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APPLICATION OF THE MATHEMATICAL MODEL "DEMAND" FOR SURFACE IRRIGATION METHODS OF ARID AND SEMI-ARID REGIONS
PRIMENA MATEMATIČKOG MODELA "DEMAND" NA POVRŠINSKE METODE NAVODNJAVANJA ZEMLJIŠTA ARIDNIH I SEMI ARIDNIH REGIONA

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SUMMARY

This study gives data on water requirements of important agricultural crops. Data on irrigation water quantity are projected values which will be used for design of the pipeline and open canals irrigation network.

The study was carried out at the location of the previously constructed irrigation and drainage system within Agro Industrial Complex Dujailah in Iraq. A large number of data were collected, such as hydro-meteorological data, crop data and soil data.

Based on the analysed area of 3,120 ha, the following classification and ratio of irrigation methods was established for the total area of 25,000 ha: 1) surface irrigation (basin, border strip), 60% or 15,000 ha, 2) other hi-tech irrigation methods (drip irrigation, micro-jets, hose-reel irrigators of different dimension, centre pivot, linear irrigators – Rangers), 40% of total system area or 10,000 ha.

As a result of applying the mathematical model "Demand", certain hydraulic parameters were precisely determined for designing the irrigation network on that part of the irrigation and drainage system where contemporary irrigation methods and techniques will be applied within the reconstruction and revitalization project.

1. INTRODUCTION

Calculation of irrigation requirements has a long history of development. Influence and inter-relations of the factors on plant development and its consumption, as well as available methods depending on interpolation of experimental data and empirically derived units, often give the possibility of different levels of reliability.

As established, water consumptive use is independent from soil conditions and precipitation. However, because the used mathematical model "Demand" includes the calculation of monthly water requirements and respective daily irrigation schedule, data on rainfall and soil properties are necessary and have therefore been included in the analysis (Aboukhaled, 1972.)

The aim of this study was twofold: 1) to classify the areas which will continue to receive surface irrigation (basin irrigation and border strip irrigation), and 2) to classify the remaining areas which will receive contemporary irrigation methods and techniques (drip irrigation, micro-jets, various sprinkler irrigation techniques via self-driving automated devices – hose-reel, with or without rain ramps. One of the aims was also to test the possibility of using central devices, e.g. centre pivot, Ranger-Linear, etc.

Distribution of the mentioned irrigation methods is determined by separate project documentation depending on: pedological and hydro-pedological soil properties, general terrain slope between two drainage collectors, capacities of existing piping, available pressure and crops. Sowing pattern update and application of modern crop rotation models were determined by project documentation and adequate agronomic bases.

2. MATERIALS AND METHODS

Experimental part of the study was carried out during 2006-2008 on the location of the previously built irrigation and drainage system within Agro Industrial Complex Dujailah in Iraq, constructed by "Poljoprivredni Kombinat Belgrade" on the total area of 25,000 ha. Study presented in this paper included irrigated area of 3,120 ha, divided into 100 plots, 58 irrigation pipelines, 5 canals of the 2nd order and the main canal I-4.

For this analysis the following data and parameters were gathered and used:

- Irrigation plots sizes
- Plots locations and positions relative to irrigation pipes and drainage canals - collectors (Stojićević, 1964, Tomić, 1988.).
- Sowing pattern and crop rotation for each plot encompassing 40-year rotation period.
- Soil moisture constants (field capacity values, wilting points, physiologically useful water), as well as infiltration size for each soil type.
- Effective root depth of the grown crops,
- Monthly evapotranspiration coefficients (ET).

Abovementioned data and values were used for:

a. Calculation of annual, monthly and daily water requirements for ten crops planned in the sowing pattern on three characteristic soils (clay, clay loam, loam) for the hydro-meteorological cycle of 40 years.
b. Assessment of these results and selection of daily calendar and irrigation time schedule for each of the 30 crops (in crop rotation), aimed at designing the irrigation pipes under pressure that will deliver water to the future self-driving irrigation systems (for areas without surface irrigation).

