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Effect of Irrigation on Salt Distribution Profile at Umjawasir Farm in the Northern State, Sudan

Nawal Khidir Nasr Al-Amin

Department of Botany and Environmental Science, College of Forestry and Range Science, Sudan University of Science and Technology, Khartoum-Sudan;
E-mail:alaminnawal@yahoo.com

Abstract: This work was carried out at Umjawasir irrigated farm in the Northern State, Sudan. It aimed to assess the salts distribution pattern within the root zone to predict soil secondary salinity development**,** which causes a risk for sustainability of production. The irrigation water was analysed and rated by monitoring average root zone salinity and soil structure stability using $E.C_i$ and SAR_i. Three sites: I (irrigated for eight years), II (irrigated for three years) and III (bare soil, as control), were studied. Soil samples were taken in 2003, every 0.25 m to a depth of 1.25 m, for each site. The soils' $E.C_e$., Na, Mg and Ca content, ESP, SAR, O.C. and N content were determined. Regression analyses were carried out to investigate the possibility of transient salinization. The results showed that the soil salt content was lower at site I than sites II and III at the soil surface (0.25-0.50 m), and at the depth of 0.75 m, sites I and II had higher $E.C_e$. compared to site III. Sites I and II showed significant (P= 0.05) differences in $E.C_e$. with depth. The results also indicated that there was washing of salts from the soil surface and accumulation at depths greater than one metre. Therefore, the hazard of development of transient salinity is expected. Further detailed investigations of the leaching factor and soil physical properties need to be done to make recommendation for suitable irrigation and cultivation practices for sustainable crop production.

Key words: Soluble salts; accumulation; irrigated farm; Sudan

INTRODUCTION

Normally the soluble salts content in the soil is low, but low rainfall and high evaporation, natural vegetation clearance, restricted drainage and high ground water table are in favour of salts accumulation within the root zone (Mengel and Kirkby 1987; Gorden 2006). In the root zone, salts accumulate by two processes: upward movement of shallow water table or salts left in the soil, during natural and agricultural processes, due to insufficient leaching (Stephen 2002). The total amount of the salts that accumulate at the root zone affects the soil productivity, chemically or through deterioration of the soil physical properties, depending on the type of the dominant ions. A high calcium, magnesium and potassium salts cause soil salinization, which improves soil structure by developing soil flocculation (fine particles bind together into aggregates) that improves soil aeration, root penetration and root growth, but salinity negatively affects plant growth. On the other hand, sodicity causes deterioration of the soil physical properties. Both salinity and sodicity are land degradation processes (USA Staff 1953; Warrence *et al*. 2002). Depending on the modes of salinity development, three types of soil salinity are diagnosed; namely, primary, secondary and transient salinization (Rengasamy 2002; Barrett 2003).

Susceptibility of the soil to high sodicity and low salinity depends on soil properties and management. High sodicity and low salinity deteriorate the soil permeability (Oster and Shainberg 2001). High salts, within the root zone, causes ionic imbalance in the plant and decrease plant available water. It is potentially toxic to the plants and negatively influences plant yield and survival (Barrett 2003). These phenomena are more pronounced in arid and semi-arid areas (Agassi *et al*. 1981; Ayers and Westcot 1985; Buckman *et al*. 2002) .

Excess neutral soluble salt in the soil disturbs plant nutrition by enhancing the uptake of sodium and chloride and reducing the uptake of essential plant nutrients, resulting in nutrients imbalance and deficiencies, which retard growth (Warrence *et al*. 2002). To characterize the salt content of the soil, the soluble salt concentration is measured by electrical conductivity of the saturation extract ($E.C_e$. in Ds m^{-1}). According to Mueller *et al*. (2003), E.Ce. is potential to site-specific soil use and management decision.

Umjawasir farm is a relief, rehabilitation irrigated project in the Northern State, Sudan. It was established in 1992 targeting displaced people who were affected by the 1986-1988 drought spell. It is about 420 ha with wheat as the main crop. This research aimed to assess the salts regime (salt accumulation or leaching) within the root zone under irrigation, taking into account water quality and irrigation duration, with $E.C_e$. as indicator, to predict the soil salt accumulation pattern which endangers sustainability of the project.

