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MAINTENANCE OF SOIL FERTILITY ON ORGANIC FARM BY MODELING OF CROP ROTATION WITH PARTICIPATION ALFALFA

ABSTRACT: The aim of this paper is to maintain soil fertility on an organic farm without livestock production by using alfalfa green biomass. The research was carried out on the farm of Mokrin PP company, by modeling and sizing of crop rotation with alfalfa (*Medicago sativa* L.) on the non-carbonate humoglay. To ensure a cost-effective technical solution, alfalfa seed production was organized. In the autumn of 2015 alfalfa sowing was carried out in a field of 5 ha. Green biomass of the first and third cuttings, as well as crop residue after harvesting of seeds in the second cutting, were mowed and chopped by harvester for low silage and stored in the silage-pit. After nine months, a mature alfalfa compost was obtained with optimum values of total nitrogen (5.04%), organic matter (42.56%), C/N, pH, humidity, and EC.

Two-year alfalfa utilization is the recommended time in this research because to the following benefits: in crop rotation, alfalfa field is provided with nitrogen by symbiotic nitrogen fixation and the alfalfa is cultivated every five years in the same field, while in the middle of that period the field is fertilized with compost produced on the farm. The amount of compost obtained by crop rotation (2016 – 48.80 t; 2017 – 62.30 t) is enough for about 20% of the arable area per year. Thus, the fields are fertilized every fourth year with 10 t ha^{-1} of compost. Thanks to alfalfa biomass and seed and also nitrogen fixation, maintaining soil fertility is resolved in a sustainable and natural way.

KEYWORDS: alfalfa, composting, fertility, organic production

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INTRODUCTION

Organic production of food is based on ecological practice, a high degree of biodiversity, and the conservation of natural resources. Council Regulation (EC) no. 834/2007 from 28 June 2007, especially points out the rational use of soil, water, and soil organic matter, by application of procedures that are not harmful to them. The plant nutrition should be provided through the ecosystem of the soil, and not by using soluble fertilizers that would be added to it. The fertility and biological activity of the soil is maintained and increased by the practice of wider crop rotation, with a greater share of legumes and the introduction of cover crops (Ugrenović and Filipović, 2017), using composted organic fertilizers originating from livestock production or farm waste. Particular emphasis is placed on the importance of livestock production for organic agricultural holdings since they provide them with the necessary organic matter for cultivated land. However, there are only forty producers in organic livestock production in Serbia (DNRL 2016). Bearing in mind the ban on the use of synthetic mineral fertilizers, and the application of commercial certified fertilizers for organic production is often not economically justified, a small volume of organic livestock production undermines the sustainability of total organic production, especially when it comes to maintaining of soil fertility. An important principle of organic production is the preservation and improvement of biodiversity. The intensification of agriculture in the last decades has severely affected biodiversity (Ugrenović et al., 2012), and the inappropriate use of synthetic agrochemicals has also caused land biodiversity loss.

A large number of researchers have considered the maintenance of soil fertility and crop-rotation in organic production in the world (Watson et al., 2008; Mohler & Johnson, 2009; Altieri, 2015; Jat et al., 2015; Wande, 2015). The obtained results can only be partially applied in the organic production of Serbia, since the agro-ecological, technical, technological, and social conditions are significantly different. Attention has not been paid yet to the maintaining of the soil fertility on organic manors without animal husbandry by modelling crop relation with the use lucerne (*Medicago sativa* L.). Compost from biomass of alfalfa has not been produced so far. Research of Ćupina et al. (2017) deals with the topic of annual cover crops and the nitrogen budget. Several transparent works are available (Ćupina et al., 2004, 2004a, Čuvardić, 2006, Ugrenović and Filipović, 2017) and additional researches with various commercial, certified organic fertilizers and soil cultivators (Filipović et al., 2012; Bogdanović et al., 2013; Popović et al., 2014; 2019; Dozet et al., 2017).

