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THE POSSIBILITY OF MAIZE GLUTEN APPLICATION FOR WEED CONTROL IN MAIZE AND SOYBEAN

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Abstract

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The objective of this study was to determine the effects of maize gluten on the weeds number and dry biomass in the maize and soybean experiment. Pre-emergence maize gluten application resulted with an effective weed control in maize, whereas the soybean had the significant loss of plants, due to the gluten fitotoxicity. Post-emergence application was found to be less successful compared with pre-emergence application particularly for soybean. *Panicum cruss-galli* L. was the most frequent weed in the both experiment. Maize gluten rate of 300 g m^2 could be recommended in control of the broad leaf weeds in maize cropping as an alternative herbicide thus a substitute for mineral nitrogen. Our research can contribute to the improvement of the weed control in sustainable cropping systems.

Key words: weed control, maize, soybean, maize gluten, nitrogen

Introduction

Among the factors that regularly influence maize and soybean cropping in the Panonnian basin are soil fertility, climatic extremes and weeds (Anda et al., 2013). The weed management has been a major problem since the intensification of agriculture, hence finding operational solution in weed control is an essential task, particularly in the sustainable agricultural systems (Carderlna, 1988). Usually weed infestation is associated with the loss of yield in the agricultural systems over the world. Accordingly, modern agriculture relies heavily on the use of synthetic herbicides for managing weeds. Concern over the long-term ecological effects of synthetic agricultural chemicals has led to increased efforts in the search for natural products for weed control suitable for the sustainable agricultural systems (Duke et al., 2002). Inability of using synthetic pesticide from the conventional production imposed the testing of different substances with natural origin that has shown potential in controlling weeds. Eco-friendly trends in weed management force scientists to reach for the innovative solutions. Along with the discovering the new interactions among species that could be utilized for weed control, novel crops with promising allelopathic activity were introduced (Bilalis et al., 2013). According to Soltys et al. (2013) natural compounds pose a great field for the discovery of new environmentally safe herbicides, so called "bioherbicides", which are produced by living organisms. This is in agreement with Weaver et al. (2007) study who explained how bioherbicides based on the alleopathic activity of certain substance modifies plant physiological or biochemical processes. Narwal (1996) stressed that the allelopathic chemicals found in natural products may be used as herbicides to develop new classes of synthetic herbicides based on natural chemicals. Since the end of last Century maize gluten (G) meal has been identified as an effective natural pre emergence herbicide for use in field, vegetable and turf grass production (Bingman and Christians, 1995; Christians, 1993). During the research, not only were the changes in germination of grassland were noted, but also the changes on some weed species. During the greenhouse research Bingman and

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Christians (1995) found that corn gluten application of 324 g m^{-2} reduced plant survival, shoot length, and root development for the black nightshade (*Solanum nigrum*), common lambsquarters (*Chenopendium album*), creeping bentgrass, curly dock (*Rumex crispus*), purslane (*Portulaca oleracea*), and redroot pigweed (*Amaranthus retroflexus*). Maize gluten is a highly concentrated protein which contains the essential and nonessential amino acids, vitamins (carotene, choline, niacin), mineral substances (P, K, Ca, Fe, Mg and Na) and nutrient proteins (60% of total protein) (Semenjčenko et al., 2013). Nutrient composition and presence of vitamins (ß-caroten, B12, B6, Biotin, tiamin etc.) and particularly N in maize gluten favors the microbiological activity in soil (Rodney and DeMuro, 2013). Previous researches have shown that the maize starch hydrolysis resulted with the di-peptides formation in the soil affecting growth of the plant root system. As a result of water stress, the plants vein because they are unable to uptake water Christians et al. (2010).

Maize has food, feed, and industrial uses and it is considered as one of the most important crop that can be grown in a range of agro ecological environments. In recent decades, the expansion of possible maize grain utilization has led to significant changes in perception of the maize production. Production of the starches and ethanol are now most important technological maize uses, but accessibility and low cost of corn gluten could bring to its wider application. Production of maize gluten is generally intended for livestock species including fish. However, maize gluten role in the weed control has been widely recognized as a solution in the sustainable cropping systems. The effect of maize gluten increases during its application, so it is assumed that the evident results with continuous incorporation can be achieved after the fourth year of application. By testing maize gluten effects in the contrasting environment and different production systems it will help in crop management improvement and further investigation of other maize co-products uses in agriculture.

