Pestic. Phytomed. (Belgrade), 29(1), 2014, 45–54
DOI: 10.2298/PIF1401045S

UDC 631.582+631.5:581.1:633.15
Original scientific paper

Effects of different cropping systems and weed management methods on free energy and content of pigments in maize

Igor Spasojević[1], Vesna D. Dragičević[1*], Milena Simić[1], Dušan Kovačević[2] and Milan Brankov[1]

[1] Maize Research Institute "Zemun Polje", Slobodana Bajića 1, 11185 Zemun Polje
[2] University of Belgrade, Faculty of Agriculture, Nemanjina 6, 11080 Zemun
**(vdragicevic@mrizp.rs)*

Received: November 15, 2013
Accepted: February 12, 2014

SUMMARY

Rotation is a cropping system that has many advantages and ensures better crop growth and yielding. Its combinination with other cropping measures can ensure optimal crop density for maximal growth and photosynthesis efficiency. The aim of this study was to investigate the influence of different cropping systems: monoculture and two rotations, including maize, wheat and soybean (MSW and MWS), and different weed management methods (weed removal by hoeing, application of a full recommended herbicide dose (RD) and half that dose (0.5 RD), and weedy check) on weed biomass and maize growth parameters - leaf area index (LAI), free energy, contents of chlorophyll and carotenoids, grain yield, and their possible relationships in two fields of the maize hybrids ZP 677 (H1) and ZP 606 (H2).

The lowest LAI and grain yield were found in monoculture, particularly in weedy check, which had relatively high weed infestation. Higher weed biomass was also observed in herbicide treated plots in monoculture. Such high competition pressure indicates a stress reflected on reduced LAI and chlorophyll content, and increased free energy and content of carotenoids. On the other hand, rotation, particularly if it is combined with the application of herbicides or hoeing, had a positive impact on yielding potential by increasing LAI and the contents of chlorophyll and carotenoids, and decreasing free energy.

Keywords: Maize; Cropping systems; Herbicides; Weeds; Energy;Chlorophylls; Carotenoids

INTRODUCTION

Maize monoculture is still present on large areas owing to the domination of maize in a general sowing structure. On the other hand, rotation is a cropping system that has many advantages, reflected in better crop growth and yielding. The most widespread rotational practice is a two-crop rotation (winter wheat-maize), while three-crop rotation (winter wheat-maize-soybean) is the next most frequent. It is well-known that maize rotation with other crops can decrease the number of pathogens, pests and weeds, maintain or increase soil fertility, enabling better conditions for maize growth and development, so that higher yields can be expected (Dolijanović et al., 2006; Stranger and Lauer, 2008; Riedell et al., 2009).

Parallel with rotation, combined application of other cropping measures (tillage, fertilization, sowing, cultivation, etc.) can provide optimal crop density for maximal growth and photosynthesis efficiency since continual application of the same measures in agricultural practice leads to disturbances in the agro-ecosystem. It would be unreal to expect that a single measure could have a satisfactory effect in weed control and lower potential weediness in a maize crop because a great number of weed species all have different life cycles and surviving types (Simić et al., 2013). Saudy (2013), for example, reported an increased maize grain yield, grain number ear^{-1} and leaf area index along with a reduction in weed dry weight of 90.5 by combining herbicide (metribuzin) treatment and hoeing. Moreover, the interdependence between yielding potential and growth parameters, such as leaf area, is emphasized. However, the relation between leaf area and an achieved grain yield depends on many factors, complicating to understand their interdependence (Milošev et al., 2008).

The complexity of interrelationships between measured plant parameters and yielding potential can be understood better by measuring some biochemical or thermodynamic parameters. Nemeny (2009) emphasized that stress in an agro-ecological system, the maximum energy input, can be calculated and quantified by thermodynamics. Plant systems transform solar energy mainly into chemical energy and then use it for a range of different reactions which ensure system stability, its growth and transition through different developmental phases. Sun (2002) recognized free energy input by water as a presumable plant growth factor. According to the Hess Law, free energy is cumulative, irrespective of its origin; hence, all the potential energy present in a plant system is given by the sum of individual energy states, which could be successfully used by the system in coupled reactions (Kadem and Caplan, 1965; Dragičević and Sredojević, 2011). It is also well-known that plants react to stress by alterating their chlorophyll and carotenoid contents. Mayfield and Taylor (1984) underlined a connection between a decrease in light harvest of maize plants and lower carotenoid content. Some other researchers, e.g. Bónis et al. (2006), have detected positive effects of some herbicides to chlorophyll synthesis, which may lead to an increase in maize yielding potential.

The objective of this study was to investigate the influence of different cropping systems: monoculture and two rotations, including maize, wheat and soybean, and different weed management methods (hoeing and two herbicide doses) on weed biomass and maize growth parameters – the leaf area index, free energy, contents of chlorophyll and carotenoids, and grain yield, as well as their possible relationships.