MATERIALS AND METHODS

Study Site: Umjawasir farm lies between longitudes 16˚53' and 16˚56'N and latitudes 31˚36' and 31˚40'E in the Northern State. The mean annual rainfall is between 50 and 75 mm, and the mean monthly minimum and maximum temperatures are 31˚C-38˚C (November to April) and 40˚C-45˚C (October to May), respectively. Relative humidity ranges between 18% and 48%. The project area is irrigated by underground water. The static water level recorded during five years was between 27.6 and 27.7 m (ADRA 1994).

Three sites were studied: Site I, the soil was under irrigation for eight years; site II, the soil was under irrigation for three years; and site III, uncultivated (non-irrigated) as a control. Soil samples were taken, in 2003, from the three sites at intervals of 0.25 m to a depth of 1.25 m. Soils' electrical conductivity ($E.C_e$), Na, Mg and Ca content, exchangeable sodium percentage (ESP), sodium absorption ratio (SAR), organic carbon (O.C.) and nitrogen (N) content were determined according to the methods of Richards (1954). Analysis of variance was carried out, using the statistical package (SAS). Regression analyses were done to determine the relationship between salinity of the extract of soil paste and irrigation duration.

To manage salinity, irrigation water could be assessed and rated by monitoring soil structure stability and crop tolerance. For crop tolerance, average root zone salinity ($E.C_{se}$) was calculated using equation (1) which was developed by deHayr (2006).

$$E.C_{se} = \frac{EC_i}{2.2x\text{LF}} \quad (1)$$

where:

$E.C_i$ = electrical conductivity of irrigation water in Ds m^{-1}

LF = average root zone leaching factor. According to deHayr (2006), LF is about 0.33 for light clay soil.

The EC_{se} value was evaluated against the criteria of soil and water salinity, based on plant salt tolerance grouping. To predict soil structure stability, the electrical conductivity ($E.C_i$.) and sodium adsorption ratio (SAR_i) of the irrigation water were correlated, using the diagram of the relationship between SAR_i and $E.C_i$. of irrigation water for prediction of soil structure stability (deHayr 2006).

RESULTS AND DISCUSSION

According to ADRA (1994), the sodium adsorption ratio (SAR_i) of the irrigation water at umjawasir is 1.67 and the electrical conductivity ($E.C_i$.) is 0.34 Ds m^{-1}. When these values were correlated, the irrigation water was considered as satisfactory and of good quality. The soil at Umjawasir is light clay (Table 1); therefore, a leaching factor of 0.33 was used and the average root zone salinity at Umjawasir, using equation (1) is as follows:

$$E.C_{se}. = \frac{0.34}{2.2X\ 0.33} = 0.47 \text{ Ds } m^{-1}$$

The average root zone salinity value (0.49 Ds m^{-1}) was within the range of very low soil-water salinity (Reference value for sensitive crop is less than 0.95 Ds m^{-1}) and can be used for salt sensitive plants. The results showed that irrigation decreased soil sodicity and salinity in the root zone.

Table 1. Field soil classification of the three sites in Umjawasir farm

Site	Sand (%)	Silt (%)	Clay (%)	Description and classification
Site I	18	37	45	Haplocambids; fine; mont; hyperthemic. Cultivated farm, parent material is colluvial-alluvial, well drained with surface crust and eroded.
Site II	19	37	44	Typic Haplocambids; fine; mont; hyperthemic. Cultivated farm, parent material is colluvial-alluvial, well drained with surface crust and eroded.
Site III	20	36	44	Haplocambids; fine montmorillomtic. Virgin land, parent material is colluvial-alluvial, well drained

The exchangeable sodium percentage (ESP) at the root zone of site I was significantly lower than at sites II and III. Sodium adsorption ratio (SAR) showed a different trend; it started to increase during the three-year irrigation period and to decrease as irrigation continued (Table 2). The exchangeable sodium at site I was significantly lower than at site II and site III, it was 1.33, 2.1 and 1.9 Cmol./kg, respectively (Table 2). Washing of sodium with irrigation confirmed the good quality of the water, particularly with respect to the soil structure stability, as stated before. High concentration of sodium in the irrigation water increases soil exchangeable sodium that can degrade soil structure, limit aeration and soil permeability, thus reducing crop productivity. Irrigated sites showed no significant differences in the soil organic carbon, nitrogen content and carbon nitrogen ratio compared to the bare soil (Table 2).