The aim of our study was to determine the number of weeds and crop density after the maize gluten application in soybean and maize experiment. Furthermore, doses of applied gluten were tested as well as the reaction of soybean (dicotyledons) and maize (monocotyledons) to its application.

Materials and Methods

For the research purposes we used maize gluten from "Jabuka", Starch Industry Pančevo, Serbia. In order to determine the possibilities of maize gluten application in maize and soybean production, the experiment was set in a semi controlled conditions of vegetation shed at the University of Novi Sad, Faculty Agriculture. This type of controlled condition does not include the control of temperature, but only water supply during the vegetation. The 2-year experiment was set up in three replication and an effect of the following 3 treatments was tested: Factor A (crop); Factor B (maize gluten doses): 0 (control); 3 g per pot; 6 g per pot; 9 g per pot; Factor C (application time) subsequent to seeding pre-emergence; during the vegetation (maize in the 3-5 leaf stage, soybean in the first trifoliate leaf stage (V1) post-emergence. In order to determine the dose-response curve of maize gluten application, a pot experiment was made with maize and soybean. Seed were sown in Mitscherlich pots at the rate of 5 plants per one pot. Three application rates of 3g, 6g and 9g per pot (equal to 100g, 200, 300 g m^{-2} G) where tested in a fully randomized experimental design with three replicates. Based on this treatment plan the following variants for maize and soybean can be distinguished: 1G- maize gluten application 3g per pot pre-emergence; 2G- maize gluten application 6 g per pot pre-emergence; 3G-maize gluten application 9 g per pot pre-emergence; 0- without maize gluten; G1- maize gluten application 3g per pot post-emergence; G2-maize gluten application 6 g per pot post-emergence; G3- maize gluten application 9 per pot post-emergence. A result of the maize gluten application was evaluated after 20 (I), 30 (II) and 40 (III) days, subsequent to the experimental set up.

For carrying out this experiment Mitscherlich pots were used, which were filled with soil that was previously used in maize (for soybean) and soybean growing (for maize). Bulk soil used for maize and soybean growing was taken from the long-term experimental field of the Institute of Field and Vegetable Crops at the Rimski Šančevi Novi Sad (Šeremešić et al., 2013). According to previous research from Nikolich et al. (2012) experimental field was characterized with the dominance of therophytes in the biological spectrum, as a consequence of strong anthropogenic impact (long-term cultivation). Thus, therophytes accounted for 84.84% (28 species), while the most common among them were again T4 therophytes (14 species; 42.42%). Geophytes accounted for only 15.15%. Before the setting up the experiment soil was sieved through a sieve (5 mm diameter). Seeding was done on 20 May, with 5 seeds of maize and soybean per pot. According to the experiment plan different amounts of maize gluten were added to the soil substrate. During the vegetation the moisture of the soil substrate in pots was kept between 70-80% of the water retention capacity of the soil. The plants were cut after a 50 day of growing when maize reached 9-11 leaves phase, and soybean started to blossom on the lowest floors of the plant (phase V4). Determination and nomenclature of weed species were carried out according to Josifović (1986) and Tutin (1980). After ending the experiment we counted number of maize and soybean as well as measured the mass of the crops and of the weeds in each pot. The plant material had been dried in an oven at 105°C for 48 h, after that the absolute dry mass was determined by using the technical scale. Analysis of variance was used to separate the treatment means when there was a significant difference at the $p < 0.01$ and $p < 0.05$ level (Mead et al., 2002).

Results and Discussion

The effect of maize gluten on weeds in the maize experiment

The maize gluten application has influenced the number of weeds in maize experiment after first counting (20 days after sowing), that led to the suppression of the most broadleaves weeds (Figure 1). This indicates fast microbiological transformation of the gluten incorporated in the soil. The treatments with pre emergence gluten application have had 1 to 3 individual weeds per pot, compared to treatments (G1, G2 and G3) where 22-28 individual weeds were counted. Comparing with the control, treatments where gluten was applied in pre-emergence phase had 9 times less weeds, and post-emergence application of gluten resulted with similar number of weeds per pot.

