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Mathematical modelling of surface irrigation for field crops in Jordan based on soil hydrological-physical properties

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SUMMARY

Jordan suffers from drought and depletion of water resources. In-field crop management, the issue of irrigation scheduling is important and influential. In this research note, a simple method was developed for scheduling surface irrigation of field crops based on inputs of crop ecology, effective root depth, soil texture, soil hydrology, and logical mathematics. It was concluded that the science of mathematics has succeeded to meet academic irrigation scheduling in terms of surface irrigation for field crops based on both soil hydrological and physical traits. Extension scholar has a decision to choose mathematical irrigation model depends on the traditional inputs or updating the model by searching for renewable inputs such as different varieties root depths, optimum row spacing of each crop, drip irrigation mathematical modelling, and digital sensing. In both cases, the input related to the effective root depth is a major and basic factor in mathematical irrigation scheduling. It is, therefore, recommendable that extension research-based systems should focus on basic mathematics to capacitate the complementary role of academics, research, and extension in irrigation modelling, and rural development.

Keywords: *irrigation schedule; soil management; mathematics modelling; sensors; effective root depth*

INTRODUCTION

Jordan is currently facing climate problems represented by depletion of water resources, high temperatures, drought, salinization of soils, and groundwater sources. Irrigation scheduling and modelling is a scientific and practical concept of determining the amount of irrigation each time and irrigation intervals (Phocaides, 2007). There is a balance between the two parties (irrigation amount, and irrigation intervals) in Jordan's case due to the conditions of drought, salinity, depletion of water resources, and erratic distribution of rain in the various regions. The availability of modern sewage treatment plants and the availability of high-volume treated water is another reason for the need to schedule irrigation, especially in the production of field and forage crops. Irrigation scheduling can be managed preciously to meet crop water demands, holding the promise of increased yield and quality (Kahlon, 2017). There are major basic inputs that must be discussed in irrigation modelling.

First, crop growth stages. Irrigating the crop only at drought-sensitive growth stages can help to manage water resources to meet crop water requirements Du et al. (2010). Rainfed agriculture cannot be relied upon to produce forage crops to compete with imported agricultural products. While scheduling the irrigation of these crops is important to balance the production, marketing, and competition on the one side and the management of the most important agricultural resource in Jordan, irrigation water on the other side. Greaves and Wang (2017) concluded that long drought cycles on corn are attributed to lower rainfall. Similar results emphasized the negative effect of drought on the growth of corn reported Randhawa et al. (2017). Corn is sensitive to moisture stress during vegetative growth and tasselling stages (Anandhi, 2016). Drought stress at these critical growth stages of corn led to reduced growth represented by plant height and leaf area development (Cakir, 2004). Ali et al. (2007) identified the stages of tillering and stem elongation as one of the moisture-sensitive stages in the wheat crop. Limited irrigation water availability can cause an increase in crop failure, defined as the complete loss of crops on a farm (Anandhi and Blocksome, 2017). It can be concluded that green forage crops need irrigation immediately after harvest to confirm re-growth (such as; alfalfa, Egyptian clover, field (silage) corn, forage sorghum, rye-grass, and Sudan-grass). Other crops need irrigation water in the stages of tillering and flowering (barley, oat, triticale, and wheat). Legumes crops are sensitive to irrigation water at flowering stages and pod filling (lentil).

Second, in addition to crop growth stages, soil texture is an important issue in this regard. Each soil texture has different hydrological properties especially about its water retention potential. Thus, soil texture can influence soil water relationships. Once the sand, silt, and clay fractions are known, the textural class can be determined. There are no soil maps in the agricultural areas of Jordan. Easton and Bock (2016) reported the plant available water percentage for several soil texture classes (sand, sandy loam, loam, silt loam, clay loam, silty clay, and clay). It was reported that many soil properties are influenced by texture, including drainage, and water-holding capacity. It can be concluded that the soil texture class has an impact on soil hydrological properties (Easton and Bock, 2016).

Third, effective root depth. The effective root zone is the depth within which most crop roots are concentrated (Alberta Agriculture and Rural Development, 2011). Those are depths to which the roots of mature crops will deplete the available water supply when grown in a deep permeable soil under average conditions (Fan et al., 2016). The effective root zone depth is the depth of soil used by the main body of the plant roots to obtain most of the stored moisture under proper irrigation. Each plant has its root development characteristics. The application of irrigation water should be limited to an amount that will penetrate only to the effective root zone depth.