Table 2. Soil properties of three sites at the root zone (0-1.25 m) in Umjawasir farm

	Site I	Site II	Site III	Mean	C.V. (%)
No. of samples	30	29	15	------	-----
Saturation (%)	61b	70 a	62 b	15	18
Na ex.(Cmol./kg)	1.33 b	2.10 a	1.90a	62 b	50
O.C. (%)	0.13 a	0.11 a	0.09a	1.90a	68
N (%)	0.02 a	0.02 a	0.02a	0.09a	27
C/N	6.50 a	5.50 a	4.50a	0.02a	69
$E.C_e.(Ds\ m^{-1})$	3.10 a	5.68 a	5.90a	4.50a	86
SAR (ratio)	3.73 b	6.66 a	5.00b	5.90a	47
ESP (%)	4.47 b	8.00 a	7.70a	5.00b	42

Means in a row followed by the same letter are not significantly different at P=0.05, using Duncan's multiple range test.

Na ex. = Exchangeable sodium; O.C. = Organic carbon; N= Nitrogen content; C/N= Carbon/ Nitrogen ratio;

$E.C_e.$ = Electrical conductivity; SAR = Sodium adsorption ratio; ESP = Exchangeable sodium percentage

Site I= Irrigated for 8 years; Site II= Irrigated for 3 years; Site III= Bare soil, (control)

Soil salinity at the soil surface (0.00-0.25 m) was 3.02, 3.79 and 4.12 Ds m^{-1} for sites 1, II and III, respectively, decreased at the depths of 0.25-0.50 m and 0.50-0.75m for site I and site II and increased thereafter (Table 3). Site III showed very sharp increase until the depth of 0.75 m and decreased thereafter (Fig.1). The high salinity below 0.50 m in bare soil (site III) is due to high evaporation, since the small amount of precipitation is not sufficient to leach salts. The gradual increase of soil salinity with depths below 0.75 m at the irrigated sites is attributed to the effect of irrigation and washing of the salt downward. The $E.C_e$. at site II was high compared to site I at all depths, and the difference was maximum below 0.75 m. This indicates the leaching of the salt as irrigation duration increases (Fig.1). The difference in salinity between irrigated and non-irrigated sites was between 0.50 m and 0.75 m. The non-irrigated site (III) had lower $E.C_e$. than the irrigated sites (I and II) at one metre depth (Fig.1). These results reveal the high leaching which could be due to good irrigation water in terms of quality and quantity, deep water table and the good soil physical properties particularly the infiltration rate (Table1).

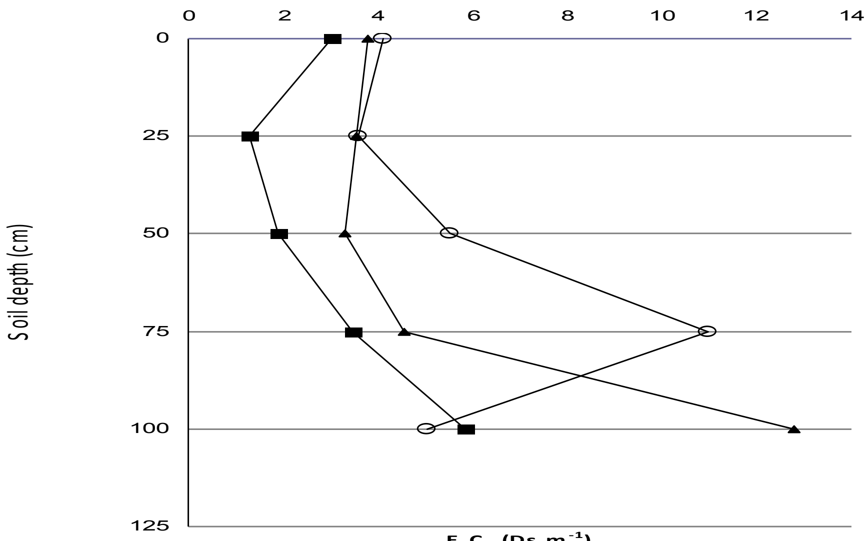

Fig.1. Soil salinity pattern as a function of depth, Umjawasir farm

The bare soil (site III) was eroded, well drained clay soil with surface crust (Table 1). It is originally saline, non-sodic ($E.C_e.= 5.9$ Ds m^{-1}, ESP =7.7 % and SAR = 5) (Table 2). Under irrigation, there were no significant differences in $E.C_e$. at depths 0.00 - 0.25, 0.25 - 0.50 and 0.50 -0.75 m, for site I and site II, but significant differences at each site were found at depths greater than one metre; namely, at 1.00 -1.25 m, where the soil became saline and non-sodic (Table 3). This shows that there was leaching of the salts from the soil surface when wheat cultivation was practiced under this system of irrigation.

