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Mirko KNEŽEVIĆ, Natalija PEROVIĆ, Ljubomir ŽIVOTIĆ,
Mirjana IVANOV and Ana TOPALOVIĆ [1]

SIMULATION OF SILAGE-MAIZE WATER BALANCE WITH CROPWAT AND ISAREG MODELS

SUMMARY

This paper presents the results of water-balance simulations in silage-corn production in the area around Bijelo Polje. Silage-maize production was simulated with CropWat and ISAREG models over three years and on two soil types. The simulated results showed a the variation between the two models and measured the difference in yield. Crop evapotranspiration over the three seasons ranged between 339.3mm and 421.8 mm. Net irrigation requirements were higher by 30-70 mm in the simulations with the CropWat model. Water-use efficiency ranged from 7.44 kg/m^3 to 11.51 kg/m^3. The obtained results confirmed both models as good tools in silage-maize water balance and indicated that silage-maize yield could be improved under irrigation.

Keywords: silage maize, CropWat, ISAREG, water balance, water-use efficiency, NIR

INTRODUCTION

Silage maize is grown in the north of Montenegro, in the river valleys around the town of Bijelo Polje. The area around Bijelo Polje is well known for the production of good-quality beef and lamb meat. The mountainous landscape and cold climate do not favour other kinds of agricultural activity. Fodder and forage are both used as animal feed. Arable land in this area is mainly restricted to the River Lim valley. Increased amounts of animal feed are currently needed. In the north of Montenegro, there is the potential for an increase in fodder production. Almost all the areas where silage maize is grown are under rain-fed conditions, even where there is a lot of available groundwater. Water stress has an important effect on water consumption and yield of maize (Kiziloglu et al. 2009). The total water requirement of maize for a whole growing period is between 500mm and 800 mm (Brouwer and Heibloem 1986). A positive linear relationship between the yield and crop-water use (Gencoglan and Yazar 1999; Istanbulluoglu et al. 2002; Kirnak et al. 2003; Oktem et al. 2003; Cakir 2004; Dagdelen et al. 2006; Payero et al. 2006) has been found for both optimal and

[1] Mirko KNEŽEVIĆ, Ph.D. (corresponding author: mirkok@ac.me), Biotechnical faculty – Podgorica, University of Montenegro, 1, Mihaila Lalica, 81000 Podgorica;
Natalija PEROVIĆ, Ph.D., Ana TOPALOVIĆ, M.Sc., Biotechnical Faculty, Podgorica;
Mirjana IVANOV, B.Sc. Hydrometeorological Service of Montenegro;
Ljubomir ŽIVOTIĆ, M.Sc., Faculty of Agfriculture, University of Belgrade.

water-stress conditions. Doorenbos and Kassam (1979) calculated a relation between water applied and crop yield that may be practiced with a certain margin of error in conditions of both sufficient and deficient water resources."

The objectives of this research are: (1) to simulate water balance in silage-maize production in the years 2008, 2009 and 2010 using the CropWat and ISAREG models; (2) to compare the results of the simulations with measured results; and (3) to determine the net irrigation requirements (NIR) and water-use efficiency (WUE) of silage maize.

MATERIAL AND METHOD

Study area

Bijelo Polje is located in the north of Montenegro at 43° 01′ 27" North latitude and 19° 44′ 26" East longitude, at an elevation of 720 m above sea level. It is located in the River Lim valley, and it is the most important town in the north of Montenegro, and is an administrative, economical, cultural and educational centre.

Climate

The climate in Bijelo Polje is typical of a mountainous area. Average annual temperature is around 8.9 ^{0}C, while mean annual precipitation is around 920 mm. Average monthly temperatures higher than 10^{0}C are recorded in the period from May to September, which is the period of vegetation for crops in this area, excluding winter-sown crops. Average monthly weather parameters in the vegetation period of silage maize recorded by the Bijelo Polje meteo-station are presented in Tables 1−3.

