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Procedia Engineering 28 (2012) 516 – 521

Procedia Engineering

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2012 International Conference on Modern Hydraulic Engineering

Multivariable Linear Regression Equation for Rice Water Requirement based on Meteorological Influence

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Abstract

The paper firstly analyzed meteorological influences on rice water requirement referring to temperature, wind speed, air saturation deficit and sunshine hours. Then, it analyzed the other meteorological factors' influences. Through introduction of natural water surface evaporation factor, a multivariable linear equation with five variables was established for rice water requirement. A five variable linear equation model, FAO56 Penman-Monteith formula and a four variable linear equation which don't have natural water surface evaporation factor were used to calculate rice water requirement in cold areas. It shows that multivariable linear equation with five variables has a more accuracy, compared with Penman-Monteith formula and four variable linear equation. As a regional empirical formula, the five variable linear equation can be applied in cold area.

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Keywords: crop water requirement; water-saving irrigation; Penman-Monteith formula; meteorological factors; multivariable linear regression equation; irrigation planning; rice water-saving irrigation; mathematical model1.Introduction

1. Introduction

Rice water consumption includes water requirement and leakage. Rice water requirement consists of transpiration and evaporation, which has an important influence on yield. Rice water requirement is the theoretical basis of rice water-saving irrigation and optimizing the allocation of farm water resource. For rice irrigation zone planning, design, management and forecasting, water requirement is an essential basic

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data. Thus, research on rice water requirement mathematical model and accurate calculating rice water requirement have not only theoretical significance but also practice value.

Through mechanism analysis of meteorological influence on rice water requirement, the natural water surface evaporation factor was introduced and the multivariable linear equation with five factor was established, based on four variable linear equation. Five variable linear equation model, FAO56 Penman-Monteith formula and four variable linear equation were used to calculate rice water requirement in cold area. It shows that five variable linear equation has a more accuracy, compared with Penman-Monteith formula and four variable linear equation.

2. Analysis of meteorological influence on rice water requirement

Rice water requirement is comprehensive affected by aspects of SPAC [1]. Among them, meteorological factors are major factors which affect rice water requirement. Relative research showed that temperature, air saturation deficit, sunshine hours and wind speed has the greatest impact.

Solar radiation is the source of all energy on Earth and unique source of crop evapotranspiration. It plays a key role in crop water requirement.

Due to absorption of solar radiation, Earth surface accumulates heat and temperature increases, which, at the same time, Earth surface radiate heat to atmosphere as long-wave radiation. According to radiation law, the radiation density of object is proportional to its fourth power. So, greater solar radiation, more heat absorption and accumulation of surface, greater long-wave radiation density from Earth surface to atmosphere. So, when solar radiation becomes greater, long-wave radiation becomes greater, energy absorption by atmosphere becomes more and temperature increases. Thus, temperature closely relates to atmospheric radiation and also closely relates to crop evapotranspiration.

Rice evapotranspiration consists of plant transpiration and evaporation among plants. The vapor pressure of evaporation surface which referring to leaf surface and water surface among plants is saturated or close to saturated. The vapor pressure of any surface which has some height from evaporation surface is actual vapor pressure, always less than saturation vapor pressure. Under gradient of saturation vapor pressure and actual vapor presser, also called saturation deficit, water molecules spreads from evaporation surface into air. Thus, rice water requirement is affected by air saturation deficit. Some researchers showed that rice water requirement is proportional to air saturation deficit [2] [3] [4].

Rice is yoshimitsu crop and has high light compensation point and saturation point. Within a certain range, photosynthesis increases with the strengthening sunshine, following by metabolic process is enhanced which referring to root water uptake, body water delivery and leaf stomata opening. It results to enhancing transpiration. Studies have shown that sunshine hours has a linear relationship to rice water requirement [1] [3].

Water vapor from field need help of water vapor gradient and wind swirling action to spread into atmosphere. Only when water vapor gradient exists, the evaporation can continued to proceed. Thus, wind speed has some certain influence on water vapor flow over rice field. In the case of no wind, air humidity over rice field is higher and the water vapor gradient is smaller. In the case of wind, lower air humidity and greater water vapor gradient. It shows wind speed makes the water vapor gradient increase. Besides, wind can make temperature gradient between leaf and air increase, resulting to rice water requirement increasing.