In the second counting 30 days after gluten application a similar number of weeds per pot were recorded (Figure 1). The third assessment showed that treatments in which G have been applied pre-emergence (1G, 2G and 3G), had < 3 weeds species, whereas number of weeds were reduced in those treatments which were treated with G in post-emergence phase (G2 and G3). It is likely that the root mucilage, weed root and microbiological activity increases transformation of corn gluten from post-emergence application. Also increased root and microbiological activity in soil could advance the N decomposition and reduce the exposure time of maize gluten. Therefore the effects of maize gluten in weed control showed better effects when applied before plant growth. The reduced weed number that was determined in the G3 variant compared to 0, G1 and G2 can be attributed to the increased efficiency the applied doses. However 300 g m^{-2} of gluten in G3 insignificantly reduces weeds number and the results resembled those reported by Bingman and Christians (1995) for corn gluten meal application, and study of Gough and Carlstrom (1999).

Measuring the maize stover mass we found that plants developed higher biomass with the addition of gluten before sowing. Many studies have shown the significant maize response to N application (Mikova et al., 2013). Average dry biomass per maize of the treatments where G was added pre-emergence was higher compared with the control, G1, G2 and G3 (Figure 2).

In the combined analysis of variance effect of application time has showed significant F-test for maize dry biomass (Table 1). Application time accounts for 41.58% variation, doses

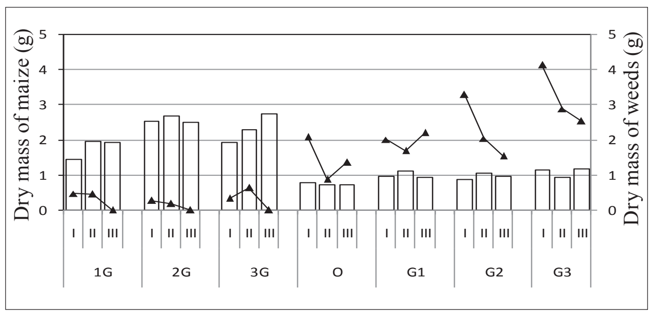

Fig. 2. Maize dry biomass per plant (g) – histogram and weed dry mass per pot (g) – horizontal lines

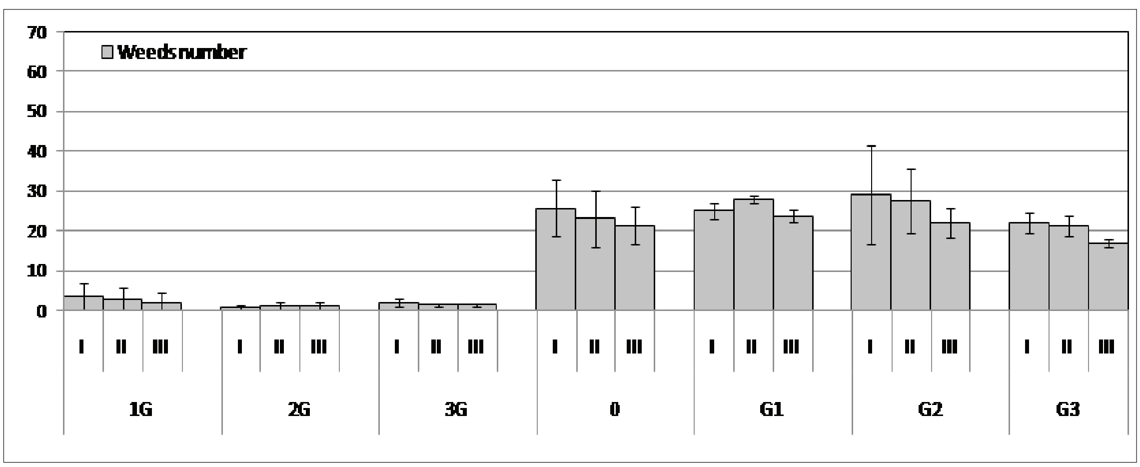

Fig. 1. The average number of weeds per pot in maize experiment after 20 days (I), 30 days, (II), and 40 days (III)

of corn gluten for 35.88%, the interaction for 16.25%, whereas the remaining 5.82% from residual influence.

The dry weed biomass after the final measurement was taken as a criterion of efficiency among different G doses. Dry mass of weeds (g) increased with the amount of the applied maize gluten in post-emergence, since G1, G2 and G3 pots were not treated and therefore weeds rapidly developed (Figure 2) Based on the obtained results, we found that the G2 and G3 treatment had higher dry weed biomass with first sampling period. However biomass decreases in the second and third sampling periods, respectively. Decreasing trend over time could be attributed to the gluten impact on the weed flora. In the combined analysis of variance the effects of application time and interaction of application time and doses of maize gluten showed significant F-test for weed dry biomass (Table 2). The application time accounted for 51.76% of weed dry mass, the doses of maize gluten with 6.83%, interaction 19.48%, whereas the remaining 15.25% variation derives from residual influences.

