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Regulated Deficit Irrigation and Its Several Problems in Practical Use

Huanjie Cai · Shaozhong Kang

prof., College of Hydraulic and Architectural Engineering, Northwest Agriculture University, Yangling, Shaanxi, P.R. China 712100

Abstract □ Regulated Deficit Irrigation (RDI) is one of the most important measures for the water-saving and high yield of crops. RDI is based on the crop and water relations. The theories of RDI werr analyzed using the experiment data in Shaanxi and Gansu Province. There are several problems of RDI in practical use, which include: the uncertainty of crop-water relations, the proper growth stages and water deficit degree of RDI applied, and the requirements of RDI to irrigation system and irrigation techniques.

Keywords □ regulated deficit irrigation, water deficit, crop water relations

I. Introduction

Water shortage is a severely limiting factor affecting agricultural production in North China. However, the water use efficiency in agriculture is less than 40%. Poor management of irrigation water is one of the principal reason for the low water use efficiency (Smith, 1996). Proper water management would maximize the water use efficiency of irrigation crops.

The relationship between yield and crop water use has been investigated by many researchers (Al-kaisi et al, 1997). Information on the optimum time to apply limited amounts of water to obtain the maximum yield of high quality crops is essential for efficient use of irrigation water (Matsunake, 1992). When the same amount of water was applied at different growth stages, there was a significant difference in productive tillers (Sharma et al, 1990).

Deficit irrigation is widely used with different degrees of success. Under deficit irrigation, crops are deliberately allowed to sustain some water deficit and yield reduction (Ragab, 1995). Plant water deficits decrease leaf growth, leaf area, leaf net photosynthetic rate and translocation of assimmilates. Nevertheless, there are situations in which plant water deficits can increase yield, and/or water use efficiency (Turner, 1990). In a study with five sunflower cultivars, Rawson and Turner (1982) Showed that withholding water for the first 45 days until the pre-dawn leaf water potential decreased to -0.5Mpa resulted in the production of larger leaves in the upper canopy, and the seed yield was also increased in this cultivar when subjected to a early water deficit compared to the frequently irrigated plants. Plant water deficits do not necessarily reduce crop yields and that mild water deficits can in fact stimulate yields (Turner, 1990, 1997). Water stress is not always injurious. Although it reduces vegetative growth, it sometimes improves the quality of plant products (Kramer, 1983). Scheierling et al (1997) indicated that, given a certain number of irrigation, crop yields vary enormously depending on the timing of irrigation, and given the optimal timing of irrigation, the increase in crop yield from an additional irrigation event diminishes as the number of irrigation increases. This implies that the number of irrigation, and thus the amount of water applied, can be reduced over a certain range without impacting ET and crop yield significantly. In order to save irrigation water and increase water use efficiency, water-saving irrigation has been introduced to irrigation practice.

Regulated Deficit Irrigation (RDI), which is based on the crop-water relations to control the soil water status in different crop growth stages, is one of the most important measures for the water-saving and high yield of crops. RDI has both economic and ecological benefit, especially in the areas of water shortage or with high water use cost. The experiment data in North China were used to analyze the problems of RDI in practical use.

II. Theoretical Basis of Regulated Deficit Irrigation

1. The relationships between crop yield and water use

Many models were developed to describe the relationship between crop yield and water use (ET). The curvilinear relationship of total ET-grain yield was widely used. Because the effect of water deficits on crop yield varied with devel- opment stages, several models have been developed to relate crop yield and water use in different stages, and Jensens model has been most widely used. In the model, the water deficit sensitivity index (i) is used to describe the sensitivity of crop yield to water deficit in different stages. The studies showed that the index varied greatly with the sites and meteorological conditions. The water deficit sensitivity index for spring wheat obtained from the experiment data at Minqin County, Gansu Province in 1992 and 1993 were shown in Table 1. It was shown that i was different for 2 years, and the peak value may not be at the same stage. The possible reasons are the variation of meteorological factors and agricultural measures. Another main reason may be the errors in experiment. The treatments may be different and the degree of water deficit may be also different in different years. It will be difficult to use it to describe the relation between crop yield and water use accurately. In the model, it is assumed that the maximum yield is obtained at fully water supply for whole growing season. Because of the curvilinear relation of ET-grain yield, excess water supply may cause the reduction of crop yield,

Table 1. The sensitive index of crop water deficit (i) at different growth stages

Year	tillering	jointing	booting	earing	filling	maturity	Correlation coefficient
1992	-0.216	0.334	0.324	0.030	0.161	0.079	0.848
1993	0.088	0.006	0.208	0.143	0.027	0.046	0.961

which means that the maxi- mum water use is not necessarily the optimal water use. The negative values of i are same reasons as described.

