© by PSP Volume 26 – No. 11/2017 pages 6517-6524 Fresenius Environmental Bulletin

EFFECT OF LAND CONSERVATION ON CONTENT OF ORGANIC CARBON AND TOTAL NITROGEN IN SOIL

Stanislaw Sienkiewicz[1], Piotr Jaroslaw Zarczynski[1], Slawomir Jozef Krzebietke[1,*], Jadwiga Wierzbowska[1], Ewa Mackiewicz-Walec[1], Krzysztof Jozef Jankowski[2]

[1]Department of Agricultural Chemistry and Environment Protection, University of Warmia and Mazury in Olsztyn, Oczapowskiego Street 8, PL 10-719 Olsztyn, Poland
[2]Department of Agrotechnology, Agricultural Production Management and Agribusiness, University of Warmia and Mazury in Olsztyn, Oczapowskiego Street 8, PL 10-719 Olsztyn, Poland

ABSTRACT

Soil is an extremely valuable component of ecosystems. Even during a break in intensive soil cultivation planned for a few years, the set-aside land should be given the best possible protection. The biomass left on fallow fields is a priceless source of humic compounds, which entails positive influence on resources of nutrients, their mobilisation and availability to future crops. The field experiment comprised five treatments: 1 – bare fallow, 2 – a plot swarded with goat's rue (*Galega orientalis* Lam.), 3 – natural fallow, 4 – a plot swarded with a mix of goat's rue (*Galega orientalis* Lam.) and aweless brome (*Bromus inermis*), 5 – a plot swarded with aweless brome (*Bromus inermis*). During the experiment, agronomic treatments were limited to mechanical weeding of the bare fallow. Plant material was sampled from the swarded plots for chemical analyses. Each year, after the growing season finished, soil samples were taken. The soil was sampled at the depth of 0-25 cm. The tests showed that the way set-aside and fallow land is maintained significantly modified both the total nitrogen and organic carbon concentrations in soil. Goat's rue and its mixture with aweless brome most evidently favoured increased concentrations of organic carbon and total nitrogen. Bare fallow prove to be the least favourable solution. The tests have also demonstrated that the amount of organic carbon compounds accumulated in soil depended on the biomass of plants on a given set-aside field and the nitrogen accumulated in that biomass.

KEYWORDS:
bare and natural fallow, *Galega orientalis* Lam., Corg., set-aside field, Ntot.

INTRODUCTION

Because of its role in crop production, soil should be constantly protected, regardless of the current economic conditions and market demands [10, 21]. The highest possible protection measures should be taken, due to many natural environmental threats, when laying aside for several years the farmland which until then has been intensively cropped [4,14]. One of the successful methods of protecting fallow land is growing grass sward [5, 11, 12, 25]. By adding considerable amounts of biomass to the cycling of matter, this solution can significantly improve properties of many agriculturally valuable soils [3,31]. Considering two aspects, such as preserving biodiversity and providing the most effective protection of fields temporarily excluded from agricultural production, grasses and their mixtures with papilionaceous plants are recommended [16, 40]. Such management of idle land enables one to monitor plant succession, contributes to enhanced landscape attributes and ensures an easy return to agricultural production on a set-aside field [10, 37]. Controlled grass sward eliminates the risk of weed infestation on fields adjacent to idle ones [9]. Permanent grass cover favours sequestration in the soil, which means that arable lands can alleviate climate change by improving the global balance of CO_2 and N_2O [1, 20, 33]. Further, the biomass left on fallow land is a valuable source of humic compounds, which entails its positive influence on resources of nutrients, their mobilisation and availability to subsequent crops [19,39,40]. A break in growing crops alongside a constant supply of biomass encourage the biological activity in soils set aside [28], which offers a chance to replenish soil resources of organic carbon [6, 18]. The role of organic matter, in the context of soil fertility, is frequently undervalued [2, 32]. However, it is actually organic matter that largely determines stable yields of many crop species [15]. Having fulfilled certain conditions, a break in crop production, even a few years long, can generate measurable benefits [14].