Table 1: Average monthly weather parameters in the vegetation period of silage maize recorded by the Bijelo Polje meteo-station (2008−10)

Year	2008			2009			2010		
Month	T_{min} (^{0}C)	T_{max} (^{0}C)	RH (%)	T_{min} (^{0}C)	T_{max} (^{0}C)	RH (%)	T_{min} (^{0}C)	T_{max} (^{0}C)	RH (%)
Apr	5.2	17.4	67.2	5.6	20.5	64.6	5.9	17.3	75.8
May	8.4	23.3	67.5	9.8	24.8	70.0	8.7	21.7	73.2
Jun	13.0	27.4	69.9	12.3	25.3	77.3	13.1	24.8	77.6
Jul	13.9	28.6	68.8	14.4	29.2	70.4	15.4	28.0	77.6
Aug	13.6	30.1	68.0	15.3	29.7	70.5	14.1	30.3	74.0
Sep	9.7	21.6	76.4	11.8	24.5	75.5	10.2	23.3	78.3

RH - Mean relative humidity (%)
T_{min} – Average monthly minimal temperature (^{0}C)
T_{max}– Average monthly maximal temperature (^{0}C)

Table 2: Monthly precipitation (mm) and total precipitation in Bijelo Polje during the vegetation period of silage maize

Year/month	Apr	May	Jun	Jul	Aug	Sep	Total
2008	14.7	36.1	65.3	65.5	67.4	69.4	318.4
2009	26.8	60.0	117.5	51.8	23.8	39.8	319.7
2010	79.8	79.6	56.2	85.1	16.0	80.0	396.7

Table 3**:** Average monthly reference evapotranspiration (mm) in Bijelo Polje during the vegetation period of silage maize

Year/month	Apr	May	Jun	Jul	Aug	Sep
2008	2.86	4.28	4.87	4.87	4.50	2.58
2009	3.22	4.33	4.39	4.94	4.33	2.79
2010	2.67	3.79	4.27	4.54	4.52	2.68

Soil

Two different soil types on which silage maize is grown were used for the simulations: a) soil with medium total available water (130 mm/m) and b) soil with high total available water (180 mm/m).

Eutric Cambisol, known as *brown eutric soil* in the classification system of the former Yugoslavia, is a very fertile and deep soil. It is a moderately permeable soil and it has a high water-holding capacity of 150-200 mm per meter depth. In this study, this soil represents the most favourable production scenario and total available water adopted for the simulations in this study was 188 mm.

Dystric Cambisol refers to brown soil on gravel and conglomerate rock. It is a soil with low-to-medium water-holding capacity, higher in the top soil (the upper 30 cm), and significantly lower in the bottom soil. It is very shallow and shallow, up to 50 cm in depth, with a high gravel content (up to 50%). Total available water for this soil adopted for the simulations in this study was 130 mm.

Crop

Zea mays L. cv. Micado and cv. ZP-434 were used as crop material. The seeds were sown in the last decade of April with a 70 cm x 25 cm plant spacing. Before sowing, 30 t/ha of cow manure was applied annually. Winter and spring soil tillage occurred each year. Silage maize is grown on several different parcels around Bijelo Polje. In this analysis, there was an assumption that the average sowing date for these parcels was 20th April for each growing season, even though the sowing date may vary among different plots. In the same manner, the length of different vegetation stages was determined as the average value for all the particular plots. The date of harvesting is 5th September, and the total duration of the vegetation season was 139 days for all the growing years. These broad decisions were made because the measurement of final yield was determined as the difference between total measured yield from all the experimental plots and the total growing area. Regarding crop response to water, the crop coefficients adopted in this work are those found in the literature. K_c value for the initial stage was taken to be 0.3, mid-season K_c was 1.2, while late-season K_c was 0.35. Maximum rooting depth was set at 1.15 m, while the critical depletion fraction was 0.55 for the whole season. Crop response to water deficit was accounted for in the simulation by means of a yield-response function, which is set to be 1.2 for the whole season.

Water balance

Crop evapotranspiration is estimated on a monthly basis as a product of reference evapotranspiration (ET_o) and crop coefficient K_c:

$$ET_c = K_c ET_o \tag{1}$$

Irrigation requirements were estimated by applying the soil water balance. NIR have been calculated by the following equation:

$$NIR = ET_c - P_{eff} \tag{2}$$

Where: P_{eff} is the effective precipitation (mm), i.e. the amount of precipitation effectively used by the crop, excluding the runoff and deep-percolation losses. The US Department of Agriculture (USDA) Soil Conservation Service empirical method (USDA, 1967) has been applied for the estimation of effective precipitation in the use of both CropWat and ISAREG.

