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Quantifying *Medicago sativa* Yield under Deficit Irrigation Technique in Sandy Soil

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Author's contribution

The only author performed the whole research work. Author AOA wrote the first draft of the paper. Author AOA read and approved the final manuscript

Research Article

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ABSTRACT

Deficit irrigation technique was introduced to find the best means to conserve irrigation water in arid lands. The most common model describing deficit irrigation is water yield response model. The main advantage of such model is that it can predict relative yield drop, which arises from relative water deficit, in order to maximize the economic return. The disadvantage of the model is that it uses evapotranspiration (ET), estimated by using meteorological data, which affects the applicability of the model when there is no weather station near the field. Furthermore, the sudden changes of weather parameters and the differences of the areas covered with green plant at different growth stages might also, affect the model applicability. Therefore, the research objectives were suggesting a modified version of FAO model, using soil moisture data instead of meteorological data to provide greater accuracy and applicability and validating the proposed model. Pot experiment was conducted to achieve these objectives. Four levels of soil available water were chosen to irrigate five cultivars of *Medicago sativa* (as one of the most important grazing crops) cultivated in two different soils (un-reclaimed). The results showed positive linear correlation between available soil water and crop yield at all the experimental treatments. Regression equations were developed to predict crop yield resulting from water deficit. The study indicated that the maximum yield is not necessarily the optimal one to maximize the profit in arid lands. The study recommended the modified model to predict yield drop and water saving and also, presented guidelines for water management of other similar plants grown in arid lands.

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1. INTRODUCTION

Water is the most valuable and important resource on Earth's surface in terms of the increasing interest in the agricultural sector day after day. So, the problem of water has become one of the most urgent challenges in the present and the future. In this respect, [1] reported that water shortage is the major bottleneck that limits sustainable development of agriculture. From this point of view, crop yield is mainly limited by available water in the arid regions (e.g. Egypt and Saudi Arabia).

The farmer must therefore have prior knowledge of crop yield responses to deficit irrigation [2]. Applying deficit irrigation can thus help increasing water productivity in arid regions, and achieve more production per unit water depleted [3,4,5,6,7,8,9,10,11]. [12] indicate that under-watering decreases yields, therefore, the question remains to find the optimum application regime. In this respect, [13] studied three deficit irrigation treatments namely regulated deficit irrigation (RDI), partial root zone drying (PRD), and conventional sustained deficit irrigation (DI). The previous authors recommended RDI and PRD as they are the simplest deficit irrigation strategies and also have an efficient control of vegetative growth without negative impact on yield. Also, [14] found in field study that the water-saving irrigation strategies DI and PRD save about 20–30% of the water used in fully irrigated potato and tomato. Moreover, [15] reported that water saved through deficit irrigation could be used to restore environmental balance through augmenting environmental flows. When optimal scheduling of deficit irrigation was applied to sandy loam and coarse sand soils, the highest water productivity is achieved [16]. Deficit irrigation, however, results in yield reduction because of the shortage of soil available water, which is occurred when this technique is followed. In such case, we can accept some yield reduction to save water.

The most simple and common model quantifying water productivity is developed by [17]. Such model (namely, yield response model) is suggested to illustrate relative yield reduction versus relative evapotranspiration reduction. The [17] model is presented in the following expression:

$$1-\frac{Y_a}{Y_m}=K_y\left(1-\frac{ET_a}{ET_m}\right)$$

Where:

$$\left(\frac{Y_a}{Y_m}\right) = \frac{actual\ yield}{\text{maximum yield}}.$$

$$\left(\frac{ET_a}{ET_m}\right) = \frac{actual\ \text{evapotranspiration}}{\text{maximum evapotranspiration}}.$$

K_y = yield response factor.

ET is calculated using pan evaporation or meteorological data through mathematical models such as Penman-Monteith [18]. However, measured actual soil moisture content is more accurate and reliable than evapotranspiration. Furthermore, the irrigation requirements cannot be estimated in case if no weather station close to the field. Studies on deficit irrigation mainly deal with grain crops [10,15,11], whereas the current study focus on grazing crop (*Medicago sativa*).