This short research note aims to design or propose a simple mathematical system for irrigation scheduling for field crops that considers logical simplicity and combines academic natural mathematics science, and extension, while highlighting the basic elements in modelling such as effective root depth, soil texture, and crop growth stages.

METHODOLOGY

The article explains the method used to schedule irrigation of field and forage crops in Jordan using surface irrigation. All the crops under this study are sown based on seed weights within specific seed rates and are not grown in a row, making the idea of irrigating by surface irrigation suitable. This study will cover the field and basic forage crops in Jordan: alfalfa, barley, Egyptian clover, field corn (silage corn), forage sorghum, rye-grass, Sudan-grass, and triticale. The most important field food crops were added: lentils, oat, and wheat. Oat and wheat are also used as forage crops. The study does not include field crops that are grown to take dry grains such as beans, chickpeas, cowpea, faba-beans, and peas and does not include sweet corn which can be grown mainly as vegetable horticultural crops in the open field (Massimi et al., 2018a). Lupines (*Lupinus* spp.), millets (*Panicum miliaceum* L.), and soybeans [(*Glycine max* (L.)) Merr.] are not common field crops in Jordan. Therefore, these crops were not addressed in this research.

Food and Agricultural Organization has conducted specialized calculations and water needs assessment trials for crops (Brouwer et al., 1986). The effective root zone is the depth within which most crop roots are concentrated, it is a measure of soil depth that holds the bulk of roots (*Table 1*). Several references have been used to document the comparison between crops regarding root depth. *Table 1* illustrates this.

The effective root zone is the depth within which most crop roots are concentrated, which was estimated as ~120 cm for alfalfa, and as ~50–100 cm for barley, and wheat (Alberta Agriculture and Rural Development, 2011). These values were comparable with our estimated values (*Table 1*), which were used as a measure of soil depth that holds the bulk of roots for alfalfa, barley, Lentil, oat, and wheat (Fan et al., 2016). Depths to which the roots of mature crops will deplete the available water supply when grown in a deep permeable, well-drained soil under average conditions were used for Sudan-grass and field corn (which was estimated also for sorghum as for Sudan-grass) (University of California UC Drought Management, 2016). Various other references have been used to determine the depth of the roots of the Egyptian clover (Sustainable Agriculture Research & Education SARE, 2012), rye-grass (Steynberg et al., 1994), and triticale (Bonachela, 1996) crops.

Table 1. **Major and most common field crops grown in Jordan and their morphological and ecological traits**

No.	Crop	Scientific Name	Annual, or Perennial Crop	Summer, or Winter Crop	Root Depth (cm)
1	Alfalfa	*Medicago sativa* L.	P	-	135.6
2	Barley	*Hordeum vulgare* L.	A	W	99.6
3	Egyptian Clover	*Trifolium alexandrinum* L.	A	W	17.78
4	Field (Silage †) Corn	*Zea mays* var. indentata L.	A	S	91.44
5	Forage Sorghum	*Sorghum bicolor* L.	A	S	106.68
6	Lentil ‡	*Lens esculenta* Moench.	A	W	73.7
7	Oat ‡	*Avena sativa* L.	A	W	77.7
8	Rye-grass	*Lolium multiflorum* Lam.	A	W	100
9	Sudan-grass	*Sorghum × drummondii.*	A	S	106.68
10	Triticale	X *Triticosecale* Witt.	A	W	135
11	Wheat ‡	Bread: *Triticum aestivum* L. Macaroni: *Triticum durum* or *Triticum turgidum* subsp. *Durum*	A	W	103.8

A: Shows that the crop is Annual, P: Shows that the crop is Perennial.
W: Winter Crop, S: Summer Crop.
†: Grown for silage (multiple harvests or cuts).
‡: Mainly food crops.
-: Shows that the crop is not within this box.

The water requirements of the crops were concluded and estimated daily by dividing the maximum water requirements for each crop during the growing season by the maximum total number of days

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of each crop season (*Table 2*). Seasonal water requirement information is documented by reference (Brouwer and Heibloem, 1986). Other sources were used for the following crops: Egyptian clover (Reed, 2008), lentil (Saraf and Baitha, 1985), rye-grass (Dickinson et al., 2004), and triticale (Info agro, 2018). On the other hand, the total growing period (******) in days is cited in (Brouwer and Heibloem, 1986), (+) cited in (Kroeck, 2011). The total growing period in days cited in both references was written in (++). The total growing period in days for is triticale is estimated like similar crops (Barley and Wheat) (***).