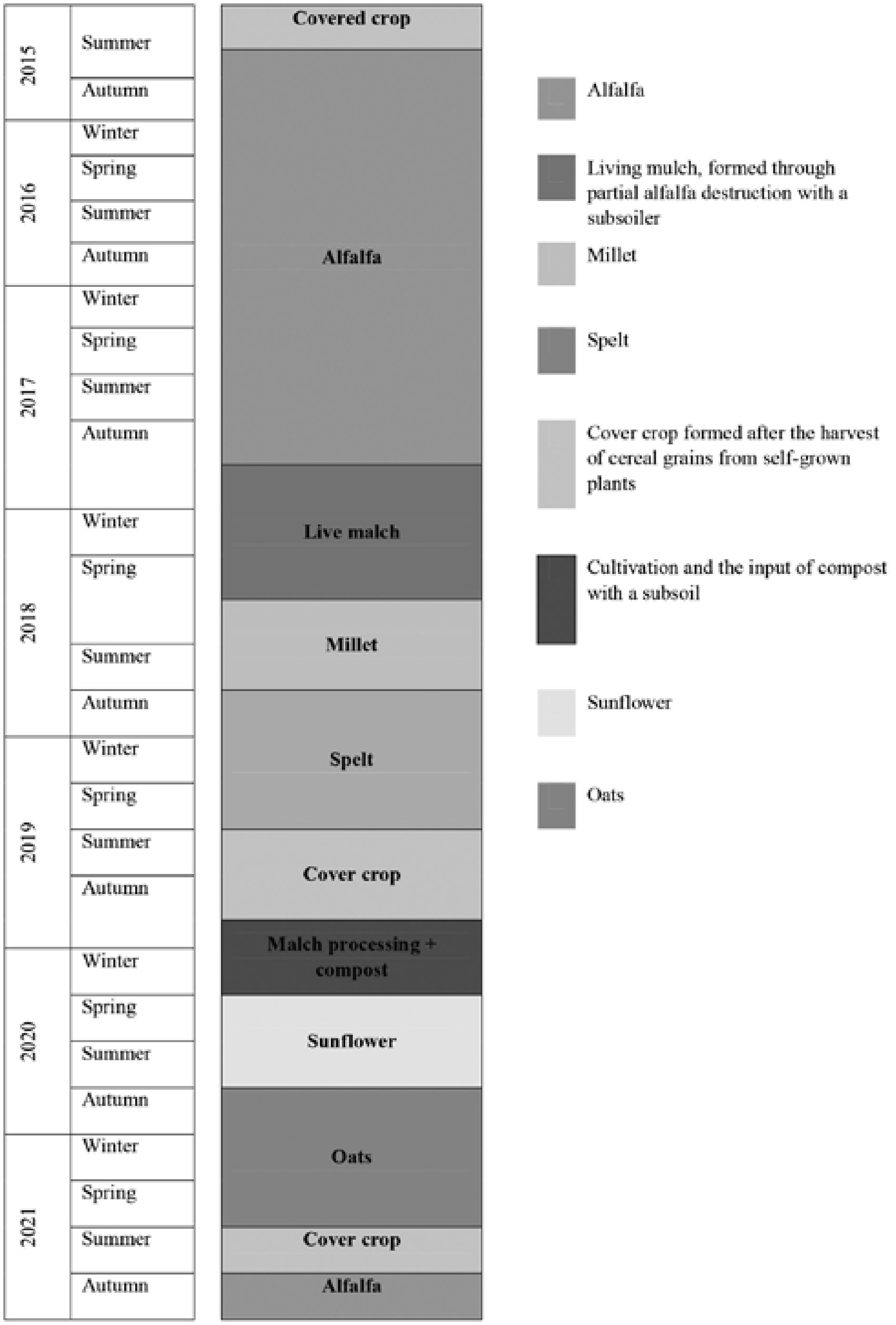
Organic production is controlled, and the Law on Organic Production (*Official Gazette of the Republic of Serbia*, 30/2010) for the maintenance of soil fertility, application of wider crop rotation and preservation of biodiversity, particularly defines the criteria that the organic producer must fulfill in the process of control and certification. In this sense, the proposed technical solution aims to address the issue of soil fertility maintenance on organic farms that do not have livestock production, modeling an optimally sized crop rotation, with the participation of alfalfa (*Medicago sativa* L.), which should: 1) provide biomass for composting to produce sufficient quantity of quality compost on the farm, 2) provide symbiotic nitrogen fixation of soil with nitrogen for future crops in crop rotation, 3) protect and improve soil biodiversity by increasing the number of useful microorganisms, 4) obtain the primary product, interesting for the processing industry and the market. All this should be modeled in a way that does not increase production costs.