During the experiment with maize, the presence of 13 weed species was determined (Table 3). The most frequent weed that was found in all treatments was *Panicum crussgalli* L., in addition to that it was also present with the higher number of individuals compared with other weeds. This indicated that the G "active matter" probably was not sufficiently effective in the case of monocotyledon weeds. According to Hesammi and Hesammi (2014) in Sorghum bicolor study the best time for weed control is before planting the or during the critical first trimester of the growth stage. Therefore, timing the gluten application is of a great importance for successful weed control.

Effect of maize gluten on weeds in soybean experiment

Generally, weeds represent one of the major challenges in modern soybean production (Suleymenova et al., 2012). Maize gluten application has influenced the number of weeds in soybean 20 days after pre-emergence application (Figure 4). In the 1G treatment, there were 6 to 9 individual weeds in all three terms of counting. In the 3G and 2G treatments we found significantly lower number of weeds compared to the first treatment (1G). These results indicate that G with doses of 100g m^2 in pre-emergence application was not fully efficient in soybean, whereas with higher doses the efficiency was significantly improved. Liu and Christians (1997) also found that dicotyledonous plant species had larger reduction in plant survival then did monocotyledon species. This could be explained with the late root appearance of monocotyledon weeds. Treatments where the G was added post-emergence had the positive effect on weeds because narrow leaves weeds dominated and sup-

Table 1
Analysis of variance for dry maize stover biomass

Sources of variation	d.f.	s.s.	s.s., %	m.s.	*F*	*p*
Application time (A)	1	573.4023	41.58	573.4023	100.103**	>0.0001
Doses of gluten (B)	3	494.9037	35.88	164.9679	28.800**	>0.0001
Interaction (AxB)	3	224.0852	16.25	74.6951	13.040**	0.0015
Blocks	2	6.5049	0.47	3.2524	0.568	0.458
Error	14	80.1937	5.82	5.7281		
Total	23	1379.0898	100			

d.f. – degrees of freedom, s.s. – total sum of squares, s.s.,% – sum of squares relative to total sum, m.s. – mean squares

Table 2
Dry biomass of weeds in the maize experiment

Sources of variation	d.f.	s.s.	s.s.%	m.s.	*F*	*p*
Application time (A)	1	15.2961	51.76	15.2961	47.540**	>0.0001
Doses of gluten (B)	3	2.0174	6.83	0.6725	2.090	0.1466
Interaction (AxB)	3	5.7567	19.48	1.9189	5.964**	0.0037
Blocks	2	1.9737	6.68	0.9868	3.067	0.0660
Error	14	4.5045	15.25	0.3218		
Total	23	29.5484	100			

d.f. – degrees of freedom, s.s. – total sum of squares, s.s.% – sum of squares relative to total sum, m.s. – mean squares.

Table 3
Overview of weeds determined in the experiment with maize

Number	Weeds	Treatments						
		1G	2G	3G	0	G1	G2	G3
1	*Hibiscus trionum* L.	-	-	-	-	-	-	+
2	*Panicum cruss-galli* L.	+	+	+	+	+	+	+
3	*Amaranthus retroflexus* L.	-	-	-	+	+	+	+
4	*Chenopodium album* L.	-	-	-	+	-	+	-
5	*Solanum nigrum* L.	-	-	+	+	+	+	+
6	*Portulaca oleracea* L.	-	-	-	+	+	+	+
7	*Veronica persica* L.	-	-	-	-	+	+	+
8	*Stellaria media* (L.)Vill.	-	-	-	-	+	+	+
9	*Stachys annua* L.	-	-	-	-	-	+	-
10	*Polygonum convolvulus* L.	-	-	-	-	-	+	-
11	*Oxalis acetosella* L.	-	-	-	-	-	-	-
12	*Ambrosia artemisiifolia* L.	-	-	-	-	-	-	-
13	*Senecio vulgaris* L.	-	-	-	-	-	-	+
Total		1	1	2	5	6	9	8

press soybean growth (Figure 3). Consequently, the number of individual weeds ranged from 37 (3G - III counting) to 57 (2G-II counting).