Table 2. **Seasonal water requirement (mm), total growing period (days), and daily water requirement (mm/day) for major and most common field crops grown in Jordan**

No.	Crop	Seasonal Water Requirement (mm)	Total Growing Period (Days)	Daily Water Requirement (mm/Day)
1	Alfalfa	800–1600	(100–365)**	4.3
2	Barley	450–650	(90)$^{+}$–(120)$^{++}$–(150)**	4.3
3	Egyptian Clover	(> 600)*	(90–120)$^{+}$	5
4	Field (Silage) Corn	500–800	(90)$^{+}$	8.9
5	Forage Sorghum	450–650	(90)$^{+}$–(120)$^{++}$–(130)**	5
6	Lentil	(230–912)*	(150–170)**	5.3
7	Oat	450–650	(60–90)$^{+}$–(120)$^{++}$–(150)**	4.3
8	Rye-grass	(1200)*	(60–90–120)$^{+}$	10
9	Sudan-grass	450–650	(90–120)$^{+}$	5.4
10	Triticale	(400–900)*	(90–120–150)***	6
11	Wheat	450–650	(120–150)**	4.3

*: Seasonal Water Requirements: scientific sources other than (Brouwer and Heibloem, 1986).

**: Total Growing Period (days) cited in (Brouwer and Heibloem, 1986).

***: Total Growing Period (days) for triticale.

+: Total Growing Period (days) cited in (Kroeck, 2011).

++: Total Growing Period (days) cited in both references: (Brouwer and Heibloem, 1986), and (Kroeck, 2011).

Scientific and Practical Approach (Using Digital Sensors)

1. A representative sample of the soil is taken, send to the laboratory to determine the soil texture and soil bulk density.
2. Check the laboratory results by adding a quantity of water to another soil sample for saturation. Saturation is the soil water content when all pores are filled with water. Field capacity is the soil water content after the soil has been saturated and allowed to drain freely for about 24 to 48 hours. Free drainage occurs because of the force of gravity pulling on the water, record the soil moisture content % by using an electronic digital probe (by weight) used in *Figure 1*. Relative humidity informs how much water vapor is in the air compared with the maximum possible. At its maximum, denoted as saturation, the relative humidity is 100%, and evaporation is inhibited, The use of a Hygro-Thermometer probe at the time of soil drainage is important because controlling 100% relative humidity will stop evaporation from the soil and ensure gravity discharge (*Figure 2*).
3. By reference to *Table 3* where the soil moisture content % multiplied by the soil bulk density (g cm^{-3}) to determine the field capacity % (by volume) from *Table 3*.

   FC % (v%) = S.M.C % (Wt %) (S.B.D (g cm^{-3})/ Water Density (g cm^{-3}). Water Density equals 1 g cm^{-3}.
   FC % (v%) = Field Capacity Percentage (Volume Percentage), S.M.C %=Soil Moisture Content Percentage (Weight Percentage)=Weight of Water (g)/ Weight of Dry Soil (g), S.B.D=Soil Bulk Density = Weight of Dry Soil (g) / Soil Volume (cm^{3}).

4. Steps can be shortened by starting the second step directly and relying on algebraic calculations through the inputs documented in *Tables 2 and 3* to schedule irrigation. Soil access to a saturation level can be achieved after rain or irrigation.

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Table 3. **The ideal bulk density (g cm^{-3}) of each soil texture, indicating the field capacity percentage and permanent welting point percentage**

No.	Soil Texture	Ideal Bulk Density for Plant Growth (g cm^{-3}) ††	Field Capacity (v%) ‡‡	Permanent Wilting Point (v%) ‡‡
1	Sand	1.6	10	5
2	Loamy Sand	1.6	12	5
3	Sandy Loam	1.4	18	8
4	Loam	1.4	28	14
5	Sandy Clay Loam	1.4	27	17
6	Clay Loam	1.4 +	36	22
7	Silt	1.4	30	6
8	Silt Loam	1.4	31	11
9	Silty Clay Loam	1.4	38	22
10	Sandy Clay	1.1	36	25
11	Silty Clay	1.1	41	27
12	Clay Loam	1.1 +	36	22
13	Clay	1.1	42	30

†† Maximum Values Taken from Soil Health- Guides for Educators (NRCS, 2014). A laboratory test may result in a different value.