Crop yield and water use relations established from experiment data varies with the environ- mental conditions, and it partly reflects the effect of water deficit on crop growth and yield. The relations do not consider the beneficial effect of mild water stress on crop yield. Therefore, in fact, the optimal irrigation schedule obtained from the relations are not optimal. It is only a optimal result at certain conditions.

2. The beneficial effect of water deficit on crop yield

Kobata (1992) showed that the final grain size of wheat subjected water shortage varied with the rate of development of water deficits. When the rate of the water deficit was rapid, the grain yield was reduced and grain size was smaller than when the water deficit was imposed more slowly by allowing the soil to dry in a humid atmosphere. In the high yield range, dry matter maybe more responsive to increase ET than grain yield. The irrigation during early GS2 (Floral initiation to pos-tanthesis beginning of grain growth) increase straw yields by 24% but had no effect on grain yield of wheat (Musik and Porter, 1990).

Table 2. Water use, grain yield and water use efficiency of winter wheat in different treatments at Changwu County, Shaanxi Province

Treatment	Water use in different growth stages (mm)						Grain Yield	WUE
	9/29/95-3/8/96	3/8-4/13	4/13-5/11	5/11/5/27	5/28/623	Total	$Kg \cdot hm^{-2}$	$kg \cdot hm^{-2} \cdot mm^{-1}$
1	32.7	10.5	32.4	45.5	39.5	160.6	2025.10	12.606
2	64.9	27.6	58.8	80.0	84.9	316.1	3575.18	11.309
3	81.4	46.1	103.8	110.4	129.5	471.1	4500.23	9.552
4	32.0	44.4	60.6	49.6	50.6	237.1	3375.17	14.233
5	56.8	8.2	38.8	77.1	94.9	275.7	3875.19	14.054
6	84.2	17.4	102.8	48.6	80.6	333.6	4575.23	13.713
7	36.9	33.2	96.7	75.8	120.4	362.9	4250.21	11.711
8	65.0	32.1	77.8	54.4	49.3	278.6	4075.20	14.629
9	96.7	4.8	74.9	119.9	83.5	379.9	3800.00	10.003
10	34.3	13.7	36.3	89.5	88.5	262.4	3175.16	12.103
11	70.3	30.2	107.7	115.3	55.6	379.1	4500.23	11.870
12	82.1	45.2	67.3	80.9	53.2	328.8	4225.21	12.852
13	80.6	6.6	54.7	118.4	81.7	341.9	4925.25	14.405
14	62.3	44.1	62.0	53.2	97.6	319.1	4025.20	12.613
15	32.7	26.6	67.0	48.2	79.1	253.5	3700.19	14.598

The experiment results of winter wheat at Changwu County, Shaanxi Province, were shown in table 2. Evapotranspiration was calculated using soil water content of 0~100cm depth. It showed that water use efficiency was the lowest in treatment 3 with well water conditions for entire growing season. The same grain yields were obtained from treatment 3 and 11, but there were big difference in the irrigation amount and WUE. It had 302mm of irrigation and 379mm of ET in treatment 11 compared with 406mm of irrigation and 471mm of ET, and WUE changed from 11.87 to 9.55 kg·hm-2·mm-1. The excessive water use may cause the deep percolation and soil evaporation during spring time when ground cover is small. The difference for these two treatments was maintaining a moderate soil water content during initial and development stage in treatment 11, a low water condition at the late part of growing season instead of well water condition for whole growing season in treatment 3. The high WUE and crop yield were obtained in treatmnt 13, which had maintained a low water content during the spring time (Figure 1) that would reduce the soil evaporation and stimulate the root growth. The soil water variation was shown in Figure 1 for three treatments with highest grain yield. It was shown that winter irrigation is necessary to gain high grain yield. The irrigation in spring may be delayed when winter irrigation was applied. Irrigation was delayed to May 11, 3 times of irrigation of 268mm was applied in treatment 13. The yield of treatment 13 was highest over all treatments. That means the mild water deficit at the beginning of jointing would be beneficial to grain yield of winter wheat.

