.58	0.33	0.17	257	7.2	16.01
50	330	480	190	1.39	0.32	0.14	243	10.2	16.12
51	350	490	160	1.44	0.29	0.15	252	14	16.17
52	360	550	90	1.46	0.28	0.13	227	5.8	20.3
53	500	440	60	1.29	0.33	0.15	250	26.8	7.48
54	550	400	50	1.47	0.33	0.16	262	7.6	8.1
55	450	400	150	1.57	0.35	0.19	303	15.7	11.5
56	330	550	120	1.41	0.29	0.12	237	15.9	14.2
57	160	450	390	1.74	0.26	0.11	208	5	8.7
58	500	330	170	1.26	0.31	0.16	211	9.2	9.35
59	380	380	240	1.45	0.28	0.13	232	5	10.16
60	400	480	120	1.57	0.31	0.17	214	6.9	29.4
61	360	630	10	1.3	0.42	0.18	216	3	7.47
62	450	530	20	1.38	0.37	0.19	211	13.4	8.75
63	440	450	110	1.52	0.28	0.16	242	0.8	27.9
64	500	420	80	1.46	0.31	0.17	283	1.7	28.5
65	510	420	70	1.54	0.3	0.11	278	0.9	20.2
66	520	400	80	1.58	0.34	0.18	315	13.9	27.2
67	430	540	30	1.58	0.34	0.19	308	7.5	22.5
68	170	730	100	1.3	0.28	0.1	225	9	14.1
69	90	400	510	1.37	0.29	0.12	219	1.4	8.4
70	490	410	100	1.65	0.36	0.19	276	5.7	13.8
71	410	300	290	1.8	0.31	0.18	274	1.6	13.4
72	430	450	120	1.78	0.35	0.19	296	3	9.4
73	310	390	300	1.34	0.27	0.14	261	0	1.7
74	30	540	430	1.57	0.32	0.18	263	0	3.1
75	400	570	30	1.8	0.33	0.18	281	0.8	3.2
76	440	400	160	1.3	0.31	0.16	289	6.1	15.1
77	470	450	80	1.38	0.35	0.19	283	13.1	22.9
78	460	490	50	1.48	0.36	0.19	288	8.9	15.9
79	200	600	200	1.5	0.3	0.14	266	2.3	1.2
80	230	560	210	1.32	0.28	0.12	277	1.6	1.6
81	270	550	180	1.49	0.3	0.17	231	30.6	11.7
82	340	500	160	1.46	0.33	0.18	268	4.1	9.1

83	150	600	250	1.45	0.29	0.12	255	0.7	14.8
84	340	590	70	1.34	0.37	0.2	233	3.4	4
85	470	460	70	1.43	0.37	0.19	243	1.8	4
86	500	440	60	1.47	0.33	0.16	262	7.6	8.1
87	550	400	50	1.57	0.35	0.19	303	15.7	11.5
88	410	490	100	1.57	0.33	0.18	263	6.6	24.51
89	190	620	190	1.34	0.28	0.12	134.1	6.8	9.1
90	390	480	130	1.31	0.34	0.15	229	11.1	11.4
91	400	510	90	1.32	0.29	0.11	241	8.66	2.3
92	480	420	100	1.49	0.31	0.14	299	4.6	12.9
93	500	440	60	1.29	0.33	0.15	250	26.8	7.4
94	410	540	50	1.48	0.29	0.16	264	0.9	25.2
95	535	348	116	1.32	0.49	0.19	191	10.2	3.9
96	560	380	60	1.26	0.4	0.23	235	1.5	3.4
97	410	500	90	1.52	0.35	0.18	255	1.6	8.6
98	280	620	100	1.38	0.24	0.11	259	5.1	11.1
99	200	390	410	1.41	0.32	0.18	250	0	1.7
100	180	630	190	1.42	0.27	0.09	248	2.1	2.1

Results and Discussion

The percentage of clay fraction in the study soils, consisting of approximately 100 soil samples, ranged from 64.22 g kg⁻¹ to 550 g kg⁻¹ (Table 1). This variability in clay content makes the available water forecasting models obtained in this study applicable to a wide range of different soil types. Results of the simple regression analysis (Table 2) showed a significant effect of clay fraction on the amount of available water, with determination coefficient value ($R^2 = 0.10^{**}$), also a significant effect of clay fraction on the amount of available water with $R^2 = 0.12^{**}$. But there is no significant effect of sand fraction on the amount of available water with $R^2 = 0.07^{NS}$. The reason for this is that the soil retains water in the form of water films that coat the surface of its particles and are interspersed in the angles confined between the soil particles. It was added that these films tend to take the same thickness around the soil particles despite the differences in particle sizes, and that soils with a fine texture contain larger surface pores and more angles for holding and retaining water, which allows them to carry a larger amount of water per unit volume compared to coarse-textured soils. David (1995); Gupta and Larson (1979); Abd El-Hady (2005); Abbas and Wheib (2021); Ati and Jabbar (2024); Ati et al. (2024) and Waheeb and Wheib (2024 a,b,c) confirmed that the moisture content of the soil increases with the fineness of the soil texture up to a certain point. The amount of water available for plants is maximized when the soil texture is a silty loam and decreases in heavy-textured soils such as clayey and clay loams, where the amount of available water in these soils does not exceed 30-35% of the total water present in these soils. He attributed this result to the small size of the particles of the clay and its high surface area, which leads to holding water molecules around the surface of the clay particles