‡‡ Taken from (Saxton et al., 2006).

+: The reference Soil Health- Guides for Educators (NRCS, 2014) have two values for this texture

Basic Mathematical Modelling Approach (*Table 4*)**:**

1. The mathematical schedule for surface irrigation will be used rather than drip irrigation, meaning that the cultivation of these crops will be linked to a specific seed rate for the unit area without the need for seed drilling.
2. Managed Allowable Depletion (MAD %) is the percentage of water available that taken by the plant. The calculations will be based on the assumption that the value is 30% as a constant indicator value of preparation for the next irrigation event.
3. It is assumed that surface irrigation efficiency is only 60% (runoff and deep percolation are substantial, but evaporation losses are generally small).
4. NIR = (MAD % × (FC %- PWP %) × D (cm) × 10). The result is multiplied with 10 to convert the value to mm.
   GIR = NIR / E %.
   Intervals (Days) = WDS (NIR) / DWR (mm).
   NIR: Net Irrigation Requirement, GIR: Gross Irrigation Requirement, FC %: Field Capacity Percentage (Volume Percentage), PWP %: Permanent Wilting Point Percentage, D: Root Depth, E%: Irrigation Efficiency, WDS: Water Depth in Soil, and DWR: Daily Water Requirement.

5. Use a rain gauge to subtract rain amounts from gross irrigation requirements, the net irrigation requirements are re-calculated based on the adjusted gross irrigation requirements (*Figure 3*).
6. All the numbers in *Table 4* are averages based on weather conditions, especially temperatures, soil texture, and stages of growth.
7. All math scores were rounded to the nearest integer number based on the mathematical rules: look at the digits in the tenth's place and avoid double-round.

7.1 Specific Conversion Notes: The records of Gross Irrigation Requirement (GIR) and Net Irrigation Requirement (NIR) will be in millimeters per square meter, i.e., one meter per 0.1 hectares. Every 1000 millimeters is equal to 1 meter (distance or depth of irrigation in one dimension and not a volumetric value) and every 1000 square meters equals 1 dunum (0.1 hectares). Thus, 1000 mm/ 1000 m^2 = 1 meter/ 0.1 hectares.

7.2 The rounded mean and mode were calculated for all types of soil textures in each crop for parameters of gross, net irrigation requirements, and irrigation intervals, as well as statistical correlation, was extracted between root depths (cm), gross irrigation requirements mean (m^3), and irrigation intervals mean (days) for each crop following the analysis by (Carlberg, 2014).

Figure 1. **Electronic probe for soil moisture content (model MO750)**

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Figure 2. **Hygro-Thermometer**

(model 445702) sensor for relative humidity (10–85%) percentage sensor (1 ° F = -17.22 ° C).

Figure 3. **Measure the amount of rain using rainfall gauge**

(1 inch = 2.54 cm, 1 cm = 10 mm)

7.3 It is necessary to determine the quantities of rain when winter crops are planted to be subtracted from the quantities approved in the mathematical schedule.

RESULTS AND DISCUSSION

The calculations in the *Table 4* (A to K) show that the mathematical approach gives a theoretical indication of how each crop is treated for irrigation in its both dimensions; amount (quantity) and irrigation intervals. All the numbers in the *Table 4* (A to K) are means based on weather conditions, especially temperatures, and based on stages of growth, and soil texture class (minimum to maximum).

This study shows the average gross and net irrigation requirements proposed mathematically for each crop in addition to the average time of days between each irrigation and the other (by devising the average for 13 soil texture classes).

From the results of the calculations, the calculated numbers of the soil texture sandy loam appear to be similar to the soil texture sandy clay loam. Similar findings were recorded for loam, clay loam, and silty clay (mode). It is also noted that the highest readings were for the three soil textures (silt, silt loam, and silty clay loam, respectively) for all crops. While the lowest was recorded for sand soils (*Table 4*: A to K).

The high percentage of available water in the three soil texture classes (silt 24%, silt loam 20%, and silty clay loam 16%, respectively) is what led to an increase in the parameters records related to the irrigation quantities and irrigation intervals compared to sand (5%) and loamy sand (7%). Easton and Bock (2016) reported that sand texture had the lowest average available water (7%) in comparison to loam (20%) and silt loam (21%) and comparison to several other soil textures. However, crops cannot be classified according to the optimum soil texture because there are important chemical factors that must be studied such as soil acidity (pH), electrical conductivity i.e.; salinity (EC), and total dissolved salts (TDS) before any generalization.