WUE (kg/m^3) was calculated by dividing fresh biomass yield (kg/ha) by evapotranspiration (mm) (Howell et al. 1990; Scott 2000).

Models

The CropWat decision-support tool was developed by the Land and Water Development Division of FAO. This computer software calculates crop water requirements and irrigation requirements on the basis of climate, soil, crop and management-input parameters. The calculation procedures used in the software are explained in FAO 56 Irrigation and drainage paper (Allen et al. 1998) and FAO 33 Irrigation and drainage paper (Doorenbos and Kassam 1979). CropWat runs simulations on daily, ten-day and monthly time steps. CropWat is a user-friendly model and offers various user-defined options for water supply and irrigation management. The output of the simulations are reference evapotranspiration (could be also input), crop water requirements under various management conditions defined by the user (i.e. full irrigation- optimum, deficit-irrigation practices, or rain-fed), NIR and relative crop yield obtained in respect of the water deficit that the crops suffer.

Simulation model ISAREG (Teixeira and Pereira 1992; Liu et al. 1998; Pereira et al. 2003) has been validated and is used in several regions and for various crops to develop improved irrigation-scheduling practices, leading to more efficient water use and water saving, and to predict the impact of water stress on yields (Teixeira et al. 1995; Liu et al. 1998; Alba et al. 2003; Zairi et al. 2003; Cancela et al. 2006; Popova and Perreira 2008). This model is based on the water-balance approach developed by Doorenbos and Pruitt (1977) and updated by Allen et al. (1998), and therefore includes the assessment of the impact of salinity on yield and parametric functions to estimate the capillary rise and percolation through the bottom boundary of the soil-root zone (Liu et al. 2006). The soil-water balance simulation with ISAREG requires weather data on reference evapotranspiration and rainfall, soil data on soil depth, field capacity and wilting point for each horizon, and crop data related to sowing and length of growing stages, crop coefficients, root depth, depletion fractions and response of crop to water deficit. The effect of water stress on yield is based on Stewart's one-phase model when the yield response factor K_y is known (Stewart et al. 1977; Doorenbos and Kassam 1979). This model offers many different irrigation-scheduling options, aiming at yield maximization under optimal or water-scarcity conditions or simply run under rain-fed conditions.

As some of the weather variables required to estimate ET_o are missing for Bijelo Polje, daily reference evapotranspiration was estimated by modified Penman-Monteith method (Allen et al. 1998) and it is an input parameter for both models. All the simulations in this study were run on a daily time step.

RESULTS AND DISCUSSION

Results of maize-soil water balance for the years 2008, 2009 and 2010, with the CropWat and ISAREG models on soil with medium and high water-holding capacities are presented graphically in Charts 1−4.

Low-to-medium total available water

On the soil with medium-available water content (Chart No. 1 and Chart No. 2), there are some differences between the simulations of the two models. In 2008, soil depletion in the ISAREG model approached the lower limit of RAW on 34 DAS, while the crop enters stress at DAS=39, five days later. The same behaviour is seen in the years 2009 and 2010, where the ISAREG simulation is already below RAW during the initial crop stage and at the beginning of intensive growth, while the CropWat simulation enters stress conditions at DAS=55 and 56 in both years. In the 2008 season, the crop entered water stress 20 days earlier than in the other two seasons in the ISAREG simulation, while in the CropWat simulation the crop re-enters the RAW regime for the few days around DAS=60 and after it falls below RAW content. The shape of the depletion curve for the two models is very similar and the distinction is related to the initial crop stage. The CropWat model directly calculates root-growth increase from the first day of vegetation, while the ISAREG model assumes that the first 20 days of vegetation will be without root growth.