3. RESULTS AND DISCUSSION

Detailed list of data necessary for the "Demand" model and output data are shown in Table 1.

Many environmental factors affect growth and development of agricultural crops. Air temperature and insolation period are especially important for this analysis. Other factors such as relative air humidity, wind speed, etc. are of secondary importance (Blaney Criddle, 1962). In order to better use the available data based on annual and seasonal variations, these factors were statistically analysed for the period 1981-2008. (Žeželj, 2013.-Table 2).

Table 1. Crop water requirements (“Demand” model)

Input data		Output data
Data type		
Hydro-meteorological data	Monthly precipitations Monthly temperatures Monthly temperature coefficient (Kt) Monthly % of day duration (insolation)	Monthly consumption Monthly crop water demand Daily water schedule Statistical summary
Crop data	Crop type Crop growing stage coefficient (Kc) Date of the first irrigation application C.U. coefficient (K) Date of the last irrigation application Root depth	
Soil data	Soil types Water constants Irrigation efficiency	

Table 2. Monthly statistical metrological data

		X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
Temp (^{0}C)	Max.	28.8	20.7	15.9	14.0	16.1	20.7	25.1	33.0	35.3	36.9	37.2	33.9
	Average	22.8	18.3	12.3	10.9	13.1	17.2	22.6	29.1	33.6	35.3	35.0	31.7
	Min.	12.9	16.0	8.5	5.6	8.8	14.3	20.1	25.5	31.5	33.4	32.8	29.2
	Average m/y	1.09	0.77	0.52	0.45	0.55	0.73	0.95	1.23	1.41	1.48	1.47	1.33
Kt	Max.	1.10	0.90	0.70	0.70	0.70	0.90	101.7	30.6	0.30	1.40	1.40	1.30
	Average	1.04	0.81	0.62	0.55	0.65	0.77	20.4	7.0	0.01	1.34	1.33	1.23
	Min.	0.90	0.70	0.50	0.40	0.50	0.70	0.0	0.0	0.00	1.30	1.30	1.10
	Average m/y	1.06	0.83	0.63	0.65	0.66	0.79	1.7	0.6	0.00	0.00	0.00	0.00
Rainfall (mm)	Max.	19.8	133.5	70.3	98.4	64.2	116.5	101.7	30.6	0.3	0.0	0.0	0.0
	Average	3.0	17.9	24.2	26.9	21.0	23.5	20.4	7.0	0.0	0.0	0.0	0.0
	Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Average m/y	0.25	1.49	2.02	2.24	1.75	1.95	1.71	0.59	0.0	0.0	0.0	0.0
Rel. humidity (%)	Max.	34.0	60.0	66.0	68.0	59.0	64.0	46.0	39.0	23.0	24.0	24.0	24.0
	Average	23.5	38.3	52.8	52.3	43.4	38.9	32.5	22.1	15.7	16.0	16.0	17.1
	Min.	15.0	26.0	40.0	34.0	32.0	26.0	20.0	13.0	11.0	10.0	10.0	10.0
	Average m/y	0.76	1.25	1.72	1.70	1.41	1.27	1.06	0.72	0.72	0.51	0.52	0.45
Wind (m/s)	Max.	4.7	4.8	4.7	5.0	5.8	6.2	5.8	5.6	7.6	9.0	7.9	6.7
	Average	2.8	2.9	2.8	3.0	3.4	3.6	3.3	3.4	4.2	4.2	3.8	3.5
	Min.	1.2	1.5	1.5	1.9	1.9	2.0	1.9	1.9	1.9	1.4	2.2	1.7
	Average m/y	0.82	0.85	0.82	0.88	1.0	1.06	0.97	1.00	1.23	1.23	1.23	1.22
% Insolation		7.95	7.11	7.05	7.20	6.97	8.37	8.75	9.62	9.59	9.77	9.24	8.34