Table 2: Prediction equations to regression of AW on Physical Parameters

Physical Parameters	Regression-b	Prediction equations $Y^{\wedge} = a + bx$	Level of sig.	R^2
Clay (g kg ⁻¹)	0.000087	$Y^{\wedge} = 0.122 + 0.000087X$	**	0.10
Silt (g kg ⁻¹)	0.00012	$Y^{\wedge} = 0.096 + 0.00012X$	**	0.12

Sand (g kg ⁻¹)	-0.000014	Y [^] = 0.154 -0.000014X	NS	0.07
Bulk density (μg m ⁻³)	-0.0147	Y [^] =0.172 -0.0147X	NS	0.03
Clay, Silt, Sand, Bulk density	Y [^] =0.056 +0.00013Clay +0.00016Silt+0.000017Sand-0.0188Bulk		**	0.31
** (P≤0.01). R ² : Determination coefficient.				

The results of the multiple regression analysis (Table 2) showed a positive correlation between the amount of available water (Y) and each of the clay, silt and sand contents, and a negative correlation between the amount of available water and the apparent soil density values. The significant coefficient of determination agreement value reached 0.31^{**}. The negative relationship between the amount of available water and the apparent soil density of the soil samples (100 samples) is attributed to the fact that the increase in the soil density implies a reduction in the total volume of soil pores and thus a reduction in its ability to retain water.

Table 3 shows that the amount of available water is negatively correlated with carbonate minerals, gypsum, and soil salinity at simple linear regression equations. Increasing the electrical conductivity of the soil solution reduces the amount of water available for the plant and this effect is more significant at soil salinity values of more than 8 dS⁻¹. These effects are very evident in dry areas because of the collection of salts through irrigation or natural processes (Salem and Atee, 2007; Ati et al., 2014; Ati et al., 2018; Salih and Alwzzan, 2022).

Table 3: Prediction equations to regression of AW on Chemical Parameters

Chemical Parameters	Regression-b	Prediction equations Y [^] = a+ bx	Level of sig.	R ²
CaCO ₃ (g kg ⁻¹)	-0.000047	Y [^] =0.162- 0.000047X	NS	0.04
CaSO ₄ (g kg ⁻¹)	0.000099	Y [^] =0.149 + 0.000099X	NS	0.04
EC dSm ⁻¹	-0.00073	Y [^] = 0.158 -0.00073X	NS	0.03
CaCO ₃ , CaSO ₄ , EC	Y [^] =0.16 -0.000027CaCO ₃ + 0.000019CaSO ₄ + -0.00070EC		*	0.07
* (P≤0.05), R ² : Determination coefficient.				

Table 4 shows the highly significant correlation coefficient values between available water, the field capacity, wilting point, and the content of clay, silt and sand, as well as the negative significant relationship between the content of available water and each of the chemical properties of the soil, calcium carbonate, gypsum, and electrical conductivity.

Table 4: Correlation coefficient between AW and difference variables

Parameters	Correlation coefficient-r with AW	P-value
FC	0.77 **	0.0001
PWP	0.24 *	0.0164
Clay	0.32 **	0.0011
Silt	0.34 **	0.0006

Sand	-0.13 NS	0.194
Bulk density	-0.06 NS	0.577
CaCO ₃	-0.07 NS	0.505
CaSO ₄	0.02 NS	0.839
EC	-0.16 NS	0.112
* (P≤0.05), ** (P≤0.01), NS: Non-Significant.		

The results of Table 5 show that the moisture content of 33 kPa plays a key role in determining the amount of available water in the soil ($R^2 = 0.98^{**}$), as the following equation $AW = \theta_{FC} - \theta_{WP}$ indicates that the increase in moisture at this tension leads to an increase in the amount of available water in the soil

Table 5: Prediction equations to regression of AW on Soil moisture (FC and PWP)

Soil moisture on AW (cm ³ /cm ³)	Regression-b	Prediction equations $Y^{\wedge} = a + bx$	Level of sig.	R ²
FC	0.5087	$Y^{\wedge} = 0.00025 + 0.5087X$	**	0.98
PWP	0.2588	$Y^{\wedge} = 0.112 + 0.2588X$	*	0.06
FC and PWP	$Y^{\wedge} = 0.0089 + 0.874FC - 0.798PWP$		**	0.84
* (P≤0.05), ** (P≤0.01). R ² : Determination coefficient.				

Finally, we recommend using and adopting the forecasting model obtained under experimental conditions to predict the amount of available water, field capacity, and permanent wilting point with clay particles with an error rate not exceeding 2%. Thus, we have obtained an accurate equation of soil properties that is easy and quick to measure and can be used in the Middle Euphrates governorates of Iraq.

$$W.P. = 0.099 + 0.0014 (\text{Clay } \%) \quad (1)$$

$$F.C. = 0.221 + 0.0023 (\text{Clay } \%) \quad (2)$$

W.P = soil water content at 1500 kPa.

F.C= soil water content at 33 kPa.

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