MATERIAL AND METHODS

An experiment was set up in the field of the Maize Research Institute at Zemun Polje in 2009 on a slightly calcareous chernozem type of soil under rain-fed conditions. After three years of experiment, which included fields with monoculture and two types of rotation: maize-soybean-wheat (MSW) and maize-wheat-soybean (MWS), the first comprehensive results of these cropping practices were obtained in 2012. The fields were ploughed to the depth of 30 cm every autumn before the sowing of any of the three crops. An amount of 30 t ha^{-1} of manure was applied to each field before the experiment, and to the rotation fields in the autumn of 2011. Two maize hybrids, ZP 677 (H1) and ZP 606 (H2), were sown in the fields with monoculture and rotation in the third decade of April at the density of 59.500 plants ha^{-1}. Mineral fertilization included monoammonium phosphate (150 kg ha^{-1}) incorporated every autumn, as well as side dressing at the stage of 5-6 leaves, based on soil analysis (available nutrients content).

All plots, monoculture and rotations, included sub-treatments with different weed management: hoeing (weeds were removed from entire subplots); weedy check (weeds stayed throughout vegetation); application of the herbicides *isoxaflutole* + *acetochlor (*750 + 768 g a.i.), which were used at the recommended dose (RD) and half of recommended dose (0.5RD). Each sub-treatment included four replications.

The level of weed infestation was evaluated 50 days after herbicide application by measuring fresh weed biomass m^{-2}. Maize leaf area, chlorophyll content and free energy were measured at the end of the anthesis phase by sampling three plants. Leaf area was determined using a LI – 3100 area meter (LI Cor, Lincoln, NE) and its relation with the soil area under plants represented the leaf area index (LAI). From the same leaves, chlorophyll content (chlorophyll *a* + *b*) and total carotenoids were determined spectrophotometrically after extraction with 70% acetone. Chlorophyll *a* was determined at λ=662 nm, chlorophyll *b* at λ=644 nm and carotenoids at λ=440 nm. The difference between dry (after drying at 130 °C) and fresh biomass referred to the contents of free, bulk and chemically bound water, which was used for calculation of thermodynamic parameters by using the sorption isotherm as suggested by Davies (1961) and Sun (2002):

$$\Delta G = RT \ln (a_w) \qquad [1]$$

where, a_w is the relative water content achieved after drying at T (130 °C); R is the gas constant (8.3145 J mol^{-1} K^{-1}); ΔG is differential free energy, which represents the amount of work that the system can perform. Its decrease signifies a domination of exergonic (spontaneous) processes which release free energy, and its increase signifies endergonic (nonspontaneous) processes which actually consume energy.

The maize grain yield was measured from two inner rows of each subplot and calculated to 14 % moisture. The experimental data of maize grain yield, LAI and weed biomass were statistically processed by the analysis of variance (ANOVA) and analysed by the LSD-test (5 %), while free energy, carotenoids and chlorophyll contents were presented with standard deviation (SD). Interdependences among maize grain yield, free energy, chlorophyll and carotenoid contents were processed by regression analysis.

Meteorological conditions

The highest average temperature in 2012 was reached in July and August (27.1 °C and 26.6 °C, respectively, Table 1). Moreover, the lowest precipitation amount of only 4 mm was recorded in August. Such conditions may have affected grain filling, and possibly also reflected on the relatively low grain yield.

RESULTS AND DISCUSSION

The obtained results showed significantly higher grain yield and LAI of H2 (17% and 12%, respectively) than H1 (Tables 2 and 3). H2 also had a significantly higher grain yield in MSW rotation and LAI in MWS rotation. Moreover, the interactions between hybrid and treatments exposed the lowest values of grain yield and LAI of both hybrids in weedy check.

Table 1. Average daily temperatures and precipitation sum during vegetative period of 2012

Month	IV	V	VI	VII	VIII	IX	Average/Sum
t (°C)	14.4	17.9	24.6	27.08	26.2	22.1	22.0
Precipitation (mm)	66.7	127.5	13.9	39.4	4.0	31.4	47.1

Table 2. Grain yield (t ha^{-1}) of two maize hybrids (H1 and H2) grown under different rotation systems and weed control treatments

	Monoculture	MSW rotation	MWS rotation	H1	H2	Average
Hoeing	5.19	5.93	5.95	5.18	6.19	5.69
Weedy check	2.46	3.64	3.68	2.88	3.64	3.26
½RD	4.89	6.06	5.72	5.22	5.90	5.56
RD	4.45	5.41	5.27	4.48	5.61	5.04
Average	4.25	5.26	5.15	4.44	5.33	4.89
H1	4.15	4.34	4.83			
H2	4.35	6.18	5.48			
LSD 0.05	Hybrid	Treatment	Rotation	H x T	H x R	T x R
	1.273	0.941	1.277	0.835	1.16	0.849