The above mentioned values were used to: 1) calculate annual, monthly and daily requirements of ten crops planned by the sowing pattern on three characteristic soils (clay, clay loam, and loam), for the hydro-meteorological cycle of 40 years, 2) evaluate results and select daily calendars and daily irrigation schedules for each of the thirty agricultural crops in rotation. The calculations were performed so as to design the new irrigation pipelines under pressure; the earlier pipelines will be used for surface irrigation (or gravitational mobility), while the new pipelines for contemporary irrigation methods and techniques will be under pressure. In case of using the abovementioned hi-tech irrigation methods, there will be a combination of the gravitational water mobility in the existing open concrete canals and new pressurized pipelines, with hydrants placed at the position of the device working perimeter. Scope and number of hydrants will be determined by the project solutions depending on the adopted irrigation methods.

Soil conditions

Soil characteristics affect gross water quantity which is brought to the fields for irrigation purposes, as well as the method of its application which finally determines the irrigation efficiency. The soil was classified into four classes from the agronomical viewpoint. The analysis included most dominant soil types, from which conclusions regarding other ones are easily drawn. Loam, clay loam and clay were chosen as three soil types from the mentioned soil classes and selected for detailed analyses. The results from these analyses were used for:

a. Hydraulic calculation and design of the border strip and basin irrigation (Vučić, 1976).
b. Determination of crop water requirements (given in this study).
c. Determination of timing and schedule of irrigation (given in this study).
d. Establishment of field experiments so as to verify the mathematical methods and the assumed empirical coefficients.

Table 3 shows values of water constants and infiltration characteristics of the mentioned soil types.

The method used in this analysis (Blaney-Criddle) is among the better ones that are available; it is often used in designing irrigation systems in arid and semi-arid climatic regions (FAO Drainage paper No 24, 1977).

The Blaney-Criddle equation states:

$U=(Kt \times Kc)\ t \times p/100$

where:

U - consumptive use in inches,
Kt – climatic coefficient dependent on the temperature (Kt=0.0173t-0.314),
Kc – empirical coefficient denoting crop developmental phase,
t – temperature in degrees Fahrenheit,
P – monthly assessment of insolation period (USDA T.C. 21,1960, Dugalic at all, 2012).

Table 3. Soil water capacity and infiltration rate

Soil class	Field capacity	Wilting point	Physiologically useful water	Irrigation rate/ Root depth			Infiltration	
	(%)	(%)	(%)	600 mm	700 mm	800 mm	cm/sx10^4	cm/hrs
clay	34.0	14.0	20.0	80	93	106	2.50	0.90
Clay loam	35.6	17.6	17.0	68	79	80	1.10	0.40
Loam	12.6	26.6	16.0	64	75	86	0.54	0.19

Table 4. Annual crop water consumption

Planned crop	Sowing date	Harvest date	Annual consumption (mm)	
			Mean values	Top requirements
Wheat	21.10.-01.12.	10.05.	417-497	472-558
Barley	21.10.	30.04-31.05	324-349	347-390
Winter mix	21.10.	30.04.	382	422
Spring mix	21.02.	30.06.	343	383
Alfalfa	11.09.	5-6 cuts	2196	2357
Berseem	11.09.	20.05.	474	518
Grain maize	21.07.	20.05.	792	869
Silage maize	21.07.	30.11.	675	733
Green maize	11.04.-21.08.	07.07.-20.11.	333-534	371-569
Faba bean	11.09.	31.05.	475	525

The results given in Table 5 show that the highest values were found in silage maize in September (271 mm) and lowest for the same crop in October (204 mm). Values are high for all three months of the growing period because this is summer.

Table 5. Final analyses results for growing season

Crop	Empirical coefficients	GROWING SEASON					
		Nov.	Dec.	Jan.	Feb.	March	April
Wheat	Kt	0.81	0.62	0.58	0.65	0.78	0.84
	K	0.50	0.70	0.70	0.70	0.80	0.80
	Kc	0.62	1.05	1.21	1.31	1.22	0.64
	Consumption (mm)	59	64	66	84	127	98
		Aug.	Sept.	Oct.			
Silage maize	Kt	1.33	1.23	1.04			
	K	1.00	1.30	1.30			
	Kc	0.75	1.06	1.25			
	Consumption (mm)	244	271	204			

Analysis resulted in adopted concept of using 50% of the total water quantity for all crops in the first month of the growing season when the root system is shallow. This potential saving of the water can be used for additional salt leaching in those areas where salinity value is over 4 mmhos/cm at 25^0C (Dieleman, 1973., Ćirić, 1991.).