MATERIAL AND METHOD

The proposed technical solution was studied on 25 ha of Agricultural enterprise Mokrin doo production areas (N 45° 57' 1213", E 20° 22' 3830") in the system of organic production, on the non-carbonate humoglay soil. To solve the soil fertility issue on organic farms with no livestock production, there was modeled and sized a five-field crop rotation, with a share of alfalfa (20%), millet (*Panicum miliaceum* L.) 20%, spelt (*Triticum spelta* L.) 20%, sunflower (*Helianthus annuus* L.) 20%, and oats (*Avena sativa* L.) 20% (Scheme 1). The goal of using alfalfa was to provide biomass for the production of compost in crop rotation for the maintenance of soil fertility. To ensure economic viability in such circumstances, the production of alfalfa seed is organized. At the end of 2015, on the surface of 5 ha, on which the pre-sowing crop was wheat, conservation treatment of the soil by both full-scale shallow cultivation and deep cultivation in one single pass was performed by Vaderstad-Top Down 300S (30 cm depth). Then, on 8 September, alfalfa (Banat VS variety) was sown by Vaderstad-Rapid 400 C sower, at a row distance of 12.5 cm, to a depth of 2–2.5 cm, with 16 kg ha^{-1} of seed. For the next two years (2016, 2017) when the crop of the first and third branches was in the phase of forming the flower buds until the beginning of flowering, the over-ground biomass was harvested with silorator for low silage, cut and stored in the silage holes on the farm in Mokrin. In the second cutting in both years, when most of the pods in alfalfa crop received a dark color, two-phase harvesting of seeds was done. Herbal residues after threshing were also utilized for composting. In the autumn of 2017, the crop was partially destroyed by soil cultivation. During the vegetation period of alfalfa, phenological observations were carried out: sprouting, intense growth, flowering, butonization, and maturation. During transportation, measurements of the amount of green biomass and recalculation of yield (t ha^{-1}) were carried out.

Process of preparation of alfalfa compost – Produced green biomass of the first and third cutting of alfalfa and dried mass of plant residues after alfalfa seed harvesting was used for composting. This mass is stored in the Power Plant PP Mokrin. To accelerate the degradation process, the microbial preparation Ecovital (2.0 l / 10 t^{-1}) was used. During the production, care measures were carried out permanently: mixing, watering, and covering of the compost pile, and for their timely implementation, measurements of temperature and humidity preservation.

Scheme 1. The model of crop rotation with the participation of alfalfa on an organic farm



The mixing was done on several occasions with loader, depending on the state of the humidity of the compost pile, to ensure the access of a sufficient amount of oxygen. Water was added as needed to maintain the humidity of the compost heap at about 65%. After nine months, a mature compost was obtained, which was measured during transport to calculate the yield (t ha^{-1}).