A general impact of the cropping system reflected only on LAI, which had two times higher values in MWS rotation. On the other hand, the interaction between cropping system and treatments emphasized a negative impact of monoculture with significantly lowest yield and LAI, which was particularly evident in weedy check. The influence of cropping systems on LAI had been also reported by Wozniak (2008). Such influence was reduced by the application of herbicides, increasing LAI in 0.5 RD and RD variants in monoculture up to the level observed in MSW rotation (Table 3). This is supported by the results of Malik et al. (2006) and Saudy (2013), who had also achieved better maize growth, higher LAI and grain yield under the positive influence of herbicides. The highest impact of rotation on LAI was observed in MWS rotation, and the highest values were recorded in the variants with 0.5 RD and hoeing, while hoeing mainly affected grain yield, increasing it significantly in monoculture and MWS rotation (Table 2). It is well-known that hoeing and application of herbicides can significantly increase maize grain yield (Khan et al., 2002; Saudy, 2013). Dolijanović et al. (2006) had reported the highest effect of a three-crop rotation (winter wheat-maize-soybean) on maize yield increase.

The mentioned lowest grain yield and LAI of both hybrids (Tables 2 and 3) were associated with the highest weed biomass in weedy check, where its values were about 2.5 times higher than the average values in both rotations (Table 4). From that aspect, weedy check was the only variant in which weed biomass (Table 4) significantly affected maize development and yielding potential, as reflected by grain yield and LAI decrease. Nakova et al. (2004) had similarly reported a significant suppression of maize LAI and grain yield under the negative effect of high weed infestation. Significant variations in weed biomass were also present under the interaction of cropping system and treatments, but the highest values were in monoculture (particularly weedy check). The lowest values of weed biomass were obtained in MSW rotation, mainly in the RD treatment, approaching the values in treatment with hoeing, where weeds were manually removed. Stoimenova et al. (2004) and Simić and Stefanović (2008) had also reported negative correlations between maize yield and weed biomass, depending on the level of competition.

According to the results shown in Figure 1, the lowest ΔG values of H1 were found in the monoculture

Table 3. Leaf area index (m^2 m^{-2}) of two maize hybrids (H1 and H2) grown under different rotation systems and weed control treatments

	Monoculture	MSW rotation	MWS rotation	H1	H2	Average
Hoeing	2.87	3.64	5.93	3.58	4.72	4.15
Weedy check	1.46	2.10	3.64	2.17	2.63	2.40
½ RD	3.43	3.70	6.06	3.90	4.89	4.40
RD	3.16	3.64	5.41	3.44	4.70	4.07
Average	2.73	3.27	5.26	3.27	4.24	3.75
H1	2.42	3.05	4.34			
H2	3.04	3.49	6.18			
LSD 0.05	Hybrid	Treatment	Rotation	H x T	H x R	T x R
	0.827	0.592	0.800	0.534	0.764	0.454

Table 4. Weed biomass (g m^{-2}) in experimental plots with two maize hybrids (H1 and H2) grown under different rotation systems and weed control treatments

	Monoculture	MSW rotation	MWS rotation	H1	H2	Average
Hoeing	-	-	-	-	-	-
Weedy check	4304	3475	2011	3200	3327	3263
½ RD	627	420	959	490	848	669
RD	480	161	672	420	456	438
Average	1804	1352	1214	1370	1544	1457
H1	1845	1243	1022			
H2	1763	1461	1406			
LSD 0.05	Hybrid	Treatment	Rotation	H x T	H x R	T x R
	1195	603.3	1202	608.9	1221	467.7

field, mainly in the hoeing treatment (21% in relation to weedy check). On the other hand, H2 had the lowest ΔG values in the treatment with hoeing in both rotational fields, mainly in MSW rotation (38% in relation to weedy check). It means that these two genotypes reacted differently to the cropping systems, with a domination of exergonic processes and energy releasing. Such energy can be released into the external environment or spent on some other processes, such as biosynthesis in coupled reactions (Kadem and Caplan, 1965; Dragičević and Sredojević, 2011). From that aspect,