III. Several Problems of Regulated Deficit Irrigation in practical Use

The effect of water deficit on crop yield and quality depends on the growth stages, degree and duration of water deficit. Because of the great difference of plant physiological characteristics, the growth stage and degree of regulated water deficit should be different for different crops.

1. The uncertainty of crop yield and water relations

If the relationships of crop yield and water use established using experiment data were the only one relation, the optimum irrigation schedule would be easily obtained from it

Table 3. Experiment results of cotton at Minqin County, Gansu Province in 1991

	Treatment Irrigation amount (mm)			Total irrigation amount (mm)	Yield of ginned cotton($Kg \cdot hm^{-2}$)*
	Bud	Beginning of boll forming	Middle of boll forming		
1		90		90	1222.5
2	75	90		165	1534.5
3	75		90	165	1297.5
4	75	90	75	240	1639.5

*: The yield of ginned cotton is the average of 3 replications.

using optimization models. In fact, the relationship is affected by may factors, such as meteorological conditions, irrigation methods and techniques, the treatments of irrigation experiment, soil types, agricultural measures, insect pest and plant diseases, etc. Therefore, these relations can not be use to determine the regulated deficit irrigation schedule. The schedule should be flexible, which should be regulated according to crop growth and soil water conditions.

2. The proper time of regulated deficit irrigation

The sensitivity of crop to water deficit varies with growth stages. Turner (1990) showed that water deficit at early growth stage was beneficial to grain yield. The key of regulated deficit irrigation is to artificially impose water deficit at certain growth stages. For most crops, the plant is small, air temperature is low, and the intensity of water use is small at the early growing stage. That means that the development of water deficit is slow at early stage. Just as the result of Kobata (1992), slow rate of water deficit development would have little effect on crop yield. Therefore, the proper time of regulated deficit irrigation should be at the early growing stage. At the middle growing stage, because of the large canopy and active growth, the intensity of water use is high and the rate of water deficit development is fast. Water deficit would have great effect on crop yield. Regulated deficit irrigation can not be use at this period. The experiment result with cotton at Minqin County, Gansu Province in 1991, was shown in table 3. There were 4 treatments totally. The date of first irrigation was same at bud stage for treatment 2 and 3 with 2 times of irrigation during growing season. Second irrigation of treatment 3 was delayed to the middle of boll forming stages compared with treatment 2 at the beginning of boll forming. The yield of ginned cotton of treatment 3 reduced 18% compared with treatment 2. IT also showed that the yield of ginned cotton of treatment 3 was similar to treatment 1 with only 1 time of irrigation at the beginning of boll forming stage. The reason is that plant of early irrigation of treatment 3 had a bigger canopy and higher intensity of water use. When second irrigation was delayed, plant would suffer serious water stress, which made a lot of leaves fall that we had observed during experiment and affected the yield. The irrigation of treatment 1 was delayed and plant canopy was smaller. The plant was imposed mild water stress. After irrigation it would normally grow.

3. Allowable water deficit degree of regulated deficit irrigation

The allowable water deficit degree should be at a proper limit. It varies with different crops, different growth stages of crops and soil texture. Meyer and Gree (1980) suggested that when soil water content of 1m soil layer decreased to 50% of available soil water, winter wheat should be irrigated. The results (figure 1) showed that when soil water content decreased to 46% of field capacity, it had no bad effect on wheat yield. The studies at Minqin Conty, Gansu Province with spring

Table 4. The yield of spring wheat for different date of first irrigation at Minqin County

Year	The date of first irrigation	Days after sowing	Irrigation amount (mm)	Grain yield ($Kg \cdot hm^{-2}$)
1990	4/27	40	75	9208.5
	5/05	48	75	10000.5
	5/13	56	75	9501.0
1991	4/28	44	75	8136.0
	5/05	52	75	8356.5
	5/10	57	75	7588.5
1992	4/28	47	75	7672.5
	5/05	54	75	7867.5
	5/10	59	75	7375.5

wheat showed that the date of first irrigation had great effect on the yield. The soil water content of 0-60cm at the jointing stage may decrease to 45% of field capacity. If first irrigation was properly delayed, it would be beneficial to crop yield (Table 4). If the first irrigation was delayed from April 27 to May 5, the yield increased. But if it was delayed to May 10, the yield reduced.