Methods of performed analyzes – After the plowing of alfalfa in autumn 2017, sampling was carried out in the spring next year to determine the basic fertility parameters of the soil: total nitrogen and carbon (CNS Elemental Analyzer Varian EL III), humus (calculation from organic carbon – CNS Analyzer), pH of the soil values (in H_2O and KCl, potentiometric), and readily available-accessed potassium (K_2O) and phosphorus (P_2O_5) by the Egner and Riehm Al methods (Egner et al., 1960). Microelements in the compost are determined by extraction using aqua regia. Also, sampling and analyses were done to determine the microbiological activity of the soil and compost.

The total number of microorganisms was determined by the plate count method on the agarized soil extract, the number of fungi on the Chapek medium, *Actinomycetes* on the medium according to Krasiljnikov, and oligonitrophiles on the Fyodorov medium. The other two groups of microorganisms Ammonifiers and *Azotobacter* spp. were determined by the most probable number (MPN) method in the liquid medium with asparagines or mannitol, respectively (Sarić, 1989; SRPS ISO 11465:2 002).

Soil respiration was determined by laboratory incubation with constant temperature and moisture. The respired carbon dioxide was trapped in the NaOH, and the remaining amount of OH^- ions was back-titrated with the solution of HCl. The amount of released CO_2 during the incubation period was calculated (Horwath et al., 1996). The presence and the most probable number (MPN) of bacterial species *S. meliloti* in the soil were determined by the indirect method „plant infection count" (Vincent, 1970). The results were statistically analyzed by the variance analysis method (ANOVA), and the level of difference significance was tested with the LSD test, at the level $P < 0.05$ (COSTAT program). To perform the analysis, benefits, costs, and variable costs were monitored.

RESULTS AND DISCUSSION

Production of biomass for composting, to produce sufficient quantity of quality compost on the farm – Total yield of alfalfa green biomass in 2016 was 16.40 t ha^{-1} (Table 1), the weight of plant residues after threshing alfalfa seeds was 2.40 t ha^{-1}, and the amount of compost obtained was 9.76 t ha^{-1}. In the second year of production (2017), the total yield of green biomass was 25.07 t ha^{-1}, the mass of plant residues after threshing of seed was 3.11 t ha^{-1}, and 12.46 t ha^{-1} of compost was obtained. The total quantity of compost produced in 2016 was 48.80 t, and in 2017 it was 62.30 t.

Table 1. The yield of the biomass of alfalfa for composting and the amount of obtained compost

	The first and third cutting	Second cutting	
	Green biomass ($t\ ha^{-1}$)	Biomass of residuals after threshing seed ($t\ ha^{-1}$)	Amount of compost ($t\ ha^{-1}$) / total (t)
2016	16.4	2.40	9.76 / 48.80
2017	25.0	3.11	12.46 / 62.30

The average value of the C/N ratio of the produced alfalfa compost is 8.51 (Table 2). The ratio of C/N at the formation of the compost heap and start of the aerobic process should be 40:1 optimally, and finally after ripening 10 (12): 1, indicating somewhat lower efficiency of the produced compost in fertilizing, but its excellent characteristics in terms of physical properties. Values: humidity, pH, and EC are optimal. According to the measured content of total nitrogen (5.04%), alfalfa compost is well supplied with nitrogen, and the content of organic matter is 42.56%.

Table 2. Agrochemical properties of alfalfa compost

C/N	Moisture %	EC mS/cm^2 g/l	pH		Organic matter			Content of readily – available				
			in KCL	in H_2O	C%	N%	(Org.C) %	P_2O_5 mg/100 g	K_2O mg/100 g	NH_4 mg/kg	NO_3 mg/kg	NH_4+NO_3 mg/kg
8.51	61.13	7.97 3.99	6.61	7.33	38.04	5.04	42.56	1.40	4.11	46.7	1437.3	1484

The total microflora in the alfalfa compost was represented in a significant number (65.22x10^6 microorganisms per gram of dry compost) (Table 3) indicating intense microbiological activity. The determined number of fungus (98.44x104) indicates a high content of organic matter and optimal substrate moisture, which confirms the good quality of the compost obtained. Also, the number of *Actinomycetes* (2.43x10^4) was significant. The presence of *Azotobacter* as a fertility indicator confirms the good water-air properties of compost, and the presence of amonifiers (7.97x10^5) the significant presence of nitrogenous organic compounds. The content of heavy metals was within the boundaries of the MAC (Official Gazette of RS, No. 23/94) (Table 4).