The assumption is that the amount of G added in stages after the first trifoliate leaf (V1) had not significantly influence the growth among treatments, however, the gluten application had phytotoxic effect on treatments before sowing. The majority of allelopathic effects, such as reduction in seed germinability and seedling growth, chlorosis, decreased ion uptake and are caused with the combination of specific interactions between allelochemicals and cellular or molecular systems influence (Gniazdowska and Bogatek, 2005). In those treatments where G had been applied in the first trifoli-

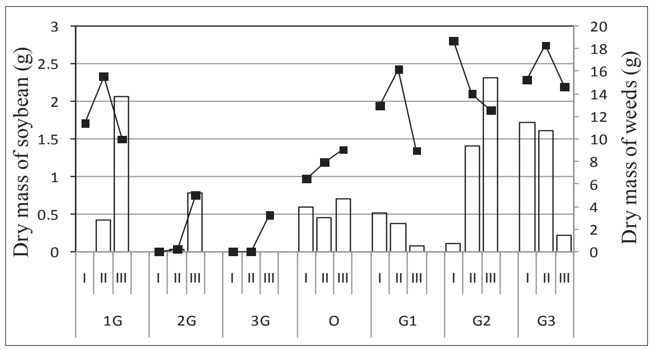

Fig. 4. Soybean dry biomass per plant (g) – histogram and weed dry mass per pot (g) – horizontal lines

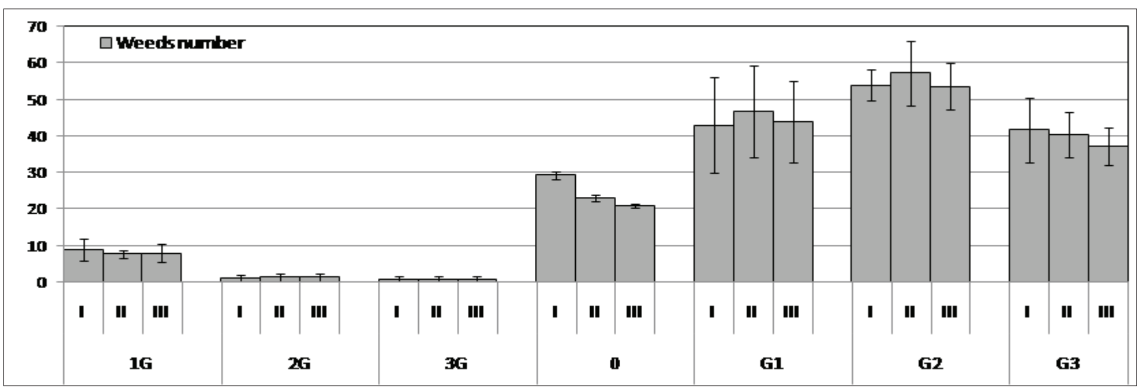

Fig. 3. The average number of weeds in soybean per pot after 20 days (I), 30 days, (II), and 40 days (III)

ate leaf stage (V1), it contributed positively to the number and weeds dry biomass since weeds already developed shoots and leaves (Figure 5). Increased gluten doses resulted with response in dry weed biomass (g), respectively. Based on these results, we found that G has a significant effect on the weed development through release of the easily accessible N compounds. Maize gluten contains 10% nitrogen by weight, and has a fertilizing effect when applied to soil (Bingman and Christians, 1995). In the combined analysis of variance the effect of doses of maize gluten and interaction with application time has showed significant F-test on the dry mass of soybean. The doses of maize gluten accounted for 65.75%, interaction for 29.72%, application time for 0.01% (Table 4).

The largest individual mass of soybean plants was recorded in the treatment in which gluten was added pre-emergence (1G), which is attributed to reduction in number of plants per pot. McDade and Christians (2000) also determined that gluten rates of 100, 200, 300, and 400 g m^{-2} reduced average seedling survival for vegetables by 48%, 65%, 73%, and 83%, respectively. Subsequent to gluten degradation in soil, weeds continues germination indicating that doses of < 200 g m^2 was less successful in weed control since they could simulate weed growing (Yu and Morishita, 2014). In the treatments 2G and 3G, there was a significant reduction in the number of both soybean and weeds. Post-emergence gluten application resulted in a lower dry biomass per plant at G1 and higher biomass at G2, whereas at G3 larger weed number inhibited development of soybean (Figure 4). Comparing the different treatments in experiment, it was found that the highest dry mass of weeds per pot was obtained in the treatment with 200 and 300g m^2 of G applied in post-emergence. Concomitantly, in treatments in which G was added before sowing, significant reduction was found in the number and dry biomass of weeds (Figure 4).