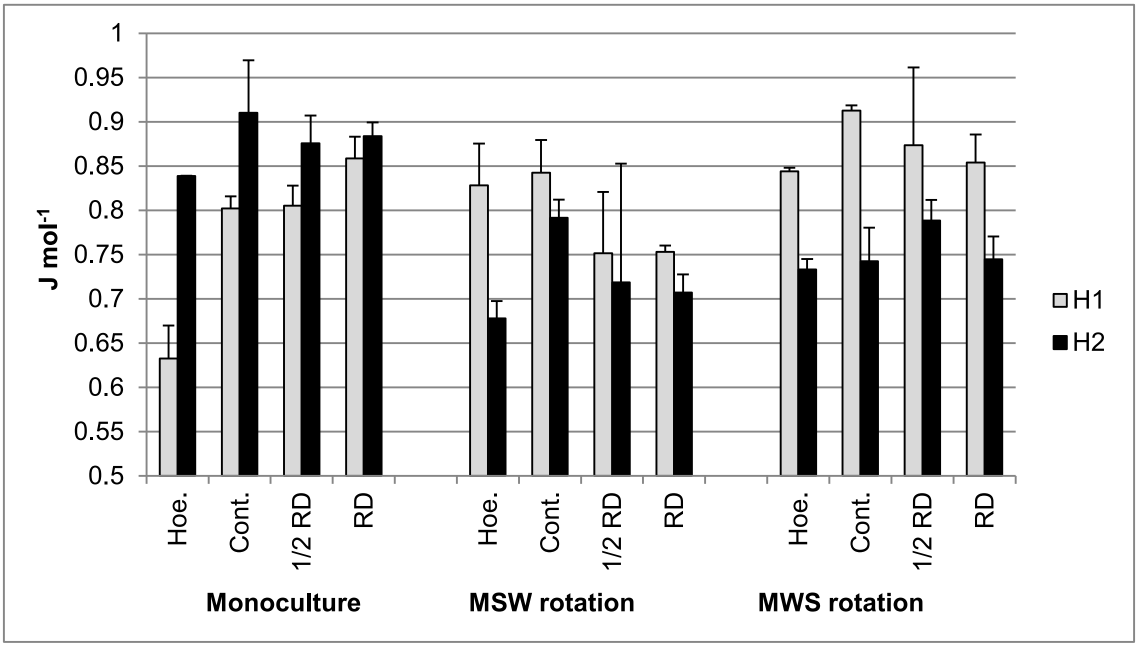

Figure 1. Free energy of two maize hybrids (H1 and H2) grown under different rotation systems and weed control treatments ± SD

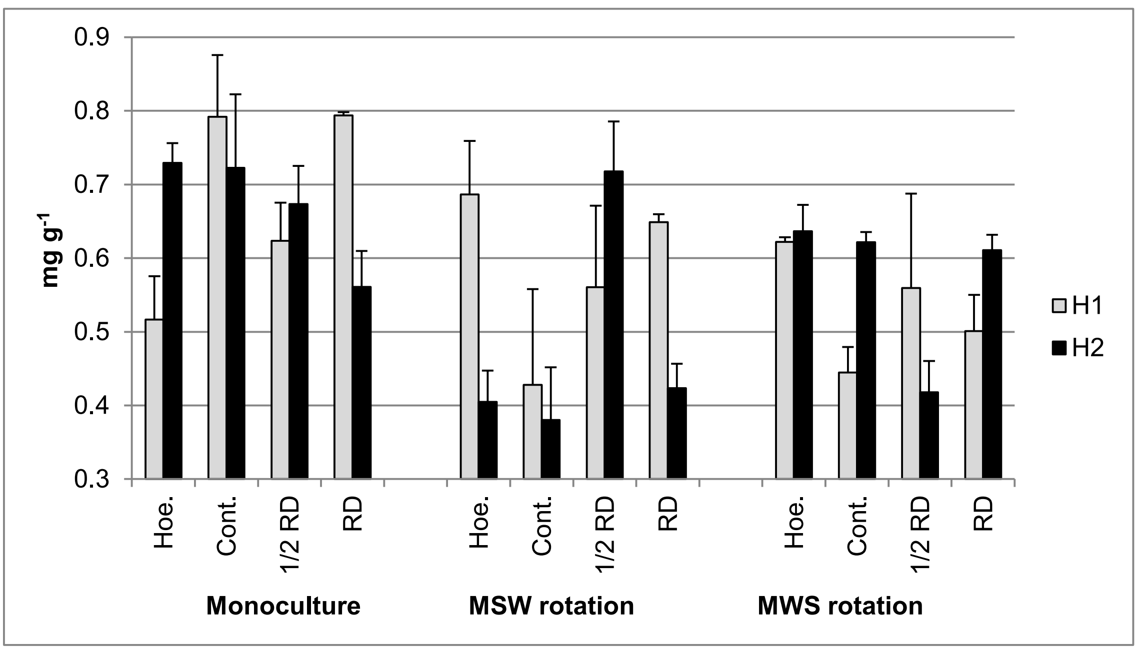

Figure 2. Content of carotenoids (mg g^{-1}) in leaves of two maize hybrids (H1 and H2) grown under different rotation systems and weed control treatments ± SD

the lowest ΔG values obtained in the variants with hoeing and RD in rotational fields (both hybrids) correspond with the highest values of grain yield (Table 2), which, coupled with the lower average ΔG obtained in MSW rotation, is an indication of system efficiency provided by treatments. This could also signify a domination of exergonic reactions (Sun, 2002; Dragičević and Sredojević, 2011), which are spontaneous. This energy release could contribute to an increase in growth/yielding potential of the system and is reflected in the negative interdependence between ΔG and grain yield in MSW and MWS rotations (R^2=0.860 and R^2=0.467, respectively, Figure 4). The variations in weed biomass that were influenced by cropping system have no significant impact on ΔG, except in MSW rotation (R^2=0.578, Figure 5).