Table 3. Number of microorganisms in alfalfa compost

Total number of microorganisms (x10^6)	Number of fungi (x10^4)	Number of *Actinomycetes* (x10^4)	Number of *Azotobacter* (MPN)*	Number of amonifiers (x10^5)
Number of microorganisms/g in dry compost				
5.22	98.44	2.44	25.00	7.97

* MPN – the most likely number from Mec Credy table.

Table 4. Content of microelements in alfalfa compost

As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	Fe
mg/kg									%
1.48	0.22	2.29	17.42	31.89	228.5	12.75	3.7	77.63	4.70

According to the recommendation of the Bundesgütegemeinschaft Kompost e.V. (2004), for the production of most arable crops, 10 to 15 t ha^{-1} of compost is applied during autumn fertilization. The amount of compost obtained by modeling the crop rotation on the Mokrin estate (Table 1) is sufficient for about 20% of the area of the field, on an annual basis. Thus, every fourth year, they were fertilized with about 10 t ha^{-1} of compost, excluding the predicted 20% of the area for establishing the alfalfa, so that the fertility of the soil is maintained in a natural way.

Providing nitrogen for future crops in the crop rotation – Total N in the soil after two years of planting alfalfa was 0.25% (Table 5), which is higher than the control plot (0.22%). This clearly demonstrated the significant influence of alfalfa on the provision of nitrogen in the soil. The obtained results confirm a large number of *S. meliloti* (1.78x104 g^{-1} absolutely dry soil) in the soil after 2 years of growing alfalfa, which is significantly higher than in the control soil ($2.00x10^2$ g^{-1} absolutely dry soil). This confirms the well-known fact that alfalfa as a host plant positively influences the number of *S. meliloti* (Delić et al., 2016), and thus the establishment of an ecological and economically significant process of symbiotic nitrogen fixation (Delić, 2014).

Table 5. Chemical properties of soil after two years of cultivating alfalfa, on non-carbonate, marsh dark soil

Parameters	pH		Humus %	Min. N mg/kg	Total N %	P_2O_5 mg/100 g	K_2O mg/100 g
Treatment	in KCL	in H_2O					
Alfalfa field	6.0	6.7	4.36 a	22.16 a	0.25 a	13.76 a	19.07 a
Control	6.1	7.3	3.59 b	11.08 a	0.22 b	15.16 a	20.66 a
LSD 0.05			0.730	14.26 ns	0.023	4.13 ns	2.23 ns

The mean values indicated by the same letter within one column do not differ significantly ($p < 0.05$); ns – not statistically significant

Protecting and improving biodiversity by increasing the number of useful microorganisms in the soil – After two years of alfalfa cultivation, the total number of microorganisms ($18.22x10^6$ g^{-1} absolutely dry soil) was higher than the control plot ($16.22x10^6$ g^{-1} absolutely dry soil) (Table 6). These results are in correlation with the intensity of respiration, which was twice as high in the soil on which alfalfa was grown. The number of fungi was also significantly higher after the production of alfalfa ($22.00x10^4$ g^{-1}) compared to the control ($12.22x10^4$ g^{-1}), and their role in the synthesis of humus was confirmed, since there was significantly more humus, after plowing the alfalfa field.

Although the number of ammonifiers did not change significantly, the role of alfalfa in increasing fertility of the soil indicates a significant number of *Azotobacter*, which was eight times higher than in the control land. Alfalfa also significantly influenced the increase in the number of bacteria *S. meliloti* (178x10^2 g^{-1}) compared to the control (2x10^2 g^{-1}). Results of the total number of microflora, ammonifiers, fungi, and *Azotobacter* sp. indicate a positive effect of alfalfa on biodiversity and the activity of microorganisms in the soil.

