Conference Paper

Specificity of Grain Maize Cultivation with Irrigation under Conditions of Forest Steppe of the Republic of Ingushetia

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Abstract

An important condition of rational usage of irrigation water is the determination and regulation of water consumption by grain maize at main growth phases providing maximum product yield per unit water supplied. The establishment of water consumption for growth periods will allow planning the irrigation regime and determining rates of water consumption and discharge. The research has shown that bioclimatic coefficients in all cases increase beginning with sprouting stage and maximize at the phase of paniculation, milky-wax ripeness, and then decreases again. The obtained data were used to calculate the bioclimatic coefficients of water consumption by grain maize using the interphase vegetation periods, from sprouts to ripening. Thus, the implemented calculation methods of total evaporation are local, and increased calculation accuracy requires determining them experimentally in specific climatic conditions.

Keywords: amelioration, irrigation rates, differential irrigation regime, critical phases, total water consumption

1. Introduction

The main limiting factor in steppe region farming is insufficient and nonstable water supply of agricultural crops during the vital phases of development. This factor appreciably determines the amount, quality and stability of harvest and necessity of irrigation ameliorations [1, 2, 4].

However, over the recent years, the area of irrigated land in Russia has considerably reduced (by 20--30 %), while the efficacy of their usage has dropped by more than 50 %. The yield of irrigated lands decreased 1.5--3 times, the technical condition of irrigation system, provision by irrigation equipment, tools for controlling irrigation and water counting have deteriorated; the irrigation land cultivation culture has unacceptably decreased in general [4, 7].

The Republic of Ingushetia is no exception. Fertile lands in combination with optimal heat climatic resources provide favorable conditions for high yield of grain crops, vegetables and industrial crops. The only inhibitor is naturally insufficient watering of the area [4, 8]. In such conditions, only irrigation can rejuvenate the deficit of water balance and increase the productivity of the land. Irrigation allows introducing to the cultivated land of moisture-loving crops that increase the yield and facilitate harvest quality. One of such crops, responsible to irrigation and capable of solving the problem of concentrated food production, is grain maize. Thus, we were to study the biological peculiarities of growth and development of maize under irrigation. The development of its cultivation technologies will unveil the main directions to increased productivity of these crops and augmented efficiency of the irrigated land.

2. Research Goal

To investigate the specificities of grain maize cultivation under conditions of irrigation for the farms of the AIC in the Republic of Ingushetia.

3. Research Tasks

1. To develop a technology for grain maize cultivation on irrigated lands of forest steppes in the Republic of Ingushetia.

2. To develop optimal regimes of maize irrigation, to determine daily expenditure and total water consumption depending on the demanded soil moisture.

3. To study the peculiarities of growth and development of maize plants at different water supply levels.

4. To identify the productivity of maize depending on the cultivation regimes and irrigation regimes.

4. Experimental Scheme

To study the regimes of irrigation and water consumption by grain maize under conditions of the Republic of Ingushetia.

Variant 1. Irrigation after soil moisture drops to 80 % of SM.

Variant 2. Irrigation after soil moisture drops to 70 % of SM (reference).

Variant 3. Irrigation after soil moisture drops to 60 % of SM.

Variant 4. Maintenance of soil moisture at a level from 70 to 90 % of SM.

Variant 5. Maintenance of soil moisture at a level from 60 to 80 % of SM.

Variant 6. No irrigation.

For all variants, the calculated soil wetting layer amounted to 0.6 m. During development and justification of the irrigation regime and water consumption by grain maize for variants 4 and 5, the soil moisture was maintained between 70--90 % of SM and 60--80 % of SM, i.e. in calculation of irrigation rates, the soil moisture was below 100 % of SM, while for variant 4, from 70 to 90 % of SM, and for variant 5, from 60 to 80 % of SM. The irrigation rates for variants 1, 4 and 5 were equal to 400 m^3/ha, because the calculated soil moisture in all cases was increasing by 20 % of SM, i.e. from 80 to 100 % of SM for variant 1, from 70 to 90% of SM for variant 4 and from 60 to 80 % of SM for variant 5. The irrigation conditions were different for these variants.

The calculated irrigation rates for soil layer wetting of 0.6 m amount to: 402 m^3/ha for variant 1 at lower threshold 80 % of SM; 602 m^3/ha for variant 2 (reference) at 70 % of SM; and 800 m^3/ha for variant 3 at 60 % of SM.

The irrigation for all variants was carried out by DDA-100MA sprinkling machine. The experimental plots were 30 meters wide; the length was a factor of the irrigation machine span and equaled to 110 meters. The long side of the plots was traverse to the temporary irrigator. The total area of the plot was 3300 m^2, the accounting area was 200 m^2. The experiment had three replications.