Among all of meteorological factors, the other ones except those above, such as rainfall, relative humidity and so on, affect rice water requirement too. Those influences are less, but their processes are compacted. Because rice water requirement is also a kind of evaporation, its nature is the same to natural water surface evaporation which is a basic data in meteorological monitoring [5]. Because of the linear relationship between rice water requirement and natural water surface evaporation, the function of natural water surface evaporation (E) can approximately describe the other meteorological factors' influences [6]. The function is followed: $f(E) = f_0 + f_5 E$

3. Mathematical model for rice water requirement

The current four variable linear equation for rice water requirement is written as follows [3]:

$$ET = f_0 + f_1 \Delta e + f_2 T + f_3 u + f_4 h \tag{1}$$

where: f_0, f_1, f_2, f_3, f_4 are constant; ET is rice water requirement, mm; Δe saturation vapor pressure deficit, kPa; T temperature, °C; u wind speed, m·s^{-1}; h is sunshine hours, h.

Based on four variable linear equation, according to analysis above, introduced natural water surface evaporation factor, the five variable linear equation can be established as follows:

$$ET = f_0 + f_1 \Delta e + f_2 T + f_3 u + f_4 h + f_5 E \tag{2}$$

where: f_5 are constant; E natural water surface evaporation, mm.

Equation (1) and (2) can be solved by regression analysis method, according to local experiment data.

FAO recommended reference crop coefficient method to calculate crop water requirement, which is written as follows:

$$ET = k_c ET_0 \tag{3}$$

where: k_c is crop coefficient; ET_0 is reference crop evapotranspiration, mm·d^{-1}.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \tag{4}$$

where: R_n is net radiation at the crop surface, MJ·m^{-2}·d^{-1}; G is soil heat flux density, MJ·m^{-2}·d^{-1}; T_a is mean daily air temperature at 2 m height,°C; u is wind speed at at 2 m height, m·s^{-1}; e_s is saturation vapor pressure, kPa; e_a is actual vapor pressure, kPa; $e_s - e_a$ is saturation vapor pressure deficit, kPa; Δ is slope vapor pressure curve, kPa·°C^{-1}; γ is psychrometric constant, kPa·°C^{-1}.

4. Instance of applying rice water requirement model

According to rice irrigation experiment station, called Qingan, test data, it calculated the rice water requirement using FAO56 Penman-Monteith equation, four variable linear equation and five linear equation.

It used regression analysis to establish empirical multivariable linear equation suitable to experiment region. The empirical formulas is written as follows:

Table 1. multivariable linear equation with four variables

Mathematical model	
returning green stage	$ET = -0.038T + 0.338h + 0.142u + 0.440\Delta e - 0.56$
tillering stage	$ET = 0.190T + 0.262h + 0.097u - 1.104\Delta e - 1.901$
jointing-booting stage	$ET = 0.101T + 0.150h - 0.004u - 0.044\Delta e + 1.163$
heading to flowering stage	$ET = 0.104T + 0.103h - 0.010u + 0.646\Delta e + 0.232$
milky stage	$ET = 0.035T + 0.145h - 0.006u + 0.933\Delta e + 0.827$
ripe stage	$ET = 0.064T + 0.147h + 0.131u - 0.453\Delta e - 0.519$

Table 2. multivariable linear equation with five variables

Mathematical model	
returning green stage	$ET = -0.036T + 0.163E + 0.326h + 0.102u - 0.446\Delta e - 0.763$
tillering stage	$ET = 0.139T + 0.255E + 0.172h + 0.046u - 1.834\Delta e - 1.034$
jointing-booting stage	$ET = 0.074T + 0.135E + 0.126h + 0.019u - 0.548\Delta e + 1.460$
heading to flowering stage	$ET = 0.096T + 0.197E + 0.074h - 0.030u - 0.151\Delta e + 0.126$
milky stage	$ET = 0.110T - 0.730E + 0.275h + 0.085u + 4.17\Delta e - 0.308$
ripe stage	$ET = 0.069T - 0.140E + 0.181h + 0.182u + 0.063\Delta e - 0.684$

Using the empirical formulas and FAO56 Penman-Monteith formula, rice water requirement in this region can be calculated. According to the measured rice water requirement in a duration of 23 years at Qingan experiment station and the calculated rice water requirement, the calculating errors of rice water requirement ET can be got, which are listed in table 3 and table 4.