Table 6. Microbiological properties of soil after two years of cultivating alfalfa on non--carbonate marsh dark soil

Parameters / Treatment	Total microflora (x10^6/g)	Fungi (x10^4/g)	*Azotobacter* number /g MPN	Ammonifiers (x10^5) MPN*	*Sinorhizobium meliloti* (x10^2) MPN	Respiration (mg CO_2/kg of soil /7 days)
Alfalfa field	18.22 a	22.00 a	316.66 a	3.16 a	178 a	733.35 a
Control	16.22 a	12.22 b	41.33 b	3.83 a	2b	476.16 b
LSD 0.05	18.78 ns	9.41	200.24	2.62 ns	195	256.98

The mean values indicated by the same letter within one column do not differ significantly ($p < 0.05$); ns – not statistically significant; * MPN – the most likely number

Alfalfa seed – a product, interesting for the processing industry and the market – Average annual level of alfalfa production in Serbia is 104,584.7 hectares (Stat. Year Book of Serbia, 2015), and as its production requires the use of quality declared seed, the need for it on the market is large. On the other hand, by cultivating alfalfa seed in primary production conditions, it is possible to generate higher income per unit area (Karagić et al., 2006). In the first year the total yield of produced natural seed was 1.95 t (0.39 t ha^{-1}), and in the second 3.15 t (0.63 t ha^{-1}). In the analyzed two-year period (2016 and 2017) in the production of alfalfa seed together with compost production, a favorable gross financial result was achieved (64,050.00 RSD ha^{-1} in 2016 and 112,020.00 RSD ha^{-1} in 2017) (Table 7). In other words, sufficient resources have been made to cover fixed costs, and the achieved profitability ensures the sustainability of the proposed technology.

The essence of the technical solution is in solving the issue of maintaining the fertility of the soil on an organic farm without livestock production, modeling and dimensioning of rotating the crops on five fields with the participation of alfalfa. The yields of alfalfa can reach 52 t ha^{-1} of green biomass, i.e. 12.6 t ha^{-1} of dry matter per year (Katić et al., 2011). By implementing the proposed technical solution a part of this biomass was used for the production of compost, to maintain the fertility of the soil on the farm, and this is precisely the innovation because alfalfa compost has not been produced in Serbia so far. To ensure economic sustainability, the production of seeds of alfalfa was realized, with very good economic indicators (Pajić and Marković, 2016). In this sense, the first and third cuttings were used to provide biomass for the production of compost, and the second for the production of seeds.

Table 7. Analytical calculation based on variable costs in the production of alfalfa seed and alfalfa compost

Description	Year	
	2016.	2017.
Production value (RSD/ha^{-1})*	**135,160.00**	**167,560.00**
Quantity of natural seed (kg ha^{-1})	390.00	630.00
Price of natural seed (RSD ha^{-1})	324.00	252.00
Compost quantity (t ha^{-1})**	9.76	12.46
Incentives (RSD ha^{-1})	8,800.00	8,800.00
Variable production costs (RSD ha^{-1})	**71,110.00**	**55,540.00**
Basic material:	*8,800.00*	*1,800.00*
Seed	7,200.00	–
Microbiological preparation	1,500.00	1,800.00
*Costs of work utilizing mechanization and operator***:*	*54,310.00*	*45,740.00*
Plowing	7,950.00	–
Seedbed tilling	2,570.00	–
Sowing	2,460.00	–
Smashing biomass with combines (x2)	13,140.00	13,140.00
Threshing of seed	10,360.00	10,360.00
Transport	8,330.00	12,740.00
Compost mixing with loader (x2)	9,500.00	9,500.00
Certification costs	*8,000.00*	*8,000.00*
Certification costs	8,000.00	8,000.00
Gross financial result (RSD ha^{-1})	**64,050.00**	**112,020.00**