Lower average contents of carotenoids and chlorophyll, together with their higher variations among hybrids and treatments, were detected in both rotation fields (Figures 2 and 3). In monoculture, the highest carotenoids (about 14%, compared to other treatments) and the lowest chlorophyll (about 11%, compared to other treatments) contents were recorded in weedy check, which could, together with the lowest values of the other parameters (LAI and grain yield) and relatively high ΔG, indicate a presence of stress caused by high weed infestation (Table 4). Such situation is supported by a negative and significant interdependence of grain yield and carotenoids (R^2=0.475; Figure 4), and by positive and significant interdependence between weed biomass and carotenoids (R^2=0.516; Figure 5) present in monoculture. This is important because lower content of carotenoids is associated with lower light harvest by maize plants (Mayfield and Taylor, 1984). Maize plants in the treatment with hoeing and both rotational fields had higher average carotenoids and chlorophyll contents (27% and 15% respectively) than in weedy check (Figures 2 and 3). The same trend was also observed in the variant 0.5 RD in MSW with the average values of up to 37% and 18% for carotenoids and chlorophyll. Bónis et al. (2006) had also reported an increase in chlorophyll content in maize leaves under the influence of herbicides. The impact of the tested cropping systems on maize growth and their interactions with weeds can be evaluated based on positive correlations of grain yield and chlorophyll and carotenoid contents in MWS rotation (R^2=0.360 and R^2=0.349, respectively, Figure 4) and significant negative correlations of weed biomass and chlorophyll and carotenoid contents in MSW rotation (R^2=0.438 and R^2=0.527, respectively, Figure 5). This situation supports a conclusion that only a combination of different measures can have an adequate weed control effect and bear the crop yielding potential in full (Simić et al., 2013).

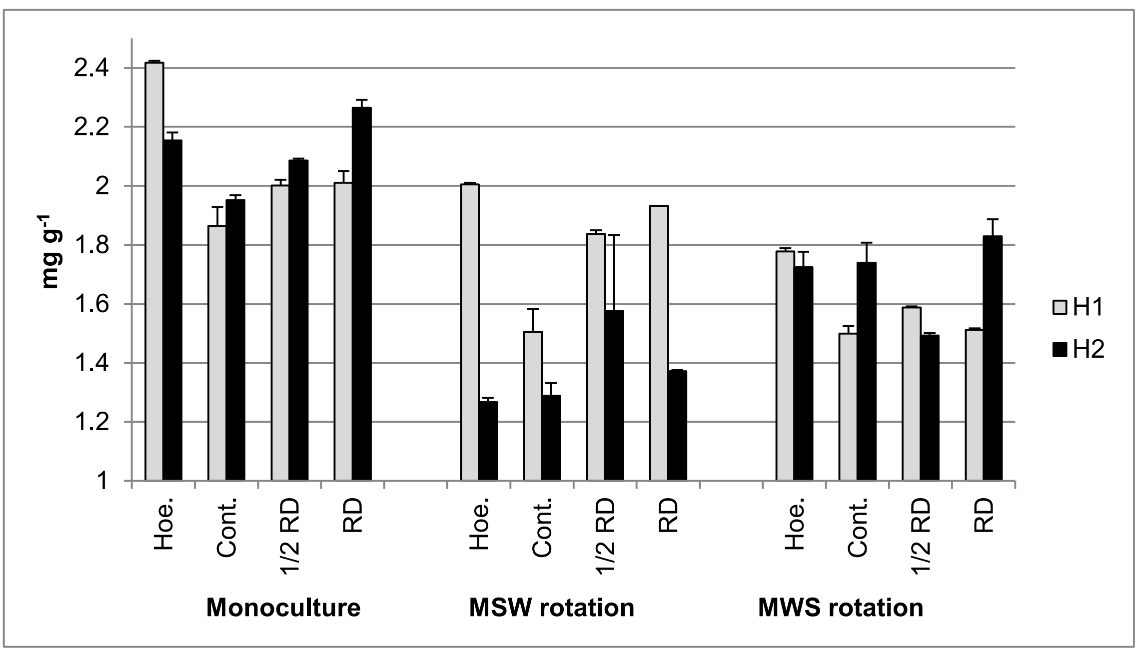

Figure 3. Chlorophyll content (mg g^{-1}) in leaves of two maize hybrids (H1 and H2) grown under different rotation systems and weed control treatments ± SD