The main objectives of this research are: 1) suggesting a modified version of FAO model, using soil moisture data instead of meteorological data to provide greater accuracy and applicability; 2) validating the proposed model using important grazing crop (*Medicage sativa*) cultivated in un-reclaimed soils (desert land).

2. MATERIALS AND METHODS

The researcher suggested a modified version of FAO model. The proposed model was:

$$1-\frac{Y_a}{Y_m}=K_y\left(1-\frac{SAW_a}{SAW_m}\right)$$

Where:

SAW_a and SAW_m are actual and maximum soil available water.

Pot experiment was conducted at Taif university experimental station, on October 2011 through January 2012, in order to validate the proposed model. The diameters and depths of each pot was 15 × 16 cm. Five cultivars of *Medicago sativa* (Magic; SW14; Hasawi; Cuf101; Hagasi) were chosen to validate the proposed model. The cultivars were only, chosen for the purpose of validating the model and will not interfere the results. The cultivars were cultivated in two soils collected from un-reclaimed areas in Taif governorate, Saudi Arabia. Four levels of soil available water were chosen to irrigate the five studied cultivars. The four levels were 100%, 80%, 60%, and 40% of soil available water, which indicate relative water deficit $\left(1-\frac{SAW_a}{SAW_m}\right)$ of 0, 0.2, 0.4, and 0.6, respectively. The treatments were done in three replicates. Thus, 120 pots were used to represent the experimental treatments (i.e. 5 cultivars × 4 water applications × 2 soils × 3 replicates). The pot weights were adopted using digital balance. Each pot contained 2 Kg of dry soil (the hygroscopic water was measured and subtracted from the air-dry weight). The used fertilizers were triple super phosphate (mixed with the soil before seedling), Ammonium nitrate (given in two doses during the first month) and Potassium sulphate (given in two doses during the first month). The application rate was 500 mg per pot of each fertilizer.

The physical and chemical analyses of the studied soils was presented in Tables 1 and 2. The analyses procedures were done according to [19].

Table 1. Physical analysis of the experimental soils

Soil	Particle size distribution, %				Texture	Total porosity (%)	Soil moisture constants (% by weight)	
	Course Sand	Fine sand	Silt	Clay			Field capacity	Permanent wilting point
1	9.2	74.7	11.2	4.9	Loamy Sand	44	16.5	6.1
2	5.7	71.4	10.6	12.3	Sandy Loam	51	21.0	8.3

Table 2. Chemical analysis of the experimental soils

Soil	EC (ds/m)	pH	Soluble ions, meq/100 g soil							
			Cations				Anions			
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
1	0.41	8.1	0.69	0.58	1.22	0.29	0.00	1.0	1.45	0.33
2	0.70	7.86	0.82	0.46	0.97	0.33	0.00	0.73	1.52	1.69

A count of 50 seeds were cultivated in each pot. All the pots were given 100% of soil available water until the plants well established (30 days) to avoid water stress during that sensitive early growing stage. The amount of full irrigation application was calculated based on the difference between field capacity and actual soil moisture content for each soil using digital balance (i.e. the final pot weight was equal to the summation of empty pot weight, soil weight and irrigation requirement). The pots were re-weighted every 4 days (fixed irrigation interval) to calculate irrigation requirement. The irrigation water was added (using balance, water tank, and graduated cylinder) to compensate the water depletion, directly before irrigation. This specific range, of irrigation application rate, was used because applying water more than 100% of soil available water is not logic from economic view, because it causes water losses without any improve in obtained yield. Also, applying water less than 40% of available water causes potential reduction of crop yield and the relationship will be changed from linear to non-linear, and hence, it is not logic applying water less than 40% of soil available water. In this respect, (18) find that the linear relationship of the FAO crop response model is only valid within 50 percent water deficit, for most crops.