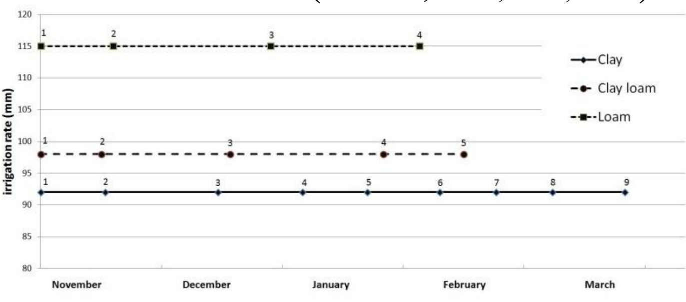

Fig. 1. Irrigation number, rate and interval for wheat

From the mentioned analysis results, examples for water consumption of two crops (wheat and silage maize) were selected and shown here out of 10 analysed crops and total 30 in crop rotation (Tab. 5, Fig. 1), and the projected values of irrigation timing and schedule for the analysed soil types (Tab. 4 and Tab. 6).

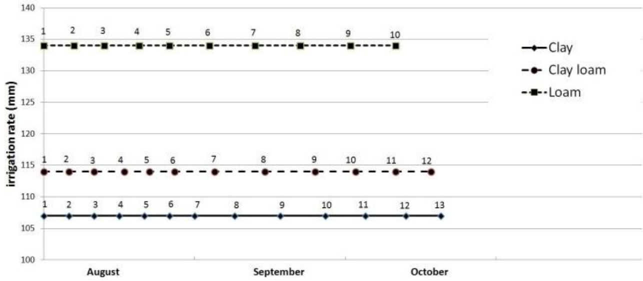

Fig. 2. Irrigation number, rate and interval for silage maize

Based on the assumption of 16 operating hours of the irrigation system and given criterion and assumption that alfalfa will be grown on 50% area covered by each irrigation pipeline, site hydromodule is calculated to be 1.61 l/sec/ha. Analysis for alfalfa showed higher values for July (3.2 l/sec/ha) because this crop is the largest water consumer (Tab. 6). This fact recommends the project solution that alfalfa should be grown on one side of the irrigation pipeline and the other half should be left fallow.

Table 6. Designed scheduling and irrigation water quantities

Crop	Root depth (m)	CLAY			CLAY LOAM			LOAM		
		interval	rate	module	interval	rate	module	interval	rate	module
Wheat	0.6	14	92	1.14	15	98	1.13	17	115	1.17
Barley	0.6	17	92	0.84	20	98	0.85	20	115	1.00
Winter mix	0.6	17	92	0.94	17	98	1.00	19	115	0.95
Spring mix	0.6	8	92	2.00	8	98	2.13	10	115	2.00
Alfalfa	0.8	7	123	3.05	7	180	3.22	9	153	2.95
Berseem	0.6	16	92	1.00	16	98	1.06	28	115	0.71
Grain maize	0.6	9	104	2.06	9	114	2.20	12	134	1.94
Silage maize	0.4	9	107	2.06	9	114	2.20	9	154	2.58
Green maize	0.6	7	107	2.65	8	114	2.40	9	134	2.58
Faba bean	0.6	15	92	1.06	15	98	1.63	20	115	0.99

Analysis results given in Tables 4 and 6 showed that the same applies to other large water consumer crops: green maize, silage maize and grain maize. Water requirements of these crops range between 1.9 to 2.6 l/sec/ha.

Water quantity for winter crops (i.e. site module) is below 1.6 lit/sec/ha.