The research was targeted to evaluate the different ways of soil conservation excluded from the agricultural use in the context of preserving its fertility. For this purpose, the content of C_{org} and N_{og} in the soil subjected to the long-term set-aside (natural fallow, goat's rue, goat's rue+aweless brome, aweless brome) and fallowing (bare fallow) was traced.

FIGURE 1
Location of the experiment

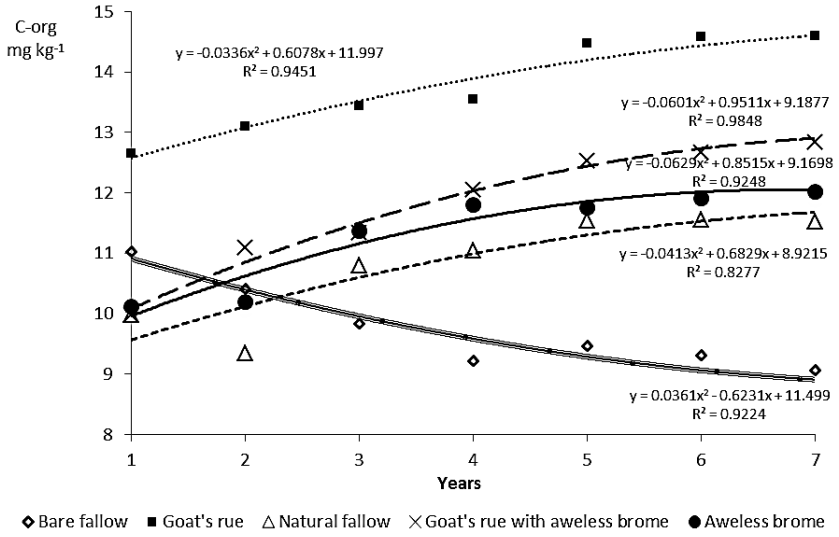

FIGURE 2
Dynamics of changes in organic carbon content in soil in the years 2000-2007

MATERIALS AND METHODS

In 1996, a field experiment was set up in Knopin in Poland - 53º57'38''N, 20º23'12''E (the municipality of Dobre Miasto, the Province of Warmia and Mazury) on some land owned by a private farmer (Fig. 1). This paper discusses the results obtained in 2000-2007. In order to mitigate the impact of uncontrolled variables on the results of experiment due to the lack of repetitions and its unconventional system, the study period was extended to eight years and the preliminary four-years period of this study was omitted. The soil under the whole experiment was classified as good wheat complex, class IIIa in the Polish soil classification system (*haplic cambisol* – IUSS Working Group WRB 2014). The abundance of the humic layer in available nutrients was as follows: 71.9 – 119.2 mg P kg^{-1}, 196.4 – 223.0 mg kg^{-1} K and 69.1 - 85.1 mg Mg kg^{-1} of soil. The content of organic carbon ranged from 9.50 to 12.03 g kg^{-1} and total nitrogen from 1.08 to 1.24 g kg^{-1}. On the selected area there were randomized the plots (480 m^2×20 treatments), on which the following types of set-aside land were started: bare

fallow, plot swarded with goat's rue (*Galega orientalis* Lam.), natural fallow, plot covered with a mixture of goat's rue (*Galega orientalis* Lam.) and aweless brome (*Bromus inermis*), plots warded with aweless brome (*Bromus inermis*)with four replications.

The bare fallow, with regular mechanical weeding treatments, was kept free from any growing plants. The weeding was performed with passive agricultural devices. No agronomic treatments were performed on the other plots. Plant-covered plots were sampled for analysis, but the whole biomass remained on field. Plant samples ($4 \times 1m^2$) were taken from the fallows in order to determine the biomass and chemical composition. Samples of the plants were collected once each year at the same growth and development stage, i.e. at the early inflorescence stage of goat's rue, when the plants had reached their maximum weight. Soil material for tests was sampled once a years, in autumn, after the plant growing season had terminated. The soil samples were taken from each treatment in four replicates from the depth of 0-25 cm. The sampled soil was brought to the air-dry state, and then passed through a sieve of a mesh diameter equal 1 mm. The soil samples thus prepared underwent chemical analyses, namely organic carbon was determined by Turin's method while total nitrogen was assayed by the distillation method after the samples had been mineralised in H_2SO_4. The determination of the concentration of N_{tot} (Kjeldahl method), having first wet mineralised the material in H_2SO_4 [24]. The results were submitted to statistical analysis using Duncan's test.