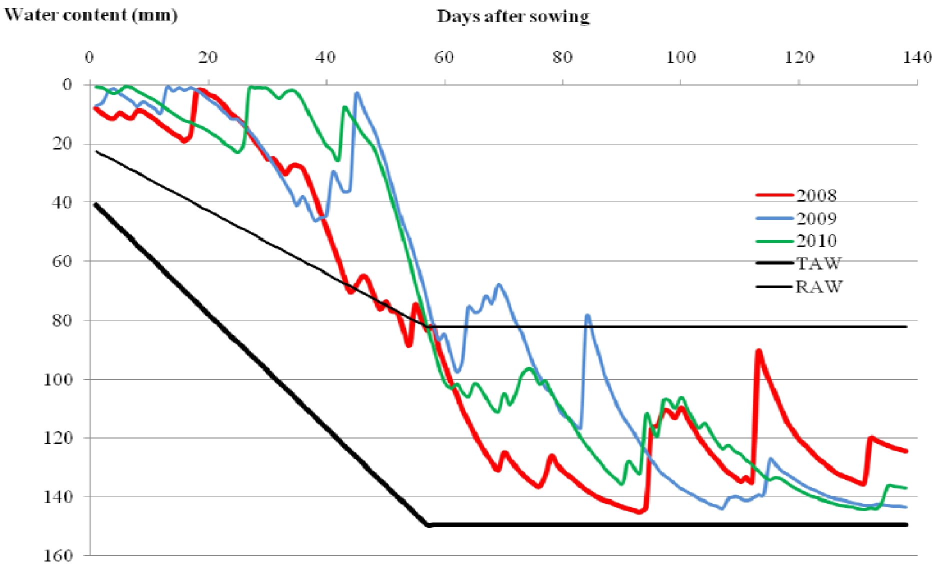

Chart 1: Water balance of silage maize simulated with the CropWat model for the 2008, 2009 and 2010 seasons on a soil with medium water-holding characteristics (TAW—total available water, RAW—readily available water)

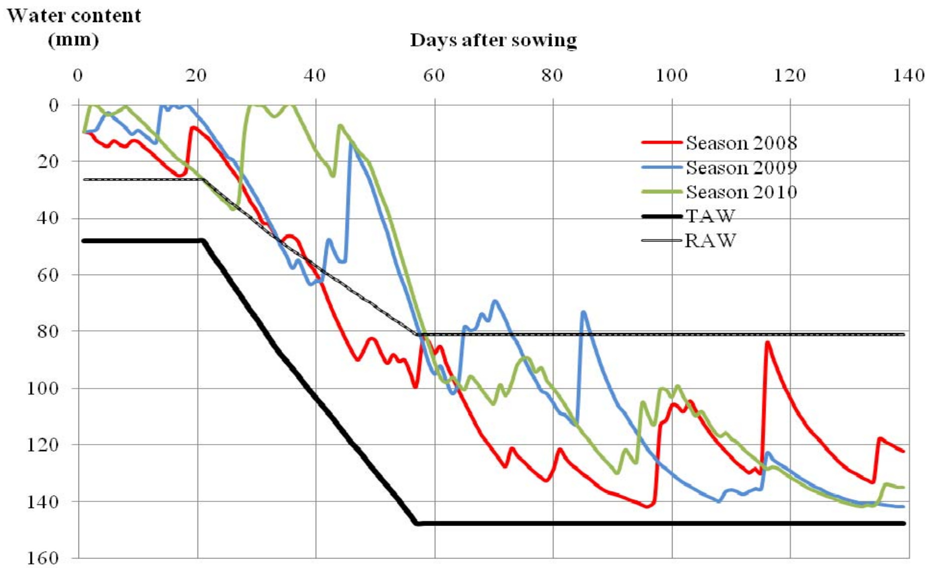

Chart 2: Water balance of silage maize simulated with the ISAREG model for the 2008, 2009 and 2010 seasons on a soil with medium water-holding characteristics (TAW—total available water, RAW—readily available water)

High total available water

On the soil with high total available water, both models behaved in a similar way in the soil with medium TAW (Charts 3−4). In 2008, the ISAREG simulation entered stress 20 days earlier than the CropWat simulation, while in 2009 the difference is around 15 days. In 2010 the CropWat simulation entered stress conditions a few days earlier than the ISAREG simulation. The main distinction between the models is related to the initial crop-growth stage. The CropWat model directly calculates root-growth increase from the first day of vegetation, while the ISAREG model assumes the first 20 days of vegetation will be without root growth.

Maximum crop evapotranspiration with the CropWat model was estimated in 2008 at 618.3 mm, while ET_m in 2009 and 2010 was 591.6 mm and 566.1 mm, respectively. Actual crop evapotranspiration (ET_a) was highest in 2009, 421.8 mm on soil with high TAW, while the lowest ET_a was estimated in 2008, on the soil with medium TAW, at 339.8 mm. The highest relative yield was in 2009, on soil with high TAW, at 65.6%, while the lowest relative yield was estimated to have come in 2008, at 45.9% on soil with medium TAW.