Table 4. **Statement of the result of mathematical calculations of the gross (GIR (m^3/0.1ha)) and net (NIR (m^3/0.1ha)) irrigation requirements of each crop (A-K) and their irrigation intervals (days)**

(A) Alfalfa

Soil Texture	**Gross Irrigation Requirement**	**Net Irrigation Requirement**	**Intervals (Days)**
Sand	34	20	5
Loamy Sand	47	28	7
Sandy Loam	68	41	9
Loam	95	57	13
Sandy Clay Loam	68	41	9
Clay Loam	95	57	13
Silt	163	98	23
Silt Loam	136	81	19
Silt Clay Loam	108	65	15
Sandy Clay	75	45	10
Silty Clay	95	57	13
Clay	81	49	11
Clay Loam	95	57	13
Mode	95	57	13
Min–Max	34–163 m^3	20–98 m^3	5–23 days
Mean	**89 m^3**	**54 m^3**	**12**

Table 4 continued

(B) Barley

Soil Texture	Gross Irrigation Requirement	Net Irrigation Requirement	Intervals (Days)
Sand	25	15	3
Loamy Sand	35	21	5
Sandy Loam	50	30	7
Loam	70	42	10
Sandy Clay Loam	50	30	7
Clay Loam	70	42	10
Silt	120	72	17
Silt Loam	100	60	14
Silt Clay Loam	80	48	11
Sandy Clay	55	33	8
Silty Clay	70	42	10
Clay	60	36	8
Clay Loam	70	42	10
Mode	70	42	10
Min–Max	25–120 m^3	15–72 m^3	3–17 days
Mean	**66 m^3**	**m^3**	**9**

(C) Egyptian Clover

Soil Texture	Gross Irrigation Requirement	Net Irrigation Requirement	Intervals (Days)
Sand	4	3	1
Loamy Sand	6	4	1
Sandy Loam	9	5	1
Loam	12	7	1
Sandy Clay Loam	9	5	1
Clay Loam	12	7	1
Silt	21	13	3
Silt Loam	18	11	2
Silt Clay Loam	14	9	2
Sandy Clay	10	6	1
Silty Clay	12	7	1
Clay	11	6	1
Clay Loam	12	7	1
Mode	12	7	1
Min–Max	4–21 m^3	3–13 m^3	1–3 days
Mean	**12 m^3**	**7 m^3**	**1**

(D) Field (Silage) Corn

Soil Texture	Gross Irrigation Requirement	Net Irrigation Requirement	Intervals (Days)
Sand	23	14	2
Loamy Sand	32	19	2
Sandy Loam	46	27	3
Loam	64	38	4
Sandy Clay Loam	46	27	3
Clay Loam	64	38	4
Silt	110	66	7
Silt Loam	91	55	6
Silt Clay Loam	73	44	5
Sandy Clay	50	30	3
Silty Clay	64	38	4
Clay	55	33	4
Clay Loam	64	38	4
Mode	64	38	4
Min–Max	23–110 m^3	14–66 m^3	2–7 days
Mean	**60 m^3**	**36 m^3**	**4**

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Table 4 continued

(E) Forage Sorghum

Soil Texture	Gross Irrigation Requirement	Net Irrigation Requirement	Intervals (Days)
Sand	27	16	3
Loamy Sand	37	22	4
Sandy Loam	53	32	6
Loam	75	45	9
Sandy Clay Loam	53	32	6
Clay Loam	75	45	9
Silt	128	77	15
Silt Loam	107	64	13
Silt Clay Loam	85	51	10
Sandy Clay	59	35	7
Silty Clay	75	45	9
Clay	64	38	8
Clay Loam	75	45	9
Mode	75	45	9
Min–Max	27–128 m^3	16–77 m^3	3–15 days
Mean	**70 m^3**	**42 m^3**	**8**

(F) Lentil

Soil Texture	Gross Irrigation Requirement	Net Irrigation Requirement	Intervals (Days)
Sand	18	11	2
Loamy Sand	26	15	3
Sandy Loam	37	22	4
Loam	52	31	6
Sandy Clay Loam	37	22	4
Clay Loam	52	31	6
Silt	88	53	10
Silt Loam	74	44	8
Silt Clay Loam	59	35	7
Sandy Clay	41	24	5
Silty Clay	52	31	6
Clay	44	27	5
Clay Loam	52	31	6
Mode	52	31	6
Min–Max	18–88 m^3	11–53 m^3	2–10 days
Mean	**49 m^3**	**29 m^3**	**6**