Soil sodicity, as indicated by the exchangeable sodium percentage (ESP), at both irrigated sites, had almost constant values. However, site I showed higher sodicity than site II, and the difference increased with depth. ESP of site III showed the same patteren as its salinity (Fig.2). Sodium adsorption ratio (SAR) at site I was almost constant throughtout the soil depths and followed different patterns at different depths at sites II and III (Fig.3 and Table 3).

The results of this work indicated that as irrigation duration increased, the soil salts content at the root zone decreased and as irrigation was prolonged, the soil showed a tendency to accumulate salts at a depth greater than one metre (Fig. 1 and Table 3). The regression analysis demonstrated that the changes in salt content of the soil for each depth, because of irrigation, have nonlinear relation of the form of exponential decay function (Fig.4)

Table 3. Soil salinity and sodicity as a function of depth in Umjawasir farm

	Depth (m)						
	0.00 - 0.25	0.25-0.50	0.50-0.75	0.75-1.00	1.00-1.25	Mean	C.V (%)
Site I (Irrigated for 8 years)							
E.C_e. (Ds m^{-1})	3.02b	1.28b	1.91b	3.48ab	5.56a	3.11	72
SAR	4.20a	3.50a	3.70a	3.50a	3.80a	3 .70	46
ESP (%)	5.30 a	4.70a	4.20a	4.00a	4.20a	4 .50	39
Site II (Irrigated for 3 years)							
E.C_e. (Ds m^{-1})	3.79b	3.54b	3.32b	4.57b	12.80a	5.6	85
SAR	5.67a	6.17a	7.40a	5.50a	8.87a	6.7	40
ESP (%)	6.33a	7.33a	6.80a	8.50a	9.31a	8.0	40
Site III (Bare soil, control)							
E.C_e.(Ds m^{-1})	4.12a	3.61a	5.53a	11a	5.05a	5.9	69
SAR	5.00a	3.33a	4.33a	6.67a	5.67a	5.9	67
ESP (%)	5.33a	6.33a	7.67a	10.00a	9.00a	7.7	47

Means in a row followed by the same letter(s) are not significantly different at P=0.05, using Duncan's multiple range test.

E.C_e. = Electrical conductivity in Ds m^{-1}; SAR = Sodium adsorption ratio; ESP = Exchangeable sodium percentage

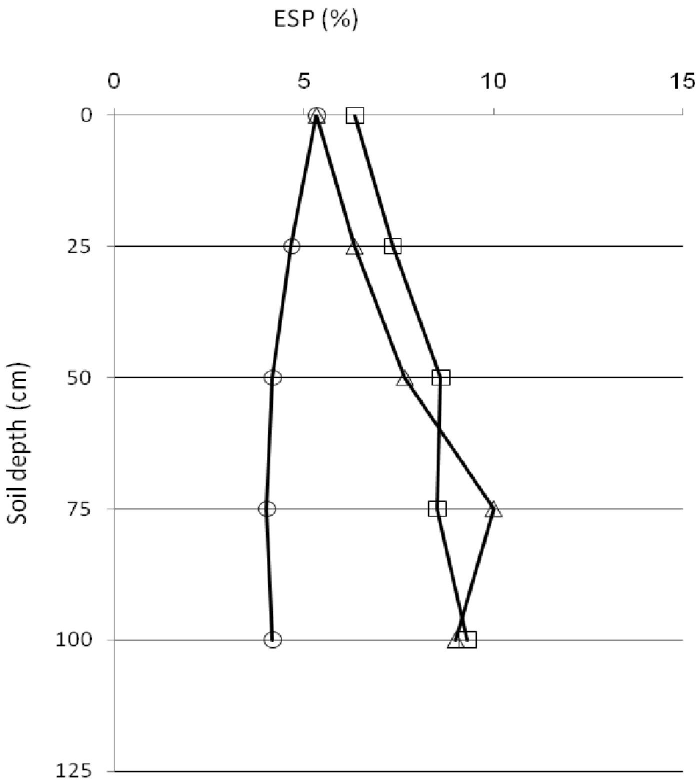

Fig.2. Soil exchangable sodium percentage pattern as a function of depth, Umjawasir farm