5. Materials and Methods

The irrigation regime, methods of irrigation and fertilization of grain maize were studied by the techniques presented in the works of B.A. Dospekhov, methodological guidelines developed at R&D Institute of Feed named after V.R. Wiliams and other generally accepted methods for establishing and performing field experiments.

To obtain adequate results and objectively evaluate them, for all the variants the following observations and studies were carried out:

1. Phenological observations were made for all experiments. The following growth phases were noted: sprouting, 5th leaf, paniculation, panicle flowering, occurrence of corn silk, ripening (milky, wax, full).

2. The density of plants was determined at each plot in two places diagonally at 10 m^2 at different phases: full sprouting and harvesting.

3. The linear growth was accounted on dynamic platforms at 25 selected plants in two locations of the plot.

4. The dynamics of green mass development, dry matter accumulation and yield analysis were performed by the method of R&D Institute of Feed.

5. The development of maize root system was observed by triple replication. The root mass was determined in one-meter layer by the method of N.Z. Stankov [13]. The monolith sample area was 0.125 m^3 (70×18 cm). The evolution of the root system along the horizons was determined by dry digging.

6. The soil nutrient status was determined by sampling before fertilizing to determine the fertilizer dosage, during sowing, as per growth phases, and during harvesting in two soil layers: ploughed layer (0--30 cm), and subsurface soil (30--50 cm). The soil samples were used to determine the dry residue and its composition, nitrate nitrogen, easily hydrolyzed nitrogen, labile phosphorus by the method of Myachigin, exchange potassium by the method of Maslova.

7. Water-physical properties of soil (density, specific mass, porosity and lowest water capacity) were determined by the techniques presented in ameliorative soil science by V.S. Astapov.

8. The soil moisture was determined by the thermostatic weight method; the samples were taken each 7--10 days, as well as before and after irrigation and precipitation more than 5 mm every 10 cm up to the depth of one meter.

9. The irrigation rate was calculated by the equation of A.N. Kostyakov,

$$m = 100 * H * a * (B_{SM} - B_{H})$$

10. The water consumption of grain maize was determined by the method of water balance with due consideration of moist reserve in soil in the beginning and at the end of vegetation, irrigation rate and precipitation over the vegetation period by the following equation:

$$T + Э = W_0 + P + M - W$$

Besides, the total water consumption of maize was determined by the bioclimatic method.

11. The irrigation water during sprinkling was accounted by water meter WD-180 mounted on the DDA-100 MA machine.

12. The grain maize yield was accounted on the plot by Don-1500 combine with an extension for grain threshing with grain sampling of 2 kg to analyze its physical qualities and dockage. The grain moisture was reduced to 14 %.

13. The mathematical processing of maize grain yield was done by the dispersion method.

14. Economical efficacy of the agro-methods was determined by flow process charts, composition of expenses for production, harvesting and transportation of the product, and its sales value.

6. Results and Discussion

The optimization of irrigation regimes was aimed at the elaboration of such irrigation rate, moisture threshold and soil wetting depth, which would provide maximum specific yield at minimum water expenditure per unit product.

These problems were covered in a number of studies that determined an optimal regime of grain maize irrigation and investigated --- for different soil and climate zones --- the admissible preirrigation thresholds, soil wetting depth and various irrigation rates aimed at increased yield. However, the opinions of the researchers are very diverse.

Many authors have established [1, 2, 11] that the lower threshold of optimal soil moisture for grain maize lies within 65--85 % of SM and depends on specific soil and climate conditions of crop cultivation and its biological specificities.

Due to uneven water demand of different plants during the vegetation period, a number of researchers recommend implementing the differentiated regime of maize irrigation as per its development phases: the reduction of moisture down to 65--70 % of SM at the initial development period and maintaining it at least at 75--80 % of SM during its critical development phases (paniculation and milky ripening [2--4] and reduction of soil moisture down to 65--70 % of SM at the end of the vegetation period [1, 8].

It was also established that maize is most sensitive to water shortage during paniculation and water ripening. The daily water expenditure during this period was 50--70 m^3/ha [5, 6]. The shortage of water at the critical maize development period caused grain yield reduction by 50 %, while the only watering during the critical phase (paniculation) increased the maize grain yield from 32 to 82 dt/ha [9, 10, 14].

The analysis of the study results showed that in maize growing, the soil moisture in the layer where the main amount of roots is situated should not drop below 75--80 % of SM. The critical factor for high yield is creation of optimal water regime during the whole vegetation period, especially during critical water consumption period beginning 1--12 days before paniculation and lasting up to milky grain ripeness [10--12].