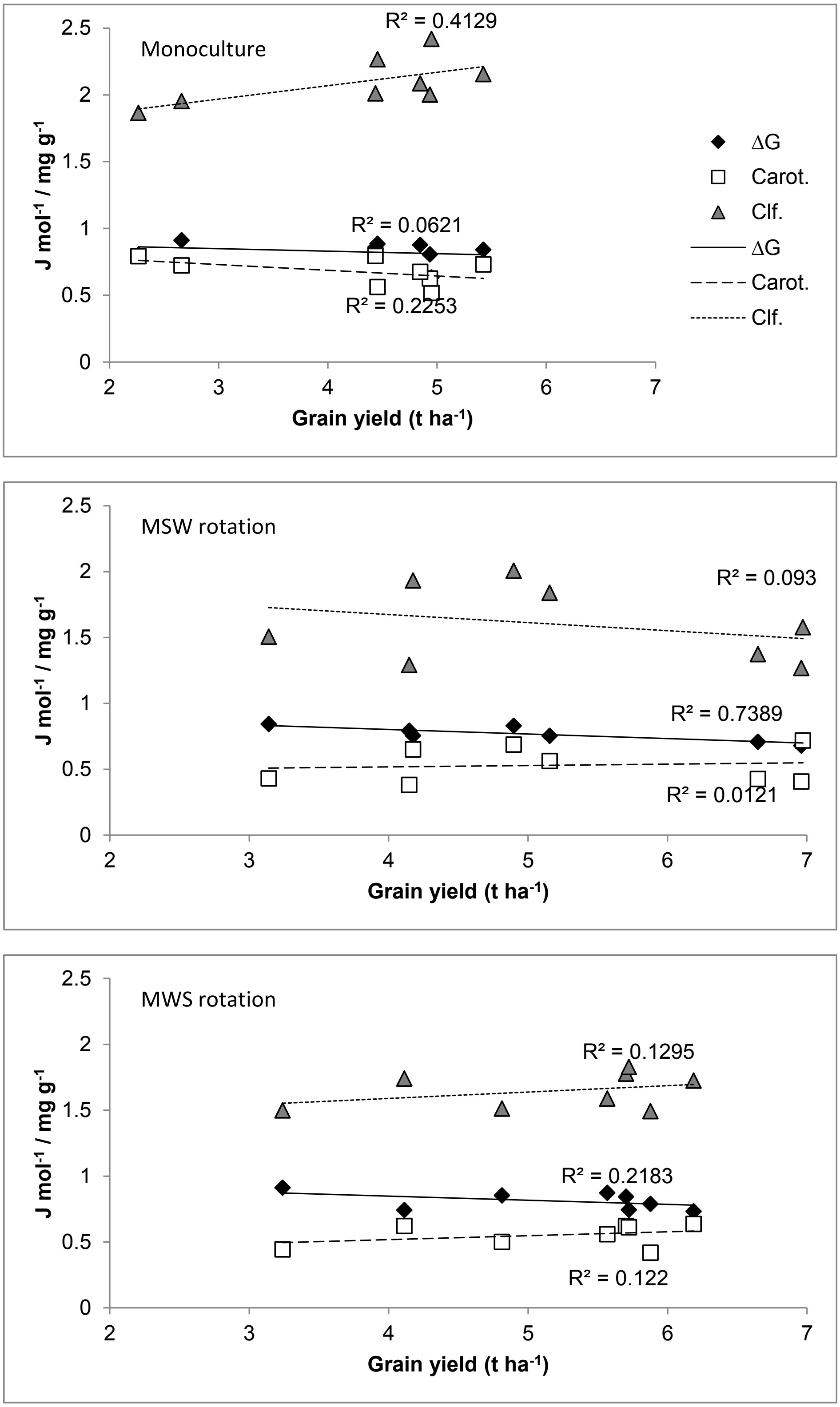

Figure 4. Interdependence between grain yield and free energy (ΔG), carotenoids and chlorphyll content in maize leaves under different rotation systems