(G) Oat

Soil Texture	Gross Irrigation Requirement	Net Irrigation Requirement	Intervals (Days)
Sand	19	12	3
Loamy Sand	27	16	4
Sandy Loam	39	23	5
Loam	54	33	8
Sandy Clay Loam	39	23	5
Clay Loam	54	33	8
Silt	93	56	13
Silt Loam	78	47	11
Silt Clay Loam	62	37	9
Sandy Clay	43	26	6
Silty Clay	54	33	8
Clay	47	28	7
Clay Loam	54	33	8
Mode	54	33	8
Min–Max	19–93 m^3	12–56 m^3	3–13 days
Mean	**51 m^3**	**31 m^3**	**7**

Table 4 continued

(H) Rye-grass

Soil Texture	Gross Irrigation Requirement	Net Irrigation Requirement	Intervals (Days)
Sand	25	15	2
Loamy Sand	35	21	2
Sandy Loam	50	30	3
Loam	70	42	4
Sandy Clay Loam	50	30	3
Clay Loam	70	42	4
Silt	120	72	7
Silt Loam	100	60	6
Silt Clay Loam	80	48	5
Sandy Clay	55	33	3
Silty Clay	70	42	4
Clay	60	36	4
Clay Loam	70	42	4
Mode	70	42	4
Min–Max	25–120	15–72	2–7
Mean	**66**	**39**	**4**

(I) Sudan-grass

Soil Texture	Gross Irrigation Requirement	Net Irrigation Requirement	Intervals (Days)
Sand	27	16	3
Loamy Sand	37	22	4
Sandy Loam	53	32	6
Loam	75	45	8
Sandy Clay Loam	53	32	6
Clay Loam	75	45	8
Silt	128	77	14
Silt Loam	107	64	12
Silt Clay Loam	85	51	9
Sandy Clay	59	35	7
Silty Clay	75	45	8
Clay	64	38	7
Clay Loam	75	45	8
Mode	75	45	8
Min–Max	27–128 m^3	16–77 m^3	3–14 days
Mean	**70 m^3**	**42 m^3**	**8**

(J) Triticale

Soil Texture	Gross Irrigation Requirement	Net Irrigation Requirement	Intervals (Days)
Sand	34	20	3
Loamy Sand	47	28	5
Sandy Loam	68	41	7
Loam	95	57	9
Sandy Clay Loam	68	41	7
Clay Loam	95	57	9
Silt	162	97	16
Silt Loam	135	81	14
Silt Clay Loam	108	65	11
Sandy Clay	74	45	7
Silty Clay	95	57	9
Clay	81	49	8
Clay Loam	95	57	9
Mode	95	57	9
Min–Max	34–162 m^3	20–97 m^3	3–16 days
Mean	**89 m^3**	**53 m^3**	**9**