The irrigation application of the 0% water saving (100% of water requirements) was calculated based on the average actual soil moisture content of the three replicates of each cultivar. The irrigation application of other water treatments were estimated as a ratio of such treatment. After two months of starting treatment application (i.e. three months from cultivation), the plants were harvested. The shoot fresh weight of each experimental treatment was measured.

The following equation (20) could be used for calculating irrigation requirements in case of open field:

$$d = \mathrm{D}\frac{(\mathrm{FC} - \mathrm{ASMC})}{100} \times \frac{\rho_s}{\rho_w}$$

Where

d	= irrigation requirement expressed as a depth, cm
D	= soil depth, cm
FC	= field capacity (% by weight)
ASMC	= actual soil moisture content (% by weight)
ρ_s	= soil bulk density
ρ_w	= water density

Also, in the field, soil moisture content could be monitored by sampling the soil using auger or through in-situ instruments.

3. RESULTS AND DISCUSSION

Four irrigation applications as a percent of available water were chosen to create soil water stress. The created levels of water stress were zero water deficit, 0.2 water deficit, 0.4 water deficit, and 0.6 water deficit. That is, to express the relationship between soil water deficit and yield for the purpose of predicting relative yield reduction (as a ratio of maximum possible yield) per relative water saving (as a ratio of maximum available soil water).

The yield (fresh shoot weight) of the five cultivars of *Medicago sativa* versus the four studied soil moisture contents was given in Table 3. Table 3, showed that the obtained yield was reduced with increasing water stress. A strong decrease in yield fresh weight was associated with 40% available water. Such result was somehow agree with [21], who studied the impact of soil water deficit on *Medicago truncatula*. Their results showed that the plant resists mild drought conditions. In accordance with our finding, [22] indicates that water deficit restricted growth of *Medicago truncatula* and *Medicago laciniata*. Table 3, also, revealed that Hasawi had highest yield followed by SW14, then Cuf101, then Magic, then Hagasi which produced the lowest yield. Such trend was found in both soils. However, soil 2 was more productive (fertile) than soil 1. This might be attributed to texture and total porosity, which was better in soil 2 than soil 1 as shown in Table 1. Table 3 indicated that the studied cultivars showed different sensitivities to soil properties. Hagasi was the most sensitive cultivar while SW14 was the most tolerant cultivar to poor soil properties. Table 4 showed the relative water application versus yield of different cultivars grown in the two soils under consideration. The data in Table 4 was employed to illustrate the regression lines and calculate the yield response factor (Ky), as shown in Fig. 1. The yield response factor (Ky) was required for predicting yield (i.e. relative to maximum yield) of *Medicago sativa* cultivars under any irrigation application at the range of water stress between 40% and 100% of soil available water. The obtained regression equations and R^2 values were presented in Fig. 1. The developed lines run through the data points (trend lines) obtained from the measured data illustrated in Fig. 1. Satisfied R^2 values were found (ranging from 0.9052 to 0.993). Such high values indicated that these equations could be employed in predicting the yield of *Medicago sativa*.

Table 3. The average yield (gram/pot) and irrigation application* (liter/pot) of the five chosen cultivars of *Medicago sativa* plant grown in two different soils

Soils	Cultivar	Available soil moisture							
		100%		80%		60%		40%	
		irrigation	yield	irrigation	yield	irrigation	yield	irrigation	yield
Soil 1	Magic	1.77	5.20	1.62	3.77	1.06	2.71	0.71	1.60
	SW14	2.02	17.61	1.58	15.15	1.21	10.2	0.81	5.52
	Hasawi	1.98	18.67	1.52	13.77	1.19	6.37	0.79	3.57
	Cuf101	1.90	12.67	1.27	8.50	1.14	6.77	0.76	5.27
	Hagasi	1.59	1.77	1.62	1.50	0.95	0.75	0.64	0.60
Soil 2	Magic	2.09	16.00	1.67	13.60	1.25	7.90	0.84	5.70
	SW14	2.25	19.20	1.80	16.78	1.35	11.55	0.90	7.81
	Hasawi	2.19	25.00	1.75	18.58	1.31	15.26	0.88	6.96
	Cuf101	2.21	18.20	1.77	14.50	1.33	11.20	0.88	2.96
	Hagasi	1.81	9.10	1.45	4.8	1.09	2.80	0.72	1.4