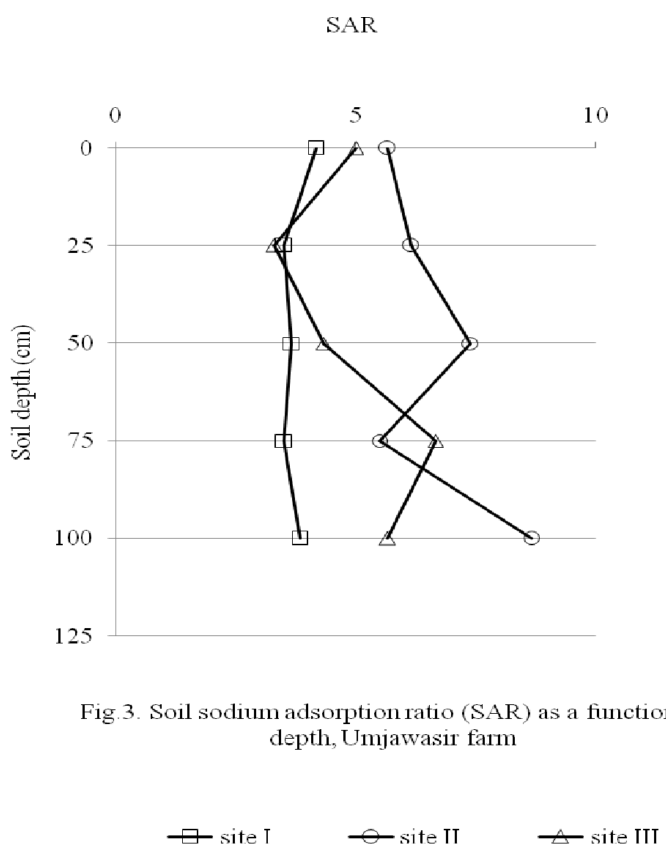

Fig.3. Soil sodium adsorption ratio (SAR) as a function of depth, Umjawasir farm

The amount of accumulated salts (y) declined to its initial value (a) with time (x) at leaching rates of 0.19, 0.10, 0.14 and 0.13 and R^2= 0.6, 0.34, 0.43 and 0.67 for soil depths of 0.00-0.25 , 0.25-0.50 , 0.50-0.75 and 0.75-1.00 m, respectively (Fig.4). Deeper than one metre, the exponantial decay relation disappeared with R^2 = 0.081 and leaching rate of 0.05 (Fig. 4). This finding confirms the tendency of the soil to accumulate salts at a depth greater than one metre as stated above.