RESULTS

Content of organic carbon in soil. The above experiment has evidenced that the way fallow land is maintained has strong influence on the content of organic carbon in the 0-25 cm soil layer. The biggest change in the soil supply of organic carbon was caused by growing goat's rue on a set-aside field (Fig. 2). From the first to the last year of the experiment, the soil under this fallow land demonstrated the most dynamic increase in C_{org} among all the tested plots. Significantly poorer humus-formation capacity, compared to monoculture of goat's rue, was attributed to aweless brome, grown alone or in a mixture with goat's rue. Likewise, maintaining natural fallow proved to be less successful in enhancing the organic carbon concentration in soil.

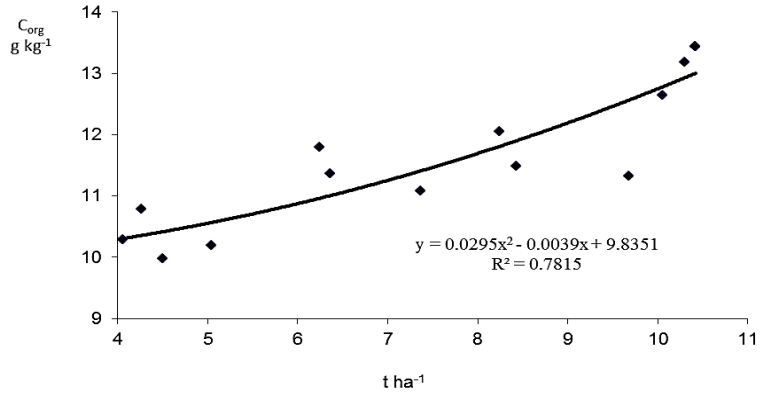

FIGURE 3

Content of C_{org} in soil depending on amount of the biomass produced on fallow land in t ha^{-1}

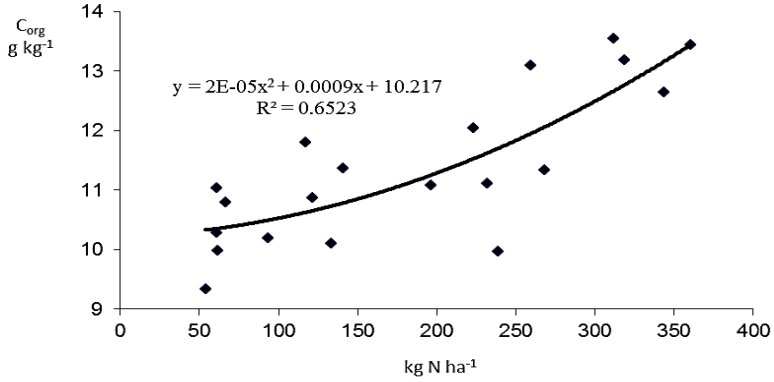

FIGURE 4

Content of C_{org} in soil depending on amount of N accumulated in the biomass on fallow land in kg ha^{-1}

TABLE 1
Mean content of total nitrogen in set-aside soil in g kg^{-1}

Treatments	Years								Mean
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	
Bare fallow	1.11	1.12	1.05	0.94	0.92	0.89	0.88	0.84	**0.97**
Goat's-rue	1.27	1.29	1.32	1.38	1.43	1.48	1.54	1.62	**1.42**
Natural fallow	1.20	1.22	1.22	1.36	1.39	1.38	1.38	1.38	**1.32**
Goat's-rue + aweless grass	1.18	1.22	1.26	1.33	1.39	1.41	1.45	1.46	**1.34**
Aweless grass	1.17	1.24	1.26	1.35	1.36	1.33	1.30	1.33	**1.29**
Mean	**1.19**	**1.22**	**1.22**	**1.27**	**1.30**	**1.30**	**1.31**	**1.33**	