4. The requirement of regulated deficit irrigation to irrigation system and techniques

In regulated deficit irrigation plant grows at water deficit condition. Good irrigation system is required to assure the application of regulated deficit irrigation, that is, irrigation water should be controlled and regulated in proper time and amount. Otherwise, the mild water deficit may develop to serious water tress, and cause great yield reduction. In order not to cause serious water stress at the part of irrigation area, a good irrigation technique and level land are needed to have high irrigation uniformity.

IV. Conclusions

Regulated deficit irrigation is based on the crop and water relations. Because of the small plant and low intensity of water use, the rate of water deficit development is slow at early stage. Regulated deficit irrigation should be applied at the early stage of growing season. The allowable water deficit degree varies with plant and growth stages. The experiment results of winter wheat at Changwu County showed that there was no bad effect on grain yield if the water content decreased to 46% of field capacity at jointing stage. For spring wheat at Minqin County, if first irrigation was delayed properly, it was beneficial to crop yield. Soil water content of 0-60 cm soil layer may decrease to 45% of soil capacity before first irrigation. At the same time, good irrigation system and techniques are required to assure crops not to suffer serious water stress when regulated deficit irrigation was applied.

Water shortage is a main limiting factor for agricultural production in arid and semiarid areas of China. The application of regulated deficit irrigation can increase crop yield and water use efficiency. The proper time and allowable water deficit degree should be further studied before it is widely used, because the mild water deficit that is beneficial to crop growth will quickly develop to serious water stress in the field.

References

1. Al-kaisi, M.M., A. Berrada and M. Stack, 1997, Evaluation of irrigation scheduling pro- gram and spring wheat yield response in Southwestern Colorado, Agricultural Water Management, 34:137-148.
2. Kobata T., J.A. Palta, and N.C. Turner, 1992, Rate of development of postanthesis water deficits and grain filling of spring wheat, Crop Science, 32(5):1238-1242.
3. Kramer, P.J., 1983. Water Relations of Plants, Academic Press.
4. Liang, Y., H. Cai, S. Kang, X. Hu, 1998, The response and adjustment of crops to soil water stress on Loess Platuea, In "Kang, S., Liang, Y., Cai, H (editors), Water-soil-crop relation and its optimum regulation in arid and semiarid areas", China Agriculture Press, Beijing: 37-66.
5. Matsunaka, 1992, Optimum irrigation period for production in spring wheat, Soil Sci. Plant Nutri., 38(2):269-279.
6. Meyer, W.S., Gree, G.C.,1980, Water use by wheat and plant indicators of available soil water, Agron. J.,72:253-256.
7. Musik, J.T., K.B. Porter, 1990, Wheat, In "B.A. Steward and D.R. Nielson (Editors), Irrigation of Agricultual Crops, American Society of Agronomy, Inc, Crop Science Society of America, Inc., Soil Science Society of America, Inc", 597-638.
8. Ragab, R., 1996, Constraints an applicability of irrigation scheduling under limited water resources, variable rainfall and saline conditions, in "Irrigation scheduling: From Theory to Practice", Proceedings ICID/FAO Workshop, Sept. 1995, Rome, Water Report, No.8, FAO, Rome, 149-165
9. Rawson, H.M. and Turner, N.C., 1982, Irrigation timing and relationship between leaf area and yield in sunflowers, Irrigation Science, 4:167-175.
10. Scheierling S.M., G.E. Gardon, R.A. Young, 1997, Impact of irrigation timing on simulated water-crop production functions, Irrigation Science, 18(1):23-31.
11. Sharma, D.K., A. Kumar, K.N.Singh, 1990, Effect of irrigation scheduling on growth, yield and evapotranspiration of wheat in sodic soils, Agricultural Water Management, 18:267-276.
12. Smith, M., 1996, Summary report, conclusion and recommendations, in "Irrigation scheduling: From Theory to Practice", Proceedings ICID/FAO Workshop, Sept. 1995, Rome, Water Report, No.8, FAO, Rome, 1-18
13. Turner, N.C., 1990, Plant wter relations and irrigation management, Agric. Water Manage., 17:59-73.
14. Turner, N.C., 1997, Further progress in crop water relations, Advances in Agronomy, 58: 293-338.