Table 3. Calculating errors of rice water requirement ET (to be continue)

year	returning green stage(%)			tillering stage(%)			jointing-booting stage(%)		
	①	②	③	①	②	③	①	②	③
1978	14.50	7.23	16.50	9.80	9.16	13.80	30.20	29.58	7.30
1979	10.50	15.51	5.30	5.70	4.78	23.10	3.60	2.00	14.80
1980	7.00	6.89	6.10	1.60	4.13	22.00	9.10	7.85	0.20
1982	14.60	14.82	22.20	12.50	12.52	4.40	0.40	1.19	0.90
1983	3.10	4.60	15.30	8.50	4.45	22.90	7.30	5.48	21.60
1984	11.00	12.49	12.50	28.70	29.31	11.60	7.20	6.68	23.20
1985	5.10	7.55	5.80	1.60	3.37	18.30	3.30	1.77	21.60
1986	14.70	12.57	27.40	1.10	0.33	8.80	2.30	1.27	17.40
1987	23.10	23.27	27.20	2.30	2.13	12.70	7.40	6.57	21.80
1988	16.20	17.01	15.40	3.60	1.93	16.70	10.30	10.32	27.30
1989	21.30	19.89	8.80	3.60	7.76	17.40	6.40	5.16	12.70
1990	10.50	13.73	4.70	8.50	10.03	28.50	9.60	9.92	26.00
1991	1.10	2.26	7.10	2.00	3.37	19.20	4.70	4.64	25.70
1992	34.00	33.45	15.00	5.20	4.27	16.00	11.10	12.02	28.00
1993	2.10	4.39	5.90	4.50	3.82	25.90	40.60	46.37	11.30
1994	18.00	21.19	15.20	4.40	3.52	14.20	0.90	0.90	18.30
1995	10.60	11.38	18.50	4.90	2.61	19.20	31.30	33.42	11.10
1996	21.00	24.15	22.80	1.50	5.46	19.30	9.30	9.30	28.10
1997	0.40	0.59	14.70	11.70	11.65	0.80	16.20	16.11	23.20
1998	9.40	14.72	10.50	0.70	0.07	17.90	5.90	6.63	17.80
1999	22.50	21.06	14.40	13.50	15.59	3.20	7.40	6.54	19.60
2000	10.50	1.72	15.20	25.60	26.30	24.10	22.00	23.03	11.20
2001	2.20	2.58	12.40	11.90	11.78	17.50	5.40	6.78	14.80
average	12.32	12.74	13.87	7.54	7.75	16.41	10.95	11.02	17.56

Note: ① the calculating errors by using five variable linear equation; ② the calculating errors by using four variable linear equation; ③ the calculating errors by using FAO56 Penman-Monteith equation.

The average years calculating errors by using five variable linear equation are shown in Table 7: returning green stage 12.3%, tillering stage 7.54%, jointing-booting stage 10.95%, heading to flowering stage 11.67%, milky stage 9.87%, ripe stage 11.08%. It shows the mathematical model of five variable linear equation is suitable for calculating rice water requirement and has a higher accuracy.

Compared with FAO56 Penman-Monteith equation, in the rice water requirement calculation in the duration of 23 years, the calculating accuracies of five variable linear equation are higher: in 16 years for returning green stage, 69.6%; in 18 years, for tillering stage, 78.3%; in 18 years, for jointing-booting stage, 78.3%; in 15 years, for heading to flowering stage, 65.2%; in 21 years for milky stage, 91.3%; in 18 years for ripe stage, 78.3%. On the average years errors, the accuracy of calculating errors by using five variable linear equation in every growth stage is higher than the ones by the calculating errors by using FAO56 Penman-Monteith equation. Similarly, the accuracy of calculating errors by using five variable linear equation is higher than the calculating errors by using four variable linear equation.