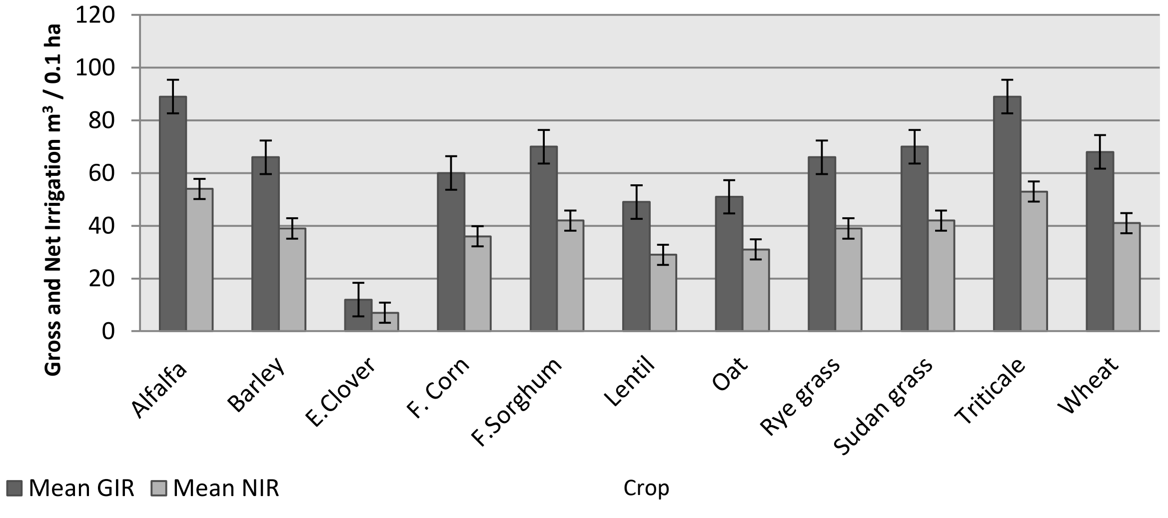
Table 4 continued

(K) Wheat

Soil Texture	**Gross Irrigation Requirement**	**Net Irrigation Requirement**	**Intervals (Days)**
Sand	26	16	4
Loamy Sand	36	22	5
Sandy Loam	52	31	7
Loam	73	44	10
Sandy Clay Loam	52	31	7
Clay Loam	73	44	10
Silt	125	75	17
Silt Loam	104	62	14
Silt Clay Loam	83	50	12
Sandy Clay	57	34	8
Silty Clay	73	44	10
Clay	62	37	9
Clay Loam	73	44	10
Mode	73	44	10
Min–Max	26–125 m^3	16–75 m^3	4–17 days
Mean	**68 m^3**	**41 m^3**	**9**

Figure 4 shows the gross and net irrigation needs mean in m^3 per 0.1 hectares for all field crops included in this study: alfalfa, barley, Egyptian clover, field (silage) corn, forage sorghum, lentil, oat, rye-grass, Sudan-grass, triticale, and wheat. Among crops, crops can be arranged descending with the gross and net irrigation requirements mean (alfalfa, triticale, forage sorghum, Sudan-grass, wheat, barley, rye-grass, field corn, oat, lentil, and Egyptian clover, respectively) as it is observed that there is a direct downward relationship with root depth *Table 1*. Thus, there is a strong positive correlation between gross irrigation requirements mean and root depth (*Table 7*).

Figure 4. **Gross and net irrigation requirements for eleven field crops based on rounded means among thirteen soil texture**



Vertical bars indicate the (±) standard error of the mean (n=13)

The effective root zone depth is the depth of soil used by the main body of the plant roots to obtain most of the stored moisture under proper irrigation. About 70% of the moisture extracted by the root is obtained in the top half of the root zone; about 20% from the third quarter; and about 10% from the soil in the deepest quarter of the root zone. Each plant has its root development characteristics. The application of irrigation water should be limited to an amount that will penetrate only to the effective root zone depth. Effective root zone or water extraction depth is the depth within which most crop roots are concentrated

(Alberta Agriculture and Rural Development, 2011). Depths to which the roots of mature crops will deplete the available water supply when grown in a deep permeable, well-drained soil under average conditions (University of California UC Drought Management, cited in National Engineering Handbook, 2016).

Table 5 shows that the percent of decrease for net irrigation requirements mean concerning to the gross irrigation requirements mean equals (40.27) as a mean among eleven field crops. Field crops in this study and their root depths (cm) were presented in the front of gross irrigation requirements mean (m^3) and the irrigation intervals mean (days) as it was derived by mathematical modelling (*Table 6*) to find the statistical correlation (*Table 7*).

The net irrigation outcome is a mathematical result of multiplying the gross irrigation value by the constant assumed factor of 60%, which reflects the efficiency of surface irrigation, losses especially due to deep percolation and surface runoff, not losses due to evaporation. On the other hand, the formula of percent of the decrease in verbal reasoning is (1–0.60, which equals 40%) (*Table 5*). This scientific observation should be considered as a necessity to shift towards drip irrigation where irrigation efficiency around 90% and a huge amount of water can be saved. There is also an imperative need to test varieties row spacing to schedule drip irrigation successfully.

Table 5. **Percent of decrease for net irrigation requirements mean about the gross irrigation requirements mean for eleven field crops**

Crop	Mean GIR	Mean NIR	Percent of Decrease
Alfalfa	89	54	0.39
Barley	66	39	0.41
Egyptian Clover	12	7	0.42
Field (Silage) Corn	60	36	0.40
Forage Sorghum	70	42	0.40
Lentil	49	29	0.41
Oat	51	31	0.39
Rye-grass	66	39	0.41
Sudan-grass	70	42	0.40
Triticale	89	53	0.40
Wheat	68	41	0.40
Mean			**0.40**

It is noted from *Table 7* that the amount of the statistical correlation is (0.82) between the root depth and irrigation intervals mean. But, it was (0.82) between irrigation intervals mean and the gross irrigation requirements mean. This means that the root depth is the main determinant factor of the gross requirements. Other studies and in-depth research should determine what is the main determinant factor for irrigation intervals such as soil texture, crop growth stage, and temperatures.