$LSD_{0.05}$ for years 0.022; $LSD_{0.05}$ for treatments 0.018; $LSD_{0.05}$ for interaction 0.050

Natural fallow was the least effective, over the whole analyzed period, in increasing the soil's resources of organic matter. Keeping a field as bare fallow led to a considerable decrease in the concentration of organic carbon in the soil layer 0-25 cm deep. Statistically proven differences were nearly 44% high compared to the plot swarded with goat's rue and 24% high versus the plot swarded with a mixture of goat's rue and aweless brome. Long-term mechanical treatments carried out to keep land free from plants depleted the soil's supplies of organic carbon by about 22%.

The calculated regression equations evidently support the claim that set-aside land should have permanent plant cover. The results yielded by the present experiment also showed that the content of C_{org} in soil, under the conditions established for the trials, was strictly correlated with quantities of dry matter produced on set-aside fields and with amounts of nitrogen accumulated in the plants, obviously excluding the bare fallow from these considerations (Fig. 3 and 4). More organic carbon appeared in the soil under goat's rue or its mixture with aweless brome than in soil under natural fallow. Natural fallow was characterised by the lowest productivity; at the same time, the plants which covered natural fallow took up the smallest amounts of nitrogen.

Content of total nitrogen in soil. Based on the field experiment, it has been demonstrated that the tested ways of maintaining set-aside land have a significant effect on the total nitrogen content in soil (Table 1). Among all the analysed ways of maintaining idle land, goat's rue contributed most to a higher concentration of total nitrogen in the tested soil layer (0-25 cm). The soil abundance in total nitrogen was significantly lower in the other plant-covered plots than in the soil swarded with goat's rue. A mixture of goat's rue and aweless brome grass or plants growing on natural fallow land had a similar effect on the total nitrogen concentration in soil. When set-aside land was swarded with aweless brome grass alone, significantly less nitrogen was accumulated in soil. These differences, although verified statistically, were not so big when compared to the effect produced by a mixture of this grass with goat's rue or determined in a field covered with natural vegetation. Considerably less nitrogen was determined in the soil under bare fallow. Keeping idle land as bare fallow led to strong depletion of total nitrogen from soil, as the mean concentration of this element in soil under bare fallow was over 30% lower.

DISCUSSION

The constant supply of organic matter in the form of biomass left on a field each year could have been one of the reasons why the concentration of organic carbon in the 0-25 cm layer of soil in plant covered plots significantly increased. This increase was the highest in soil under goat's rue or a mixture of goat's rue and aweless brome. Studies carried out by Żarczyński and Sienkiewicz [41] or Suominen et al. [35] imply that goat's rue or a mixture of goat's rue with aweless brome, used to sward set-aside land, are highly capable of accumulating nutrients. The above authors claim that goat's rue as well as its mixture with aweless brome can produce large amounts of biomass during a growing season. Owing to the high productivity of both the aerial parts of this species and its developed root system with underground stolons, goat's rue is a potential source of organic substances, the biggest one among all the plants grown on the fallow fields in the present experiment. Keeping the tested fields idle for a few years favoured steady accumulation of organic matter on and in the soil laid fallow. An analogous, positive effect of a mix of papilionaceous plants with grasses on the concentration of organic carbon in uncropped soils has been recorded by Sabienne et al. [27]. Long-term set-aside leads to the formation of turf, which is dominated by grass. Hence, the similar effect was probably obtained by the cover of fallow land with aweless brome. A similar increase in the concentration of organic carbon has been reported by Fullen et al. [12], who found out that growing perennial ryegrass (*Lolium perenne*) for ten years on fallow land led to an increase in the soil resources of organic carbon by 10.7 gkg^{-1}despite the fact that the field was situated on strongly inclined terrain. The above authors, analogously to Schroth et al. [30], attributed higher C_{org} concentration in fallow soil to the effect produced by