The given figures show calculated values of irrigation rates and intervals for three selected soil types for silage maize, i.e. in the growing period of winter and spring crops. Number of irrigation rates with shorter intervals is evidently more than double for all soil types in summer growing period as compared to the winter period.

Irrigation network will be designed based on 14-day irrigation interval in April and 7-day interval in July and August.

4. CONCLUSIONS

During 2012-2014 the activities commenced in order to prepare the implementation of the reconstruction and revitalization project on the irrigation and drainage system within AIC Dujailah-Iraq, previously constructed by PKB.

Based on the results of the experiment and the given analysis, the following can be performed:

a. classification of the areas which will continue receiving surface irrigation (basin and border strip, 60% areas or around 15,000 ha),

b. classification of the remaining areas which will receive contemporary irrigation methods and techniques (drip irrigation, micro-jets, various sprinkler irrigation methods, 40% areas or 10,000 ha).

Data on irrigation water quantity are the projected values which will be used to design the irrigation pipeline and open canals network.

Based on this analysis, the projected site hydromodule is 1.61 l/sec/ha on all areas with clay and clay loam and basin irrigated areas.

Plots with loam soil, where due to general slope of $1\text{-}2^{o}/_{oo}$ necessitated border strip irrigation, have somewhat larger value of 1.7 l/sec/ha in order to meet winter crops top requirements in late March and early April.

Maximum irrigation interval is 14 days, and minimum is 5 days.

Irrigation time, i.e. system engagement, will be over 16 hours, in the period of top consumption on areas under alfalfa in July and August, as well as spring mixture in April and early May.

Generally, the system will be operating for 16 hours, except for abovementioned conditions, and for the case of border strip irrigation on heavy soils, where 24 hours are necessary to complete 3 irrigations (one lasts for 8 hours). After implementation and regular exploitation of contemporary hi-tech systems and irrigation equipment, with the altered sowing pattern, there will be no constraints regarding system operating hours.

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During 2012-2014, expert authorities of Serbia and Iraqi Government, with selfless commitment of the Iraqi Embassy in Belgrade and especially His Excellency the Ambassador Dr. Falah A. Abdulsad, commenced joint activities aimed at starting the project of reconstruction and revitalization of irrigation and drainage system within Dujailah-Iraq Agro Industrial Complex.

PRIMENA MATEMATIČKOG MODELA "DEMAND" NA POVRŠINSKE METODE NAVODNJAVANJA ZEMLJIŠTA ARIDNIH I SEMI ARIDNIH REGIONA

Rezime

U radu je dat prikaz podataka o zahtevima važnijih poljoprivrednih kultura za vodom. Informacije o količinama vode za navodnjavanje predstavljaju projektne veličine koje će se koristiti za dimenzionisanje irigacione mreže cevovoda i otvorenih kanala.

Istraživanja su sprovedena na lokaciji ranije izgrađenog irigaciono-drenažnog sistema u okviru Agro Industriskog Komplesa Dujailah u Iraq. Prikupljen je veliki broj podataka kao što su hidrometeorloški podaci, podaci o kulturama (usevima) i podaci o zemljištu.

Na osnovu analizirane površine od 3.120 ha, utvrđena je sledeća klasifikacija i učešće pojedinih metoda navodnjavanja, na ukupnoj površini od 25.000 ha: 1. Površinsko navodnjavanje (potapanje-basen, plavljenje-border strip), 60% ili 15.000 ha, 2. Ostali, Hi-tech metodi navodnjavanja (kap po kap, mikro jet, Tifoni različitih dimnzija, Centar Pivoti, Lineari-Rendžeri), 40% od ukupne površine sistema, ili 10.000 ha.

Kao rezultat primene matematičkog modela "Demand", detaljno su određeni hidraulički parametri za dimenzionisanje irigacione mreže na onom delu irigaciono-drenažnog sistema, gde će projektima rekonstrukcije i revitalizacije biti primenjeni savremeni metodi i tehnike navodnjavanja.

Ključne reči: navodnjavanje, zemljište, hidraulični paramteri, irigacija, usev.

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