This study is only part of the integrated system of crop modelling in the case of crop rotation scheduling. Many studies have found similar results and emphasized the importance of crop rotations within agricul-tural development plans. A similar conclusion was recommended for forage agronomic crops in Jordan using treated wastewater (Massimi et al., 2018b).

It is also difficult to limit the specific soil texture of each crop unless other factors such as soil pH and the soil salinity limits may determine the recommended texture of each crop. This study needs to be scientifically proven on the research ground, with replicates to reduce the expected errors.

Table 6. **Major and most common field crops grown in Jordan and their root depths (cm) were presented in the front of gross irrigation requirements mean (m^3) and the irrigation intervals mean (days) as it was derived by mathematical modelling**

No.	Crop	Root Depth (cm)	Gross Irrigation Requirements Mean (m^3)	Intervals Mean (Days)
1	Alfalfa	135.6	89	12
2	Barley	99.6	66	9
3	Egyptian Clover	17.78	12	1
4	Field (Silage) Corn	91.44	60	4
5	Forage Sorghum	106.68	70	8
6	Lentil	73.7	49	6
7	Oat	77.7	51	7
8	Rye-grass	100	66	4
9	Sudan-grass	106.68	70	8
10	Triticale	135	89	9
11	Wheat	103.8	68	9

Table 7. **Statistical correlation for eleven field crop root depths (cm), gross irrigation requirements mean (m^3), and irrigation intervals mean (days)**

	Root Depth	GIR Mean	Intervals Mean
Root Depth	1		
GIR Mean	0.999	1	
Intervals Mean	0.82	0.82	1

Figure 5 shows the regression statistics where the dependent factor (mean of irrigation intervals days) is significantly affected by the independent factor (root depth). The correlation value (0.82) is described as a high positive correlation.

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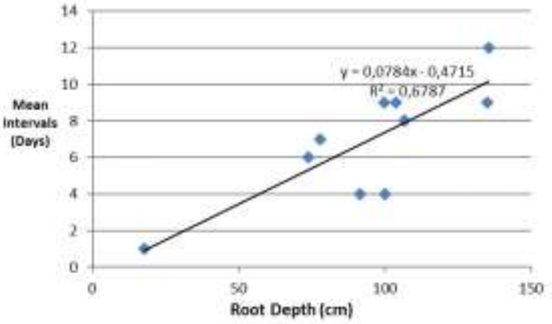
Figure 5. **Regression of mean intervals and root depth, function, and R^2**



CONCLUSION AND RECOMMENDATIONS

It has been well recognized that the science of mathematics has succeeded to meet an academic irrigation scheduling in term of surface irrigation for field crops based on both soil hydrological and physical properties due to the presence of fully documented botanical, morphological, and ecological field crops description with guaranteed supportive logical, mathematical, and statistical modelling. Thus, the prevailing model of irrigation scheduling for field crops in Jordan remains a scientific (academic) one, where an extension scholar can depend on his model, other research scholars, and any other sources. Irrigation models using digital sensing is another alternative practical tool, it is designed based on mathematical fundamentals, and it considers soil hydrological and physical properties.

Extension scholar's decision to update the mathematical irrigation model depends on mutual advanced research findings. It is an act of choosing between simplifying the irrigation model based on (effective root depth, soil texture, critical growth stage, and temperature) or searching for renewable inputs (different varieties root depths, optimum row spacing of each crop, and drip irrigation mathematical modelling) or to take advantage of each merit in specific situations. The first method is the same as the author and his team's 2017 work on corn and sorghum plants within the Norman Borlaug Fellowship (Massimi et al., 2020). This underscores the need to value each merit of an irrigation model in specific situations before putting in place any type of procedure. In both cases, the input related to the effective root depth is a major and basic factor in mathematical irrigation scheduling.

It is, therefore, recommendable that extension-research based systems should focus on science to capacitate the complementary role of academics, research trials, and extension program demonstrations in rural development.

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