The irrigation rates and the number of maize watering operations depend on the soil density, wetted layer and irrigation threshold, mechanical soil composition, ground water depth, soil and air temperature, air speed, density of plants and other factors.

Thus, we established that during maize irrigation, depending on soil, climatic and other conditions, such parameters as the lower threshold of soil moisture, wetting depth, irrigation and sprinkling rate vary quite appreciably. That is why their values with due account for the biological peculiarities and development phases of maize can be established only by field studies in specific soil and climatic conditions.

On the irrigated lands the cultivation of grain maize has a number of specificities connected with morphobiological structure of maize plants and different demand for heat, feed, lighting and other factors for productivity formation.

In this connection, a particular importance has the selection of highly productive maize breeds and hybrids responsive to irrigation and investigation of their reaction for irrigation conditions during different phenological phases. It is important to learn the dynamics of linear growth, leaf surface, dry matter accumulation.

A major effect on formation and development of generative organs (flowers and seeds) is made by water availability of soil and air humidity. This is why that determination of necessary watering conditions and methods of regulation of generative organ formation are the basics for plant productivity enhancement.

An important condition of rational usage of irrigation water is the determination and regulation of water consumption by grain maize at main growth phases providing maximum product yield per unit water supplied. The establishment of water consumption for growth periods will allow planning the irrigation regime and determining norms of water consumption and discharge.

Our studies demonstrated that the largest specific fraction in total water consumption is 57--58 % from precipitation, 18--37 % from irrigation water and 6--22 % from soil water.

Despite the highest indicator of total water consumption for variant 1 (5470 m^3/ha), the water availability conditions were better as compared to other variants. It demonstrated the highest grain yield of 10.51 t/ha and the lowest water expenditure. The coefficient of water consumption of total water consumption amounted to 539 m^3/t (Table 1).

The deterioration of water availability reduces the total water consumption; however, the yield also drops, so the efficacy of water usage decreases. Indeed, the water expenditure for 1 ton of grain maize for variant 2 increases up to 580 m^3/t, while for

TABLE 1: Efficacy of irrigation water usage (averaged over 3 years).

Variants	Total water consumption [m^3/ha]	Grain yield [t/ha]	Coefficient of water consumption [m^3/t]	Coefficient of irrigation water usage *		
				Irrigation rate [m^3/ha]	Yield surplus [t/ha]	Coefficient [m^3/t]
1. 80 % of SM in layer of 0.6 m	5470	7.51	539	2000	3.30	31.7
2. 70 % of SM in layer of 0.6 m, (reference)	5387	6.28	580	1770	2. 07	349
3. 60 % of SM in layer of 0.6 m	4840	5.70	746	1290	1. 49	568
4. Maintenance of soil moisture at a level from 70 to 90 % of SM	5020	7.0	651	1470	2. 79	299
5. Maintenance of soil moisture at a level from 60 to 80 % of SM	4430	6.64	715	800	2. 43	404
6. No irrigation	3890	4.21	754	--	--	--

Note: * Relation of irrigation rate to yield surplus

variant 3 that is 746 m^3/t. For variant 4, where the soil moisture was maintained at 70--90 % of SM, the coefficient of water consumption increased up to 651 m^3/t. However, as compared to variant 1, the irrigation rate decreased by 530 m^3/ha from 2000 to 1470 m^3/ha, so for this variant the coefficient of irrigation water usage amounted to 299 m^3 per ton of yield surplus.

The efficacy of irrigation water usage on other irrigated variants declines, because the formation of 1 ton of yield surplus required: 317 m^3/t for reference variant, 349 m^3/t for variant 2, while for variant 3 it increased up to 568 m^3/t.

During the vegetation period in different growth and development phases, the total water consumption by maize changes and depends on water availability increasing from sprouting to paniculation and decreasing from milky-wax to full ripening of the grain.

The investigation has established that total water consumption and average daily water consumption by maize tends to increase with improvement of water availability. While for the variant with no irrigation, the total water expenditure over grain maize vegetation period amounted to 3890 m^3/ha, the irrigation of variant 1 consumes 5470 m^3/ha. The average daily water consumption changes from 37 to 43 m^3/ha.

Thus, under conditions of the Republic of Ingushetia, for optimal irrigation regime of grain maize (80% of SM in 0.6 layer for variant 1), the total water consumption amounts to 5470 m^3/ha, while the water consumption coefficient equals 539 m^3/t.

The largest average daily water consumption for variants 1--4 is observed during the period from 10 leaves to paniculation (57--60 m^3/ha a day); in the beginning and at the end of vegetation, the water consumption decreases 2 times and more.