Thus, it can be seen that, compared with FAO56 Penman-Monteith equation and four variable linear equation, five variable linear equation ,with natural water surface evaporation factor, has more feasibility and higher accuracy.

Table 4. Calculating errors of rice water requirement *ET* (continuing)

year	heading to flowering stage(%)			milky stage(%)			ripe stage(%)		
	①	②	③	①	②	③	①	②	③
1978	17.20	19.39	24.80	4.20	26.25	13.60	17.30	18.92	4.90
1979	11.90	12.09	12.80	6.10	20.45	13.70	4.20	9.90	4.80
1980	1.40	2.16	2.20	9.40	7.72	18.20	10.70	16.62	4.60
1982	1.50	0.73	4.10	1.80	6.83	10.20	13.40	14.45	23.40
1983	7.20	5.51	6.80	7.30	5.95	20.20	9.60	10.46	20.50
1984	15.30	14.77	19.30	19.00	24.87	29.70	31.50	25.92	12.30
1985	1.00	1.32	16.80	15.10	4.54	21.10	9.60	11.14	28.20
1986	12.80	14.67	18.50	14.20	16.67	23.90	7.00	10.48	24.20
1987	0.40	0.66	18.30	15.90	3.59	22.40	0.70	1.54	26.40
1988	4.80	2.88	16.30	3.00	5.23	24.60	37.40	39.67	12.20
1989	8.90	8.32	0.10	5.10	6.20	17.90	10.30	8.90	20.30
1990	2.20	2.50	13.80	2.70	1.35	16.30	36.50	36.58	11.20
1991	0.30	0.10	7.30	13.50	25.89	14.00	11.70	9.90	25.60
1992	26.90	26.69	35.90	31.00	32.33	12.90	2.50	3.04	23.70
1993	8.50	9.04	18.10	3.30	1.70	20.70	6.70	6.84	27.10
1994	31.20	28.89	13.80	9.30	9.08	21.10	5.60	4.44	23.70
1995	23.20	24.51	14.10	5.90	1.05	18.10	4.00	0.45	23.20
1996	24.40	29.20	13.50	4.70	3.94	21.20	5.10	6.81	25.10
1997	23.40	25.56	14.10	20.30	25.87	13.50	11.40	9.12	27.00
1998	1.20	0.57	7.90	9.70	23.04	13.90	8.80	7.59	25.30
1999	4.60	3.82	12.30	10.30	8.36	23.50	6.30	3.31	20.20
2000	16.70	16.56	13.90	10.60	12.95	18.40	3.20	4.63	21.40
2001	23.30	22.16	13.50	4.50	7.08	22.40	1.30	0.03	18.40
average	11.67	11.83	13.83	9.87	12.22	18.76	11.08	11.34	19.73

Note: ① the calculating errors by using five variable linear equation; ② the calculating errors by using four variable linear equation; ③ the calculating errors by using FAO56 Penman-Monteith equation.

5. Conclusion

Through analysis above, it is showed that temperature, air saturation deficit, sunshine hours , wind speed and natural water surface evaporation are the greatest important factors for rice water requirement.

Based on analysis of meteorological factors, there are many linear mathematical model for rice water requirement, referring to single factor, double factors and multiple factors.

In multiple factors models, the natural water surface evaporation has not been introduced as a variable. In this paper, it was introduced and a five variable linear equation was established.

According to rice irrigation experiment station test data, two empirical multivariable linear equations suitable to experiment region were established. Compared with FAO56 Penman-Monteith and four variable linear equation, the five variable linear mathematical model has more feasibility and higher accuracy.

Acknowledgements

This paper are supported by the following funds: National Key Technology R & D Program, Grant No. 2009BADB3B04; Key Technology R & D Program of Heilongjiang Province of China, Grant No. GA09B105-1.

The program team leader is Prof. ZHANG Zhong-xue, much special thanks to him.

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