plants grown and left on a given field. According to Fullen [13], presence of grasses on set-aside fields favours retention of water and nutrients in soil, which can have strong influence on concentration of organic matter in soil. Sarmiento and Bottner [29] also report about the positive impact of setting aside farmland on the soil content of organic carbon. However, these authors attribute such effects mostly to a larger number of microorganisms in uncropped soil. In turn, Warren and Topping [38] report that different combinations of plant cover may produce different effects on soil properties. The two researchers underline that the final result largely depends on the soil itself, in which the major effect is played by the share of floatable particles. In our own studies, maintaining land as bare fallow had a negative influence on the stability of the discussed soil fertility indicator and led to depletion of organic carbon resources. Similar results were achieved by Asuming-Brempong et al. [43], who concluded that when soil was kept as bare fallow, the soil resources of organic carbon were not improved. These results correlated with reports about the negative effect of intensive soil tillage on soil humus supplies [38]. Intensive mechanical soil tillage intensifies oxidation of organic matter, especially in the topmost layers of soil. Ploughing physically disturbs the surface layer of soil, in which the content of O_2 grows; moreover, residues on top of the soil are dispersed and have more contact with soil particles, which enhances the microbial activity. There are many reports suggesting that presence of plant cover strongly determines several chemical attributes of soils excluded from farming [17]. Warren and Topping [38] emphasise that the results obtained under such conditions are predominantly shaped by contributions of particular plant species covering idle land. To some extent, this conclusion is supported by the results of the total nitrogen concentration in soil obtained in our experiment. The highest concentration of this nutrient was found in the soil under goat's rue. Goat's rue is a perennial species, which Oldham and Ransom [23] go as far as to call an invasive species. Egamberdieva et al. [7] point to the fact that this plant, owing to a symbiotic association with nitrogen-binding bacteria, can accumulate large quantities of nitrogen. Nõmmsalu et al. [22] prove that this plant can accumulate from 180 up to 480 kg Nha^{-1} in a year. It is probably because of such capability as well as well-developed roots which keep goat's rue well supplied with water that the soil under this plant has been demonstrated as being the most abundant in total nitrogen. According to Zhong et al. [42], presence of papilionaceous plants on arable lands, owing to their capacity of binding free nitrogen, is highly desirable. A contribution of papilionaceous plants to plants growing on a field improves yields and can successfully compete with farmyard manure fertilization, as Tonitto et al. [36] showed. However, growing papilionaceous plants creates a risk that excessive amounts of nitrogen will be accumulated in soil, as assimilated during their growing season. After its mineralisation, there is a risk that mineralised forms of nitrogen can travel downwards into the soil profile and reach underground water [34]. The loss can range from 100 to 300 kg Nha^{-1} a year after set-aside land is again used for agricultural production, as reported by Richter et al. [26]. Eggenschwiler et al. [8] stated that mixtures of perennial papilionaceous plants with grasses did not pose any threat to the environment related to nitrogen supplies. Less dynamic changes as well as a slower rate of increase in total nitrogen concentration in soil under a mix of goat's rue with aweless brome grass indicate that this is a safer way of maintaining fallow land than sowing a monoculture of goat's rue. In contrast, keeping idle land as bare fallow resulted in a steady decrease in the concentration of this nutrient in soil. Nitrogen was most probably mineralised and then leached downwards into the soil profile. This event, as Richter et al. [26] suggest, can be encouraged by the fact that there are no plants to deter underground water transfer, and agronomic practice greatly accelerates the rate of mineralisation in soil under a fallow field. This is why Froment et al. [11] recommend sowing idle fields, if only for a short time, with such plant as ryegrass so as to reduce the loss of nitrogen.

Both the authors' own results and the numerous cited reports indicate that fallowing has a strong effect on shaping soil's fertility. Results of the research presented in this paper have enabled us to conclude that long-term setting aside of farmland produces some effect on the concentration of organic carbon and total nitrogen. The nature of fluctuations in the levels of both nutrients depends on how the farmland set aside for some time is maintained. Certainly, the worst possible method proved to be bare fallow. Plant cover, depending on its type, largely prevented negative changes in soil. The biomass produced by plants each year was left on a fallow field, improving the general balance of organic matter. The results clearly indicate that growing goat's rue or its mixture with aweless brome raises the soil's supplies of organic carbon and total nitrogen. When fallow land is maintained in such a way, instead of being depleted from nutrients, it can be made more fertile. The results of our experiment demonstrate rather clearly that both goat's rue and its mixture with aweless brome should be recommended for maintaining farmland temporarily laid fallow.