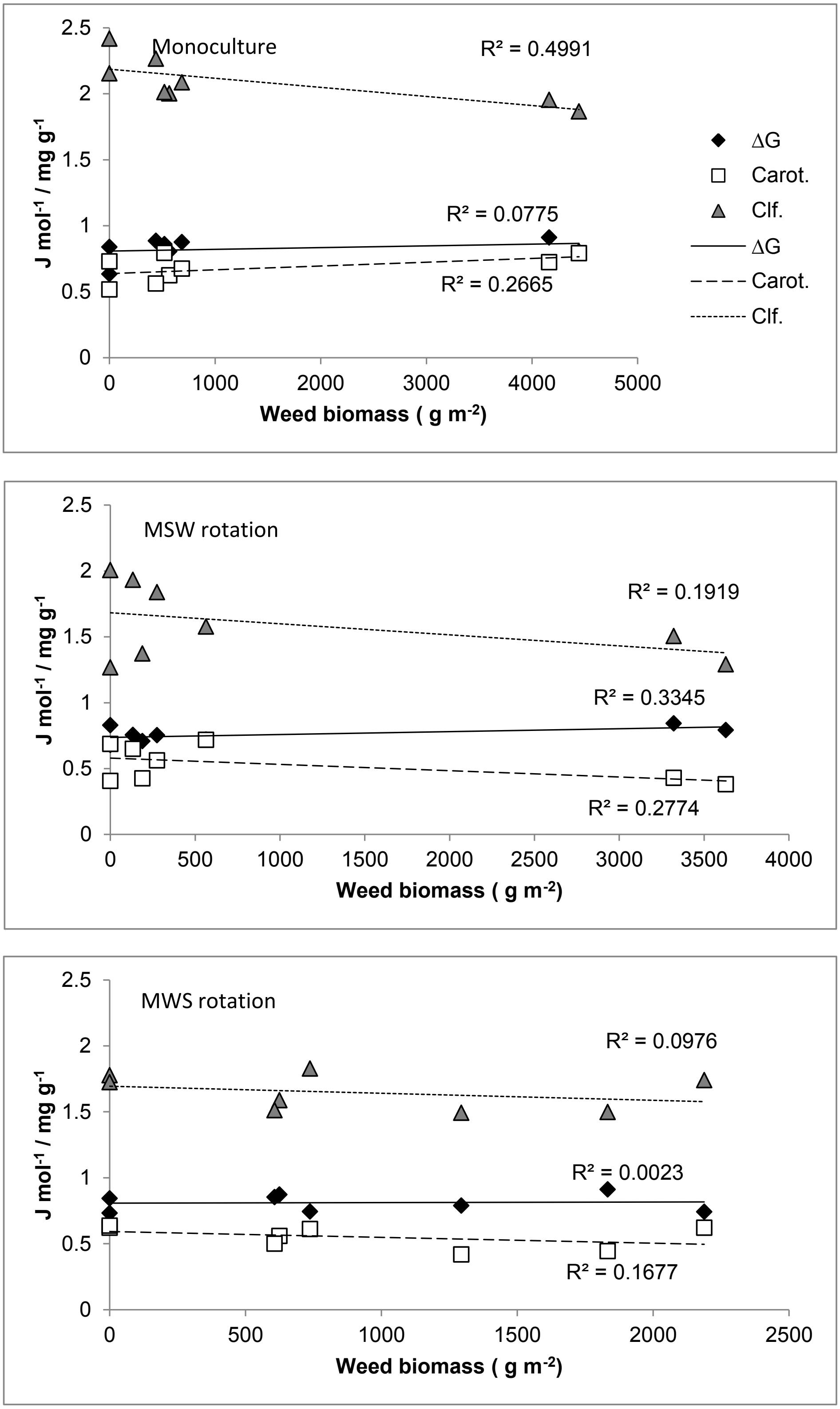

Figure 5. Interdependence between weed biomass and free energy (ΔG), carotenoids and chlorophyll content in maize leaves under different rotation systems

It can be inferred from the obtained results that the decrease in maize yielding potential in monoculture can be associated with relatively high weed infestation, and with stress reflecting on reduced LAI and chlorophyll content, and increased ΔG and carotenoids content. On the other hand, rotation, particularly if it is combined with herbicide treatment or hoeing, had a positive effect on the yielding potential by increasing LAI, ΔG, chlorophyll and carotenoids contents. Hoeing had an advantage as a treatment that had the highest impact on the measured parameters and grain yields but, considering also the labour involved in weed removal, the combination of RD and MSW rotation can also give satisfactory results, particularly if the increased energy potential (lower ΔG values) is also regarded.

ACKNOWLEDGMENT

This work was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia under the project TR-31037.

REFERENCES

Bónis, P., Árendás, T., Marton, C.L., & Berzsenyi, Z. (2006). Herbicide tolerance of Martonvásár maize genotypes. *Acta Agronomica Hungarica,* 54, 517-520.

Davies, D.D. (1961). Bioenergetics. In T.A. Bennet-Clark, P.B. Salt, C.H. Waddington, & V.B. Wigglesworth (Eds.), *Intermediary Metabolism in Plants, Cambridge Monographs in Experimental Biology 11*. (pp. 35-52). London, UK: Cambridge University Press.

Dolijanović, Ž., Kovačević, D., Oljača, S., Broćić, Z., & Simić, M. (2006). The yield grain of winter wheat and maize in continuous cropping, two- and three-crop rotation. *Journal of Scientific Agricultural Research,* 67, 81-90.

Dragičević, V., & Sredojević, S. (2011). Thermodynamics of Seed and Plant Growth. In J. Carlos Moreno Piraján (Ed.), *Thermodynamics - Systems in Equilibrium and Non-Equilibrium*. Rijeka, Croatia: INTECH, 1-20.