** irrigation application for the two months after treatments*

Table 4. The relative water application and relative obtained yield

Cultivars	Relative water deficit ($1-\frac{SAW_a}{SAW_m}$)	Relative yield reduction ($1-\frac{Y_a}{Y_m}$)	
		Soil 1	Soil 2
Magic	**0.6**	0.692	0.644
	0.4	0.479	0.506
	0.2	0.275	0.15
	0	0	0
SW14	**0.6**	0.687	0.6417
	0.4	0.421	0.3984
	0.2	0.14	0.126
	0	0	0
Hasawi	**0.6**	0.809	0.722
	0.4	0.659	0.39
	0.2	0.263	0.257
	0	0	0
Cuf101	**0.6**	0.584	0.837
	0.4	0.466	0.385
	0.2	0.329	0.203
	0	0	0
Hagasi	**0.6**	0.661	0.846
	0.4	0.576	0.692
	0.2	0.153	0.473
	0	0	0

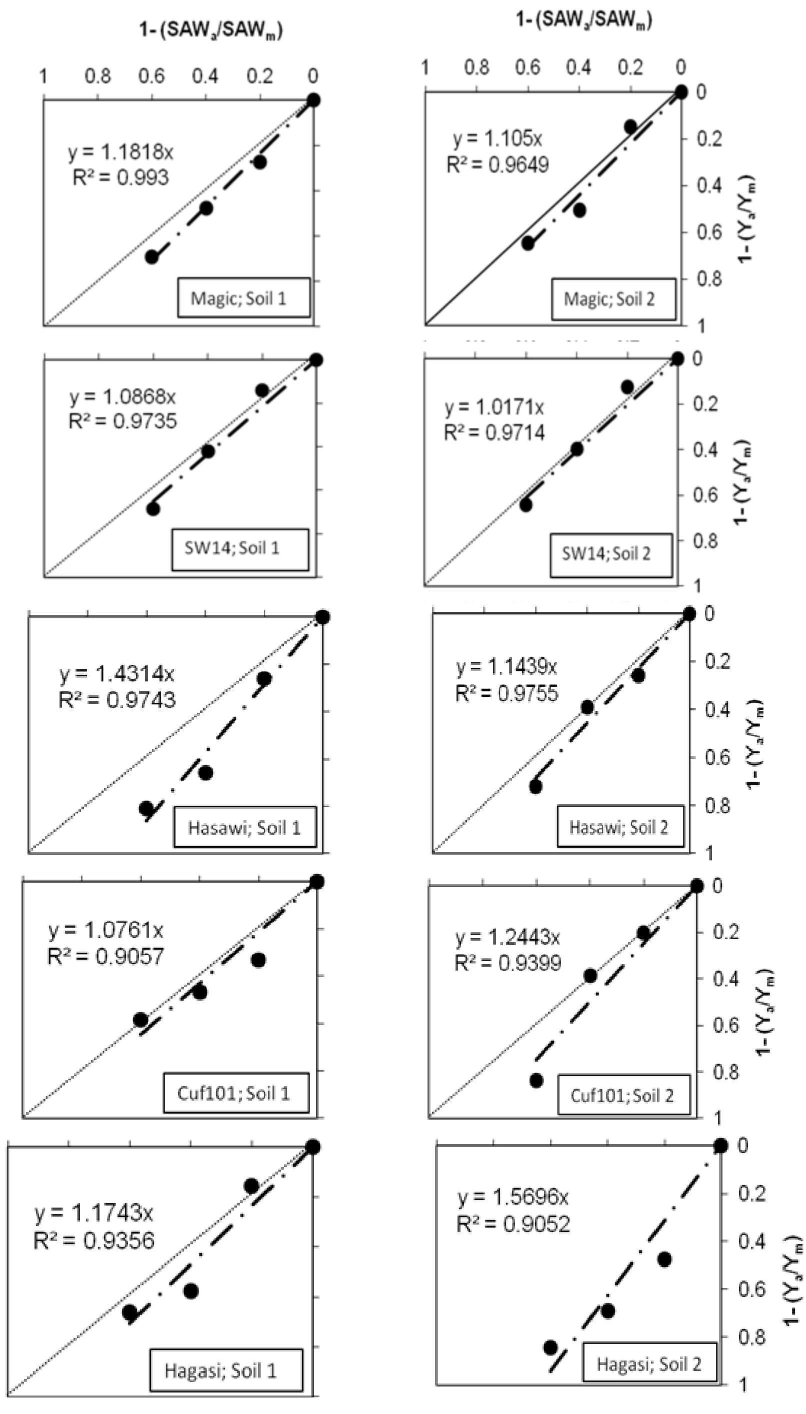

Fig. 1. Relative yield reduction versus relative water deficit of the five cultivars in the two soils (Where Y is equal to $1-\frac{Y_a}{Y_m}$ and X is equal to $1-\frac{SAW_a}{SAW_m}$)

The crop yield response factors, calculated according to the fractional yield reduction $(1-\frac{actual\ yield}{\text{maximum yield}})$ as a result of the decrease in irrigation application rate $(1-\frac{actual\ \text{soil available water}}{\text{maximum soil available water}})$ were ranging from 1.0171 to 1.5596. All Ky values were more than one, which indicate that the studied cultivars of *Medicago sativa* are sensitive to drought. This result is expected in such un-reclaimed poor soils. A reasonable explanation could be excluded from (18) who found that the relationship considers only water stress as the factor affecting crop yield and assumes the other factors affecting crop yield as fixed. (4) found that when good environmental conditions are exist the slope is steeper than poor conditions. Also, (23) indicated that soil physical properties and soil water contents directly affect evaporation from the soil and indirectly regulate crop transpiration through their influence on crop water status. Therefore, it could be concluded that monitoring soil moisture content is relatively controlled and reliable than ET calculated by mathematical models using a large number of meteorological data. The results indicated that the accustomed equation $[1-\frac{Y_a}{Y_m}=Ky\left(1-\frac{SAW_a}{SAW_m}\right)]$ is valid to be used to predict *Medicago sativa* yield and similar plants under different irrigation applications, in the case of scheduling irrigation