* Gross financial result (RSD ha^{-1}). ** The compost value was not assessed. *** Based on the price list of the Cooperative Association of Vojvodina (2017)

According to this new technology, it is recommended that the exploitation time of the alfalfa crop should be two years. This is an advantage for farmers because, thanks to symbiotic nitrogen fixation, the entire surface in a crop rotation can be provided with nitrogen more efficiently since the accumulation of nitrogen by this process in the soil in later years of alfalfa crop decreases. In this way, in crop rotation, alfalfa returns to the same field every fifth year and in the middle of the period, organic fertilizer produced on the farm is applied. Thanks to the production of alfalfa seed economic viability is assured, in addition to the maintenance of soil fertility in a sustainable and natural way.

CONCLUSION

The proposed new technology recommends the use of alfalfa for two years. In that way, the cultivated soil could be sufficiently provided with nitrogen under proposed crop rotation, by symbiotic nitrogen fixation. In the five-year crop rotation, alfalfa returns to the same field every five years, while in between the soil receives nutrients from composted alfalfa. This technology is precisely the innovation because such compost has not been produced in Serbia so far. The quantity of alfalfa compost obtained by designing the crop rotation with alfalfa on an organic farm in Mokrin is enough for about 20% of the arable land, on an annual level, and with which every fourth year they fertilize it with about 10 t ha^{-1} of compost. Results of the total number of microflora, ammonifiers, fungus, and *Azotobacter* sp. indicate a positive effect of alfalfa on biodiversity and the activity of microorganisms in the soil.

Thanks to the production of alfalfa seed that provides economic sustainability, the proposed technology for maintaining soil fertility is done in a sustainable and natural way.

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ОДРЖАВАЊЕ ПЛОДНОСТИ ЗЕМЉИШТА НА ОРГАНСКИМ ФАРМАМА МОДЕЛИРАЊЕМ ПЛОДОРЕДА КОРИШЋЕЊЕМ ЛУЦЕРКЕ

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РЕЗИМЕ: У органској производњи се истиче значај сточарске производње, јер она обезбеђује неопходне органске материје за обрађено земљиште. Међутим у Србији се органска сточарска производња одвија код свега четрдесет произвођача што доводи у питање одрживост овог система пољопривредне производње. Циљ техничког решења је одржавање плодности земљишта на органском газдинству које нема сточарску производњу. Истраживање је спроведено на имању ПП „Мокрин", на површини од 25 ha, моделирањем и димензионирањем плодореда са учешћем луцерке, на бескарбонатној ритској црници. Како би се обезбедила економска одрживост организована је производња семена луцерке, а сетва је обављена у јесен 2015. године на 5 ha. Зелена биомаса првог и трећег откоса, као и просушена биомаса после бербе семена, кошене су и сецкане комбајном за ниску силажу и складиштене у сило јаме. После девет месеци добијен је зрео луцеркин компост, добро обезбеђен азотом (укупан азот 5,04%), органском материјом (42,56%) и оптималних вредности: C/N, pH, влажности и EC.

Искоришћавање луцерке од две године је препоручено време у овом истраживању. Тиме се цела површина у плодосмени симбиотском азотофиксацијом брже обезбеђује азотом, луцерка се на исту њиву враћа сваке пете године, а на половини тог периода њива се ђубри компостом произведеним на имању. Количина компоста добијена моделирањем плодореда у Мокрину (2016. год. 48,80 t, а 2017. год. 62,30 t), довољна је за око 20% површина њива, на годишњем нивоу. Тако се оне у плодосмени, сваке 4 године ђубри са 10 t ha^{-1} компоста. Захваљујући производњи семена луцерке, која обезбеђује економску одрживост, предложеном технологијом одржавање плодности земљишта решава се на одржив и природан начин.

КЉУЧНЕ РЕЧИ: луцерка, компостирање, органска производња, плодност