CONCLUSIONS

Both the authors' own results and the numerous cited reports indicate that fallowing has a strong effect on shaping soil's fertility. Results of the research presented in this paper have enabled us to conclude that long-term setting aside of farmland produces some effect on the concentration of organic carbon

and total nitrogen. The nature of fluctuations in the levels of both nutrients depends on how the farmland set aside for some time is maintained. Certainly, the worst possible method proved to be bare fallow. Plant cover, depending on its type, largely prevented negative changes in soil. The biomass produced by plants each year was left on a fallow field, improving the general balance of organic matter. The results clearly indicate that growing goat's rue or its mixture with aweless brome raises the soil's supplies of organic carbon and total nitrogen. When fallow land is maintained in such a way, instead of being depleted from nutrients, it can be made more fertile. The results of our experiment demonstrate rather clearly that both goat's rue and its mixture with aweless brome should be recommended for maintaining farmland temporarily laid fallow.

ACKNOWLEDGEMENT

This research was supported by the Ministry of Science and Higher Education of Poland as the part of statutory activities (No. 20.610.002-300) and Research Project No. 2 P06R 061 28 financed by KBN.

REFERENCES

[1] Baležentienė, L. and Mikša, O. (2017) Seasonal carbon exchange in organic and conventional ley and winter wheat agroecosystems in central Lithuania. J. Elem. 22(2), 629-641.

[2] Bertora, C., Zavattaro, L., Sacco, D., Monaco, S. and Grignani, C. (2009) Soil organic matter dynamics and losses in manured maize-based forage systems. European Journal of Agronomy. 30, 177-186.

[3] Biederbeck, V.O., Zentner, R.P. and Campbell, C.A. (2005) Soil microbial populations and activities as influenced by legume green fallow in a semiarid climate. Soil Biology & Biochemistry. 37, 1775-1784.

[4] Boellstorff, D. and Benito, G. (2005) Impacts of set-aside policy on the risk of soil erosion in central Spain. Agriculture, Ecosystems & Environment. 107, 231-243.

[5] Clotuche, P., Godden, B., Van Bol, V., Peeters, A. and Penninckx, M. (1998) Influence of set-aside on the nitrate content of soil profiles. Environmental Pollution. 102, 501-506.

[6] Curcio, E., Danise, T., Innangi, M., Coppola, E., Alvarez-Romero, M., Fioretto, A. and Papa, S. (2017) Soil characterization and comparison of organic matter quality and quantity of two stands under different vegetation cover on Monte Faito (Campania, S-Italy) Fresen. Environ. Bull. 26, 8-18.

[7] Egamberdieva, D., Berg, G., Lindström, K. and Räsänen, L.A. (2010) Co-inoculation of Pseudomonas spp. with Rhizobium improves growth and symbiotic performance of fodder galega (*Galega orientalis* Lam.). European Journal of Soil Biology. 46, 269-272.

[8] Eggenschwiler, L., Jacot, K.A. and Edwards, P.J. (2009) Vegetation development and nitrogen dynamics of sown and spontaneous set-aside on arable land. Ecological Engineering. 35, 890–897.

[9] Ekeleme, F., Chikoye, D., and Akobundu, I.O. (2003) Changes in size and composition of weed communities during planted and natural fallows. Basic and Applied Ecology. 5, 25-33.

[10] Firbank, L.G, Smart, S.M, Crabb, J, Critchley, C.N.R, Fowbert, J.W, Fuller, R.J, Gladders, P, Green, D.B, Henderson, I. and Hill, M.O. (2003) Agronomic and ecological costs and benefits of set-aside in England. Agriculture, Ecosystems and Environment. 95, 73-85.

[11] Froment, M.A., Grylls, J.P., Collins, C. and Chalmers, A.G. (1999) Rotational set-aside; influence of vegetation and management for one-year plant covers on soil mineral nitrogen during and after set-aside at five sites in England. Journal of Agricultural Science. 113, 1-19.