base on soil moisture measurements rather than ET. In this respect, (24) conducted two-year study to assess the effects of deficit irrigation upon water productivity and final biomass of tomato under semi-arid condition. Their results recommended 50% reduction of ET application to save water, improving tomato use efficiency, minimizing fruit losses and maintaining high fruit quality levels.

Based on the obtained data presented in Table 4, the modified model and the knowledge of unit price of both applied water and obtained yield, an economic estimation of *Medicago sativa* could be concluded. The simplicity and applicability of the proposed model is because of that no units of cultivated area and obtained yield need to specified (the model use relative values) and also the intercept equal to zero which include only the slope of the obtained straight line. Simply one can relate the yield reduction to water deficit, without any calculations and also can convert it back to any other units.

Furthermore, more benefit of the model in un-reclaimed and arid lands where water is extremely limited and labor is expensive. This could explained by (25) who reported that “in arid environment, the main challenge for crop production is water deficit”.

4. CONCLUSION

1- As long as the main goal is to maximize the profit as well as saving water, it could be said that the maximum yield is not necessarily the optimal one, but could be less.
2- Deficit irrigation technique is recommended in arid regions such as Egypt and Saudi Arabia where water resources are limited.
3- The study recommended using suggested modified model to predict yield reduction caused by soil water deficit to optimize irrigation scheduling of different cultivars of *Medicago sativa* (the most important grazing crop). The model is simple, accurate and reliable and can help in future water management for un-reclaimed soils (e.g. Egyptian and Saudi deserts).

4- Further studies are needed to develop a general model with parameters relative to specified soil properties and different cultivars for the purpose of predicting yield under wide range of water stress, soil types and cultivated plants.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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