During the experiment, dry weed biomass after the last measurement was considered as a criterion of the efficiency on G doses. In the combined analysis of variance dry mass of weed showed significant F-test for application time, doses of maize gluten, and blocks. The application time accounted for 41.01%, doses of corn gluten for 14.25%, blocks for 0.16% (Table 5).

During the experiment with soybean, the presence of sixteen weed species was determined (Table 6). Among observed weed species *Abuthilon thephrasti* L., *Datura stramonium* L and *Panicum cruss-galli* L. were represented in most treatments. In the soybean experiment, similar to maize, *Panicum cruss-galli* L had higher number of individuals at different pots.

Table 4
Dry mass of soybean vegetative mass

Source of variation	d.f.	s.s.	s.s.%	m.s.	*F*	*p*
Application time (A)	1	0.0006	0.01	0.0006	0.037	0.8492
Doses of corn gluten (B)	3	3.8523	65.75	1.2841	78.607**	< 0.0001
Interaction (AxB)	3	1.7421	29.72	0.5807	35.548**	< 0.0001
Blocks	2	0.036	0.62	0.0181	1.105	0.3482
Error	14	0.2287	3.90	0.0163		
Total	23	5.8598	100			

d.f. – degrees of freedom, s.s. – total sum of squares, s.s.% – sum of squares relative to total sum, m.s. – mean squares;

Table 5
Dry mass of weeds in the soybean experiment

Source of variation	d.f.	s.s.	s.s., %	m.s.	*F*	*p*
Application time (A)	1	239.3385	41.01	573.4023	21.364**	<0.0001
Doses of gluten (B)	3	83.1524	14.25	164.9679	14.055**	<0.0001
Interaction (AxB)	3	232.5155	39.85	74.6951	0.241**	0.8668
Blocks	2	0.9517	0.16	0.4758	39.301	<0.0001
Error	14	27.6091.1937	4.73	1.9721		
Total	23	583.5671	100			

d.f. – degrees of freedom, s.s. – total sum of squares, s.s., % – sum of squares relative to total sum, m.s. – mean squares;

Table 6
Number of different weeds determined in the experiment with soybean

Number	Weeds	Treatments						
		1G	2G	3G	0	G1	G2	G3
1	*Datura stramonium* L.	+	+	-	+	+	+	+
2	*Abuthilon thephrasti* L.	+	+	+	+	+	+	+
3	*Solanum nigrum* L.	+	-	-	+	+	+	+
4	*Panicum cruss-galli* L.	+	+	+	+	+	+	+
5	*Portulacea oleracea* L.	+	-	-	+	+	+	+
6	*Sonchus arvensis* L.	-	-	-	+	+	-	-
7	*Veronica persica* L.	-	-	-	-	+	+	+
8	*Chenopodium hybridum* L.	-	-	-	+	+	-	-
9	*Solanum dulcom* L.	-	-	-	+	+	-	-
10	*Stelaria media* L.	-	-	-	-	+	+	+
11	*Polygonum convulus* L.	-	-	-	-	+	-	+
12	*Oxalis acetosella* L.	-	-	-	-	-	+	-
13	*Amarathus retroflexus* L.	-	-	-	-	-	-	+
14	*Xanthium srumarium* L.	-	-	-	-	-	-	-
15	*Artiplex patula* L.	-	-	-	+	-	-	-
Total		5	3	2	9	11	8	9

Conclusions

The application of maize gluten resulted with the significant reduction in the number of weeds in maize, accordingly pre-emergence application can be appropriate in weed control. In soybean experiment maize gluten application significantly reduced the soybean plants in pre-emergence, contrary to post-emergence application were number of soybean was not affected. In the treatments with maize 13 different weed species were found, whereas in the treatments with soybean 15 species were determined. The most common weed among both experiments was *Panicum cruss-galli* L. An effective weed control in maize experiment can be achieved with application >300 g m^{-2} gluten in pre-emergence, whereas in soybean cropping weed control was not fully achieved. Besides herbicide effect, it was found that gluten application has a significant effect on plant growth after N released by microbial degradation. For season-long suppression of weeds repeated applications of maize gluten is required. By developing the technology of application, maize gluten can become an important preparation in weed control of sustainable agricultural systems.

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