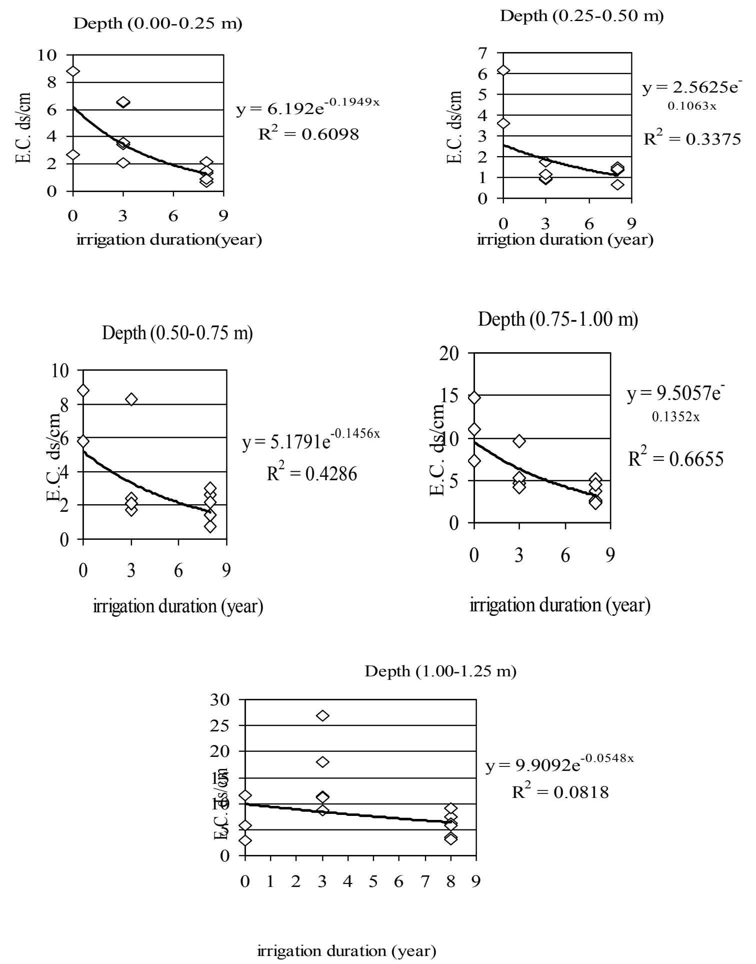

Fig.4. Change in salinity as a function of irrigation duration in Umjawasir farm

Generally, the present study showed that there was washing of salts in Umjawasir farm from the soil surface and its accumulation at a depth greater than one metre, leading to transient salinity with time (Table 3 and Fig.4). This findindg agrees with Fitzpatrick (2002) who reported small rate of salt accumulation in the subsoil layer (transient salinity), in an Australian wheat growing region, which over time can be detrimental to the crop.

It is recommended that detailed investigations for Umjawasir project be carried out to determine the leaching factor, soil physical properties and water quantity for sustainable production.

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تأثير الري على نمط توزيع الأملاح في قطاع التربة في مشروع أم جواسير بالولاية الشمالية- السودان

نوال خضر نصر الامين

قسم النبات والبيئة- كلية علوم الغابات والمراعي، جامعة السودان للعلوم والتكنولوجيا، الخرطوم السودان

موجز البحث: أجرى هذا البحث في مشروع أم جواسير بالولاية الشمالية ، السودان، بهدف تقييم نمط تراكم أو غسل الأملاح في قطاع التربة (عند عمق الجذور) ومدى تأثيره على استدامة إنتاجية المشروع. اجري تحليل لمياه الري ومن ثم عيرت بتقدير ملوحة التربة عند عمق الجذور، باستخدام فرق الجهد ($E.C_i$) ونسبة الصوديوم لنسبة عنصري الماغنسيوم والكالسيوم (SAR_i) **و**تأثيرها على بناء وتركيب التربة. أخذت عينات التربة من ثلاثة مواقع: الموقع الأول بدأت الزراعة فيه منذ ثمان سنوات والموقع الثاني بدأت زراعته منذ ثلاث سنوات أما الموقع الثالث (الشاهد) فلم يستخدم للزراعة. أخذت العينات في عام 2003م من كل موقع إلى عمق 1.25 مترا ً وكانت المسافة بين كل عمق وآخر 0.25 متراً. شملت القياسات فرق جهد التربة، والنسبة المئوية للصوديوم في محلول التربة (ESP)، ونسبة الصوديوم لنسبة عنصري الماغنسيوم والكالسيوم (SAR)، في محلول التربة بالإضافة إلى تحديد نسبة الكربون العضوي ونسبة النيتروجين. أشارت النتائج إلى أن الموقع الأول أقل ملوحة من الموقعين الثاني والثالث عند السطح (0.25-0.50 م)، واظهر الموقعان الأول والثاني ملوحة أعلى مقارنة بالموقع الثالث عند عمق 0.75 متراً. كما أظهرا اختلافاً معنوياً في .E.Ce مع زيادة العمق. أظهرت الترب التي استخدمت للزراعة زيادة في مستوى $E.C_e$. مع زيادة العمق، دلت لنتائج على أن هناك غسيل للأملاح من سطح لتربة وتراكمها عند عمق يزيد عن متر، لذلك فان من المتوقع ظهور ملوحة طارئة. ولكن يجب أن تعزز نتائج هذه الدراسة دراسة معدل الغسل في التربة وخصائص التربة الفيزيائية حتى يمكن الوصول إلى التوصية المناسبة لإدارة مياه الري والمعاملات الفلاحية المناسبة لاستدامة الإنتاجية.