Khan, M.A., Marwat, K.B., Hassan, G., & Khan, N. (2002). Impact of weed management on maize (*Zea mays* L.) planted at night. *Pakistani Journal of Weed Science Research,* 8, 57-61.

Malik, A.M., Zahoor, F., Abbas, H.S., & Ansar, M. (2006). Comparative study of different herbicides for control of weeds in rainfed maize (*Zea mays* L.). *Weed Science Society of Pakistan Abstracts,* 62,

Mayfield, S.P., & Taylor, W.C. (1984). Carotenoid-deficient maize seedlings fail to accumulate light-harvesting chlorophyll a/b binding protein (LHCP) mRNA. *European Journal of Biochemistry,* 144(1), 79-84.

Milošev, D., Šeremešić, S., & Kurjački, I. (2008). Lisna površina i dinamika formiranja organske materije pšenice u zavisnosti od sistema ratarenja. *Zbornik radova, Institut za ratarstvo i povrtarstvo, Novi Sad,* 45(II), 207-213.

Nakova, R., Baeva, G., & Nikolov, P. (2004). Competition between maize and *Xanthium strumarium* L. *Pesticidi i fitomedicina,* 19(4), 257-263.

Neményi, M. (2009). Thermodynamic modelling of agroecological systems especially regarding stress in plant production. *Cereal Research Communications,* 37(Suppl 1), 529-532.

Riedell, W.E., Pikul, J.L., Jaradat, A.A., & Schumacher, T.E. (2009). Crop rotation and nitrogen input effects on soil fertility, maize mineral nutrition, yield, and seed composition. *Agronomy Journal,* 101(4), 870-879.

Saudy, H.S. (2013). Easily practicable packages for weed management in maize. *African Crop Science Journal,* 21(4), 291-301.

Simić, M., Dragičević, V., Srdić, J., Brankov, M., & Spasojević, I. (2013). Importance of IWMS for maize weed control. *Zbornik naučnih radova Instituta PKB Agroekonomik,* 19(1-2), 89-100.

Simić, M., & Stefanović, L. (2008). Kompeticija - najčešći oblik interakcije između useva i korova. *Acta herbologica,* 17(2), 7-21.

Stoimenova, I., Alexieva, S., Taleva, A., & Djonova, E. (2004). Biomass of maize depending on plant growth management strategies. *Acta herbologica,* 13(2), 401-406.

Stranger, T.F., & Lauer, J.G. (2008). Corn grain yield response to crop rotation and nitrogen over 35 years. *Agronomy Journal,* 100(3), 643-650.

Sun, W.Q. (2002). Methods for the Study of Water Relations under Desiccation Stress. In M. Black & H.W. Pritchard (Eds.), *Desiccation and Survival in Plants: Drying Without Dying.* (pp. 47-91). New York, USA: CABI Publishing.

Wozniak, A. (2008). Wpływ zrośnicowanego udziału pszenicy jarej w zmianowaniu na indeks powierzchni liści (LAI). *Acta Agrophysica,* 12(1), 269-276.

Efekti različitih sistema gajenja kukuruza i kontrole zakorovljenosti na status slobodne energije i sadržaj biljnih pigmenata

REZIME

Plodored, kao sistem gajenja ima brojne prednosti koje se ogledaju u boljem rastu i prinosu useva. Njegovom kombinacijom sa drugim merama gajenja moguće je obezbediti optimalnu gustinu za maksimalan rast i efikasnost fotosinteze. Cilj ovog rada je da se ispita uticaj različitih sistema gajenja: monokulture i dva tipa rotacija koja uključuju kukuruz, pšenicu i soju (MSW i MWS), zajedno sa različitim merama kontrole zakorovljenosti (okopavanje, upotreba preporučene (RD), polovine preporučene (0,5 RD) doze herbicida i kontrola bez uklanjanja korova) na biomasu korova, parametre rasta kukuruza – indeks lisne površine (LAI), slobodnu energiju, sadržaj hlorofila i karotenoida, prinos zrna, kao i njihove međusobne odnose kod dva hibrida kukuruza: ZP 677 (H1) i ZP 606 (H2)).

Najniži LAI i prinos zrna bili su ostvareni u monokulturi, posebno u kontroli, zajedno sa relativno visokom zakorovljenošću. Veća biomasa korova je bila u tretmanima sa herbicidima u monokulturi. Ovakva situacija bi mogla da ukaže na prisustvo stresa koji se odražava na smanjenje LAI i sadržaja hlorofila, kao i povećanje vrednosti slobodne energije i karotenoida. Sa druge strane, plodored, posebno u kombinaciji sa herbicidima ili okopavanjem ispoljio je pozitivan uticaj na prinos preko povećanja LAI, sadržaja hlorofila i karotenoida i smanjenja slobodne energije.

Ključne reči: kukuruz, sistemi gajenja, herbicide, korovi, energija, hlorofili, karotenoidi