[12] Fullen, M.A., Booth C.A. and Brandsma, R.T. (2006) Long-term effects of grass ley set-aside on erosion rates and soil organic matter on sandy soils in east Shropshire, UK. Soil & Tillage Research. 89, 122-128.

[13] Fullen, M.A. (1998) Effects of grass ley set-aside on runoff, erosion and organic matter levels in sandy soils in east Shropshire, UK. Soil & Tillage Research. 46, 41-49.

[14] Gathumbi, S.M., Cadisch, G. and Giller, K.E. (2004) Improved fallows: effects of species interaction on growth and productivity in a monoculture and mixed stands. Forest Ecology and Management, 187, 267-280.

[15] Grignani, C., Zavattaro, L., Sacco, D. and Monaco, S. (2007) Production, nitrogen and carbon balance of maize-based forage systems. European Journal of Agronomy. 26, 442-453.

[16] Hedlund, K., Santa Regina, I., Van Der Puten, H.W., Lepä, J., Diaz, T., Korthals, G.W., Lavorel, S., Brown, V.K., Gormsen, D., Mortimer, S.R., Rodriguez-Barrueco, C., Roy, J., Smilauer, P., Smilauerova, M. and Van Dijk, C. (2003) Plant species diversity, plant biomass and responses of soil community on abandoned land across Europe: idiosyncracy or above-belowground time lags. Oikos. 103, 45-58.

[17] Huang, J., Li, J., Nti Nkrumah, P., and Appiah-Sefah, G. (2016) Effects of recovery of wetland vegetation on active nutrients fractions in albic soils. Fresen. Environ. Bull. 25, 754-761.

[18] Karlsson, L.O.T., Andrén, O,. Kätterer, T. and Mattsson, L. (2003) Management effects on topsoil carbon and nitrogen in Swedish long-term