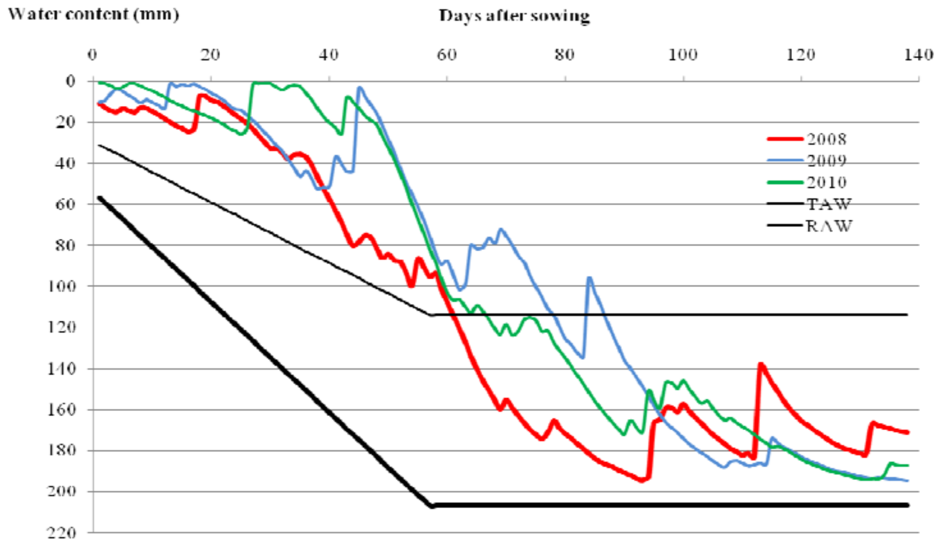

Chart 3: Water balance of silage maize simulated with the CropWat model for the 2008, 2009 and 2010 seasons on a soil with high water-holding characteristics (TAW—total available water, RAW—readily available water)

WUE varies significantly between years, without any strict relationship. It ranged from 7.44 kg/m^3 on soil with high TAW in 2009 to 11.51 kg/m^3 on soil with medium TAW in 2010. When compared with measured yield and maximum yield set at 65 t/ha, relative yield obtained after simulation differed from 1.2% to 15.5% in all three seasons, except for 2009, when, on soil with high TAW, it was estimated to be 35.8% higher. The results of actual crop ET in the Bijelo Polje region, obtained under rain-fed conditions, fit well with those obtained in other studies (Istanbulluoglu et al. 2002; Cakir 2004; Dagdelen et al. 2006; Gencoglan and Yazar 1999; Payero et al. 2006; Kiziloglu et al. 2009).

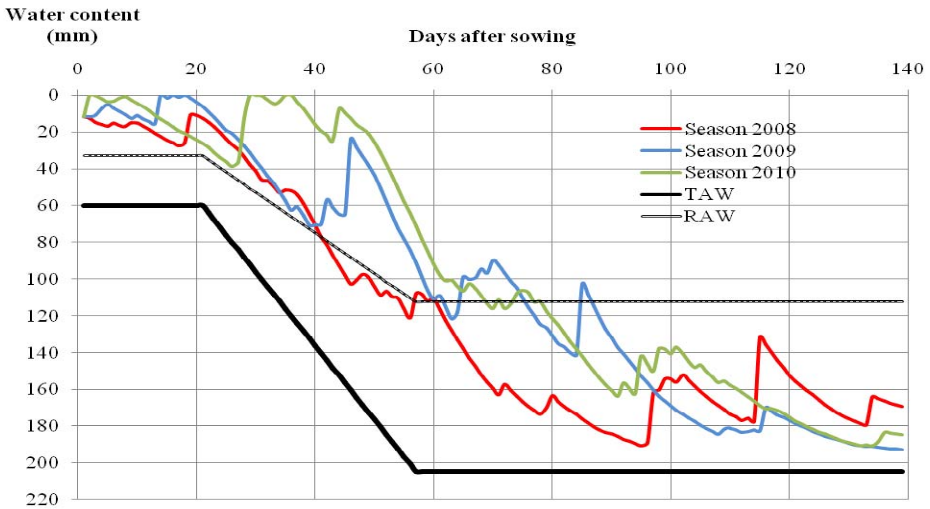

Chart 4: Water balance of silage maize simulated with the ISAREG model for the 2008, 2009 and 2010 seasons on a soil with high water-holding characteristics (TAW—total available water, RAW—readily available water)