Currently, the total evaporation is mainly determined by three methods: method of water balance, methods based on determination of water steam streams in atmosphere, including the method of energy consumption measurement for evaporation, so called method of heat balance and calculation methods of evaporation determination.

We determined the evaporation (water consumption) by four methods: method of water balance, method of S.M. Alpatyev, method of G.K. Lgov and method of D.A. Shtoyko [1, 11]. The reference method was method of water balance (Table 2).

Table 2: Total evaporation of maize established by experiment and calculations, variant 1, m^3/ha (average over 3 years).

Calculation method	Interphase vegetation periods				Over veget. period	Deviation from (K)	
	Sprouts -- 10 leaves	10 leaves -- paniculat-ion	Paniculation -- milky-wax ripening	Milky-wax -- full ripening		m^3/ha	[%]
Water balance (ref.)	784	1641	1963	612	5000	--25	0.4
Alpatyev	858	1837	1947	636	5278	--192	4
Lgov	851	1816	1732	420	4819	--651	12
Shtoyko	678	1422	1824	474	4398	--1072	19

The method of water balance is based on the control of water availability in soil, as well as incoming and outgoing part of the water balance.

The method of Alpatyev is based on the usage of biological evaporation coefficients and sum of average daily air moisture deficit values.

Table 2 shows that the average discrepancy in total evaporation indicators determined by the water balance method and calculated by the methods of Alpatyev and Lgov amounts to --192 and --651 m^3/ha, i.e. 4 and 12 %. This difference in the indicators of 0.5--1 % was noted from the phase of 10 leaves and it also increased from milky-wax ripening to full one up to 19 and 48 %, respectively. The largest difference of the calculated indicators of 19 % was noted decreasingly from the water balance method when using the method of Shtoyko.

According to Table 2, the method of Alpatyev can be recommended for industrial use as the most accurate.

Taking into account, that none of the methods provided 100 % convergence with calculated figures, and the most justified methods are those based on implementation of biological evaporation curves, we assumed necessary to refine the bioclimatic coefficients for conditions of Ingushetia in connection with the sum of temperatures and soil moisture deficits.

The calculations used indicators of total evaporation by growth phases in soil layer of 1.0 meter for variant 1 and for resource-saving variant 4. With known sum of temperatures and air moisture deficit, we determined these coefficients by the growth phases.

The dependence of the bioclimatic coefficients on total water consumption were processed on a computer. As a results, regression equations were derived for variants 1 and 4 with reliable approximation coefficients.

The research has shown that bioclimatic coefficients in all cases raise beginning with sprouts and maximize at the phase of paniculation, milky-wax ripeness, and then decreases again. The obtained data were used to calculate the bioclimatic coefficients of water consumption by grain maize using the interphase vegetation periods, from sprouts to ripening.

Thus, the implemented calculation methods of total evaporation are local, and increased calculation accuracy requires determining them experimentally in specific climatic conditions.

The considered methods at the initial and final development stages overestimate total maize evaporation, while at the stage of active vegetation, they underestimate it. In this connection, we have calculated the correction factors that allow correcting the total maize evaporation over the vegetation period.

The comparison of evaporation data obtained by the calculation method and measured by the method of water balance have demonstrated the best convergence of two methods: method of Alpatyev and method of Lgov.

The experimental data were used to refine the bioclimatic coefficient for calculating evaporation by the methods of S.M. Alpatyev calculated by the sum of temperatures and by the method of Lgov calculated by the sum of air moisture deficit values.

We have calculated the biological coefficients by interphase periods of maize vegetation and established that in the phases of active vegetation, the total maize evaporation even at optimal irrigation exceeds the evaporation from the water surface.

7. Conclusions

1. The main components of total water consumption are precipitation and irrigation rate.

2. The largest average daily water consumption for variants 1--4 is observed during the period from 10 leaves to paniculation (57--60 m^3/ha a day); in the beginning and at the end of vegetation, the water consumption decreases 2 times and more.

3. Statistically justified bioclomatic coefficients were obtained for grain maize which allow more accurately calculating and correcting the irrigation regime.

4. The most accurate calculation method for total evaporation determination and selection of the irrigation regime are methods of S.M. Alpatyev, implementing the obtained bioclimatic coefficients using the sum of average daily sir moisture deficit values, and that of Lgov, implementing the sum of cumulative average daily air temperatures beginning from the sprouting stage.

8. Conclusions

Under the conditions of irrigation in the forest steppe zone of the Republic of Ingushetia on maize areas, it is recommended to maintain the soil moisture in 0.6-meter layer close to 80 % of SM with the irrigation rate of 2000 m3/ha, which correspondingly provides the yield surplus of up to 4.3 t/ha.

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