field experiments-budget calculations with and without humus pool dynamics. European Journal of Agronomy. 20, 137-147.
[19] Kacorzyk, P., and Głąb T. (2017) Effect of ten years of mineral and organic fertilization on the herbage production of a mountain meadow. J. Elem. 22(1), 219-233.
[20] MacDonald, J.D., Rochette, P., Chantigny, M.H., Angers, D.A., Royer, I. and Gasser, M.O. (2011) Ploughing a poorly drained grassland reduced N_2O emissions compared to chemical fallow. Soil & Tillage Research. 111, 123-132.
[21] Mertz, O., Wadley, R.L., Nielsen, U., Bruun, T.B., Colfer, C.J.P., Neergaard, A., Jepsen, M.R., Martinussen, T., Zhao, Q., Noweg, G.T. and Magid, J. (2008) A fresh look at shifting cultivation: Fallow length an uncertain indicator of productivity. Agricultural Systems. 96, 75-84.
[22] Nõmmsalu, H., Meripõld, H., Metlitskaja, J. and Raig, H. (1996) Fodder galega (*Galega orientalis* Lam.): a promising new leguminous forage plant. Seed Science & Technology. 24, 359-364.
[23] Oldham, M. and Ransom, C.V. (2009) Goatsrue (*Galega officinalis*) Seed Biology. Weed Science. 57, 149-154.
[24] Panak, H. (1997) Metodical Guide to Agricultural Chemistry. Wydawnictwo ART Olsztyn (in Polish).
[25] Poptcheva, K., Schwartze, P., Vogel, A., Kleinebecker, T. and Hölzel, N. (2009) Changes in wet meadow vegetation after 20 years of different management in a field experiment (North-West Germany). Agriculture, Ecosystems and Environment. 134, 108-114.
[26] Richter, G.M., Beblik, A.J., Schmalstieg, K. and Richter, O. (1998) N-dynamics and nitrate leaching under rotational and continuous set-aside -a case study at the field and catchment scale. Agriculture, Ecosystems and Environment. 68, 125-138.
[27] Sabiene, N., Kušliene, G. and Zaleckas, E. (2010) The influence of land use on soil organic carbon and nitrogen content and redox potential. Zemdirbyste. 97, 15-24.
[28] Salamon, J.A., Wissuwa, J. Jagos, S., Koblmüller, M., Ozinger, O., Winkler, C. and Frank, T. (2011) Plant species effects on soil macrofauna density in grassy arable fallows of different age. European Journal of Soil Biology. 47, 129-137.
[29] Sarmiento, L. and Bottner, P. (2002) Carbon and nitrogen dynamics in two soils with different fallow times in the high tropical Andes: indications for fertility restoration. Applied Soil Ecology. 19: 79-89.
[30] Schroth, G., Kolbe, D., Pity, B. and Zech, W. (1995) Searching for criteria the selection of efficient tree species for fallow improvement with special reference to carbon and nitrogen. Nutrient Cycling in Agroecosystems. 42, 297-314.
[31] Sienkiewicz, S., Żarczyński, P. and Krzebietke, S. (2011). Effect of land use of fields excluded from cultivation on soil content of available nutrients. Journal of Elementology. 16(1), 75-84.
[32] Sleutel, S., DeNeve, S., Németh, T., Tóth, T. and Hofman, G. (2006) Effect of manure and fertilizer application on the distribution of organic carbon in different soil fractions in long-term field experiments. European Journal of Agronomy. 25, 280-288.
[33] Smith, P. (2004) Carbon sequestration in croplands: the potential in Europe and the global context. European Journal of Agronomy. 20, 229-236.
[34] Sosulski, T., Szara, E., Stępień, W., Szymańska, M. and Borowska-Komenda, M. (2016) Carbon and nitrogen leaching in long-term experiments and DOC/N-NO_3^- ratio in drainage water as an indicator of denitrification potential in different fertilization and crop rotation systems. Fresen. Environ. Bull. 25, 2813-2824.
[35] Suominen, L., Jussila, M.M., Mäkeläinen, K., Romantschuk, M. and Lindström, K. (2000) Evaluation of the Galega-Rhizobium galegae system for the bioremediation of oil-contaminated soil. Environmental Pollution. 107, 239-244.
[36] Tonitto, C., David, M.B. and Drinkwater, L.E. (2006) Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agriculture, Ecosystems and Environment. 112, 58-72.
[37] Tscharntke, T., Batáry, P. and Dormann, C.F. (2011) Set-aside management: How do succession, sowing patterns and landscape context affect biodiversity? Agriculture, Ecosystems and Environment. 143, 37-44.
[38] Warren, J.M. and Topping, C.J. (1999) A space occupancy model for the vegetation succession that occurs on set-aside. Agriculture, Ecosystems & Environment. 72, 119-129.
[39] Wyłupek, T. and Gawryluk, A. (2016) Statistical assessment of certain properties of soil under permanent grasslands. J. Elem., 21(2), 585-594.
[40] Żarczyński, P. Sienkiewicz, S. and Krzebietke, S. (2008) Accumulation of macroelements in plants on newly established fallows. Journal of Elementology. 13(3), 455-461.
[41] Żarczyński, P. and Sienkiewicz, S. (2007) Content of macroelements in plants growing on fallow fields. Journal of Elementology. 12(3), 217-224.
[42] Zhong, Z., Lemke, R.L. and Nelson, L.M. (2009) Nitrous oxide emissions associated with nitrogen fixation by grain legumes. Soil Biology & Biochemistry. 41, 2283-2291.

[43] Asuming-Brempong, S., Gantner, S., Adiku, S.G.K., Archer, G., Edusei, V. and Tiedje, J.M. (2008) Changes in the biodiversity of microbial populations in tropical soils under different fallow treatments. Soil Biology Biochemistry. 40, 2811-2818.

Received: **24.02.2017**
Accepted: **27.08.2017**

CORRESPONDING AUTHOR

Sławomir Krzebietke
Department of Agricultural Chemistry and Environment Protection, University of Warmia and Mazury in Olsztyn, Oczapowskiego Street 8, PL 10-719 Olsztyn Poland

e-mail: slawomir.krzebietke@uwm.edu.pl