Table 4: Crop maximum evapotranspiration (ET_m), actual evapotranspiration (ET_a), relative yield, NIR and WUE on soils with medium and high TAW obtained with the CropWat model

Year	2008		2009		2010	
Soil	medium	high	medium	high	medium	high
ET_m (mm)	618.3	618.3	591.6	591.6	566.1	566.1
ET_a (mm)	339.8	375	373.7	421.8	344	394.3
Relative yield (%)	45.9	52.7	55.8	65.6	52.9	63.6
NIR (mm)	342	304	300	274	281	252
Maximum yield (t/ha)	65					
Measured yield (t/ha)	30.2	30.2	31.4	31.4	39.6	39.6
Simulated yield (t/ha)	29.8	34.3	36.3	42.6	34.4	41.3
WUE (kg/m^3)	8.89	8.05	8.40	7.44	11.51	10.04

Maximum crop evapotranspiration with the ISAREG model was estimated to be 626.7 mm in 2008, while ET_m in 2009 and 2010 was 604.9 mm and 577.6

mm, respectively. The estimated values are for around 10-15 mm higher than those found in simulations with CropWat. Actual crop evapotranspiration (ET_a) was highest in 2009, at 420.7 mm on soil with high TAW, while the lowest ET_a was estimated in the year 2008, at 339.3 mm on the soil with medium TAW. These ET_a values are very similar to those obtained with CropWat. The highest relative yield was estimated to be in 2010, at 66.4% on soil with high TAW, while the lowest relative yield was estimated to be in 2008, at 45.0% on soil with medium TAW.

WUE varied greatly across the years, without any strict relationship. It ranged from 7.46 kg/m^3 on soil with high TAW in the 2009, to 10.52 kg/m^3 on soil with medium TAW in 2010. WUE values in 2008 and 2009 were similar for both models on different soil types, while, in 2010, estimated WUE values were higher after simulations with ISAREG by 5−6%. Simulated yield expressed in absolute terms differed by 3.1 to 15.1% among years and soils, except in the case of 2009 for the soil with high TAW, where it was 31.4% higher than measured one.

Table 5: Maximum crop evapotranspiration (ET_m), actual evapotranspiration (ET_a), relative yield, NIR and WUE on soils with medium and high TAW obtained with the ISAREG model

Year	2008		2009		2010	
Soil	medium	high	medium	high	medium	high
ET_m (mm)	626.7	626.7	604.9	604.9	577.6	577.6
ET_a (mm)	339.3	374.3	381.1	420.7	366	416.1
Relative yield (%)	45.0	51.7	55.6	63.5	56	66.4
NIR (mm)	302	271	271	243	269	234
Maximum yield (t/ha)	65					
Measured yield (t/ha)	30.2	30.2	31.4	31.4	39.6	39.6
Simulated yield (t/ha)	29.3	33.6	36.1	41.3	36.4	43.2
WUE (kg/m^3)	8.90	8.07	8.24	7.46	10.82	9.52

Results presented in Tables 4 5 indicate that, in the 2008 and 2010 seasons, there was a small difference between measured and simulated yield. The greatest difference appeared in the 2009 season. The main cause for this differences in obtained results was the rainfall events that occurred from 29th May to 3rd June, with a total of 72.3 mm recorded (45 mm recorded on 3rd June), and on 12th July, when the rainfall of 42.9 mm was recorded. These strong rainfall events were very intensive and effective precipitation of these rainfalls was much lower than that calculated by the models.

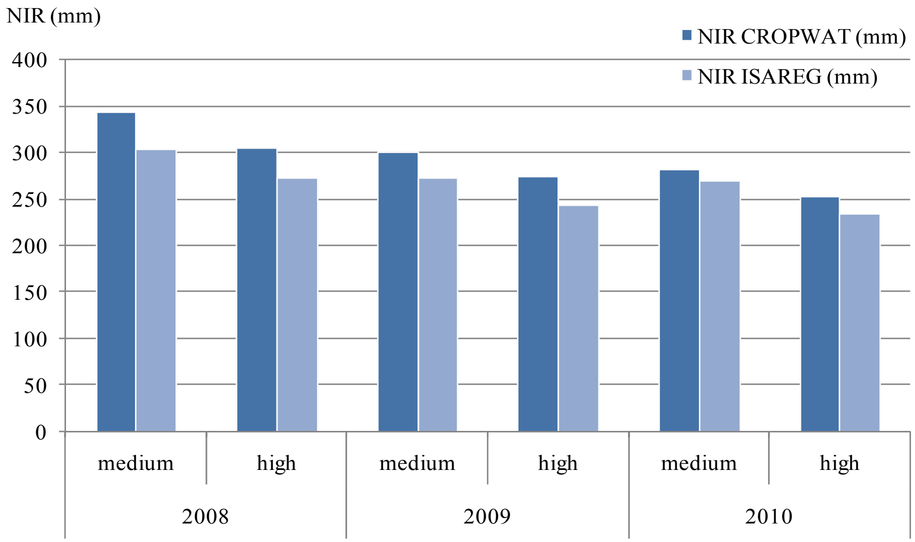

Chart 5: NIR in silage-maize production obtained after simulations with two models, in three consecutive years and on two soil types

In Chart No. 5 NIR obtained after simulations with the CropWat and ISAREG models are graphically presented. The overall conclusion is that ISAREG irrigation requirements are lower than those obtained after simulations with CropWat. The differences were 12 mm and 18 mm in 2010; 29 mm and 31 mm in 2009; and 33 mm and 40 mm in 2008, where the highest yield reduction occurred.

CONCLUSION

According to the results of this three-year study, silage-maize yield was decreased by water stress. The water balance of silage maize grown in the north of Montenegro was successfully simulated with the CropWat and ISAREG models. The obtained results have indicated the small difference among models related to the initial growth stage and root growth. The difference in crop evapotranspiration estimated with CropWat was very similar to those estimated with ISAREG. Except in the 2009 season, the relative yields obtained in the simulations were very close to measured yields. NIR obtained with CropWat were for only 18−40 mm higher than those obtained with ISAREG. Maximum silage-maize yield in the north of Montenegro could be obtained with 252−342 mm of irrigated water after simulation with CropWat, and with an estimated 234−302 mm of irrigated water with ISAREG, depending on the season. WUE in the North of Montenegro is within the range of values found in the literature (Kiziloglu et al. 2009). Modelling of water balance in silage-maize production should be used more in the future and determined more accurately in the Bijelo Polje area, in order to obtain better understandings of silage-maize potential in the region and to combat climate-change uncertainties.

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Mirko KNEŽEVIĆ, Natalija PEROVIĆ,
Mirjana IVANOV, Ljubomir ŽIVOTIĆ i Ana TOPALOVIĆ

PRORAČUN VODNOG BILANSA U PROIZVODNJI SILAŽNOG KUKURUZA SA CROPWAT I ISAREG MODELIMA

SAŽETAK

U ovom radu su prikazani rezultati proračuna vodnog bilansa zemljišta u proizvodnji silažnog kukuruza u okolini Bijelog Polja. Proizvodnja silažnog kukuruza je proračunata za tri godine i na dva tipa zemljišta sa CROPWAT i ISAREG modelom. Dobijeni rezultati ukazuju na razlike između dva modela i mjerenog prinosa. Evapotranspiracija kulture tokom tri sezone se kretala između 339.3 i 421.8 mm. Neto potrebe za vodom su za 30-70 mm veće u simulacijama sa CROPWAT modelom. Efikasnost korišćenja vode od strane biljke se kretala od 7.44 to 11.51 kg/m^3. Dobijeni rezultati su potvrdili da se oba modela mogu koristiti u praćenju vodnog bilansa u proizvodnji silažnog kukuruza i ukazuju da se prinos silažnog kukuruza može poboljšati korišćenjem navodnjavanja.

Ključne riječi: silažni kukuruz, CROPWAT, ISAREG, vodni bilans, efikasnost korišćenja vode, neto norme navodnjavanja