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Transition paths of former low productive agricultural land

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The paper presents the main results of the research on various types of low productive soils management carried out over a ten-year period (1995–2004) at the Lithuanian Institute of Agriculture, Vokė Branch. The balances of energy and main nutrients were calculated to evaluate the advantages and negative effects of various treatments of soil management. Experimental results showed the type of phytocenosis affecting nutrient cycling in the ecosystem. It was determined that conventional field crop rotation is characterised by the highest requirement for nutrients (58.0 kg ha^{-1} N, 12 kg ha^{-1} P, 85 kg ha^{-1} K) compared with phytocenoses of the cut grassland (more intensive removal of Ca only) or the abandoned land. The evaluation of the productivity in various phytocenoses gave a clear answer why abandonment of soils or setting aside is less favourable than the establishment of cultural swards or land afforestation (3–4.4 times). Within the established cenoses, afforestation and establishment of cultural sward were exceptionally effective in terms of productivity (605–875 GJ ha^{-1} during 10 years). All the types of agrophytocenoses compared were several times more productive than the fallow. The productivity of the cenoses decreased in the following order: pine afforestration → cultural sward → fallow (natural sward), among which the fertilized ones were more productive. Taking into account the 10-year experimental results we conclude that transition of agricultural land is characterized as a complex of factors having a strong effect on the energy and nutrients turnover. Extensive agriculture or enlargement of land abandonment exerts a negative effect on the bordering fields with intensive agriculture, because it creates perfect conditions for weed occurrence, diseases and pests. Furthermore, from the energy viewpoint it is the least effective way.

Key words: fallow, afforestation, renaturalization, balance of biogenic elements

INTRODUCTION

In Lithuania, the largest part of agrocenoses cover the areas of former forests, and, under the conditions of intensive farming, the forms of natural landscape are transformed irrespective of the natural basis as on large areas of the former Soviet Union (Родоман, Каганский, 2004). Due to the over-intensive land reclamation carried out during the years of collective farming (1960–1990), large areas of natural perennial vegetation were destroyed, the areas under pastures and grasslands declined, and soil erosion processes were intensified. With a reduction in anthropogenic load, agroecosystems return to their primeval state through self-regulation, and artificially-formed field contours disappear (Rusanov, 2003). However, in those cases when natural ecosystems have been fundamentally reorganised into agrophytocenoses, natural restoration of their initial state is impossible (Cairns, 1988). The national strategy for sustainable development (Dėl..., 2003) points out that with spontaneous renaturalization, the areas of forest and other natural territories increase as well as biological and landscape diversity, and during the last decade afforestation of unproductive land has resulted in 1% increase in the total woodland area, which will consequently enhance the ecological stability of the territories (Dėl..., 2003). Consideration of various ecological and economical factors based on experimental results is necessary for planning of low productive soils management. The importance of climatic resources dynamics for land use was demonstrated by Bukantis and Rimkus (Bukantis, Rimkus, 1997), and scenarios until 2050 were created for different regions of Lithuania. Differences in soil class explain a large part of the land abandonment pattern and the associated transition paths as well as transition rates (Sluiter, de Jong, 2007). In a companion paper (Marcinkonis, 2007) we clarify the effect of various cenoses on soil agrochemical properties, especially the strength and dynamic of the effect. The objective of the research discussed in this paper was to determine the variation of nutrients and energy turnover in various cenoses by comparing the reference site and the observation sites of other cenoses, the productivity of optimally fertilized and non-fertilized sites, as well as nutrient balance in the cultivated soil and perennial swards.

MATERIALS AND METHODS

Stationary experimental sites (SES) were set up in 1995 in Vilnius district, Didieji Lygainiai village. The experiments were conducted until 2004. From the geomorphological viewpoint, it is a fluvoglacial zone the relief of which is a slightly undulating plain with a slight southerly inclination. Common sandy soils prevail in the region, and the agronomic value of soils is very low. The site represents the East Lithuanian soil zone, which is

10 m	I a	II a	Protection zone (hayfield)	III	Protection zone (hayfield)	IV	20 m
10 m	I b	II b					
	20 m	20 m	10 m	20 m	10 m	20m	

Fig 1. Scheme of stationary experimental sites (SES) (size in meters)

the remotest one from the sea, and the climate is continental here. During the experimental period, annual precipitation varied from 519 mm to 766 mm (average 650 mm, long-term average 677 mm), long-term average temperature being 5.7 °C.

The soil of the experimental site is loamy sand on fluvoglacial gravel Haplic Luvisol with the content of org. C 1.0%, C / N ratio 12–14, soil pH in KCl 6.0. The last liming was performed in 1985 when about 250 t ha^{-1} of calcareous sapropel was applied.

Crop and soil management practices. In 1994, rye stubble was ploughed in and, in 1995, in the spring-ploughed, moderately cultivated soil, four sites were set up: 1) crop rotation or field site (I), 2) cut grasslands (II), 3) fallow (III), and 4) afforested sites (IV). The four experimental sites were arranged in one row (Fig. 1). The sites I and II were subdivided into two parts "a" and "b". In part "a" plants were fertilized, while in part "b" plants were not fertilized. The size of all the four sites was 400 m^2 each. The size of the subdivided sites I a, I b, II a, and II b was 200 m^2 each.

No crop or soil management operations were done in III D, IV MK and V MB sites. The yield was calculated from all the site area.

Methods of laboratory analyses. Dry matter yield of the above-ground phytomass was estimated, and N, P, K, Ca and Mg contents were measured in the plants. The plant samples were tested for total nitrogen content by the Kjeldahl technique, total phosphorus by the Denizhe technique modified by Maliugina and Chrenova, whereas total potassium and calcium were tested by flame photometry.

In order to compare the productivity data of phytocenoses, gross production (grain, straw, tubers, hay, pine forest biomass) was recalculated into total energy amount (TE) expressed in GJ. To calculate total energy of I–III SES, we used the following equation:

$$TE = 0.0238\ cP + 0.03972\ cF + 0.0188\ cFi + 0.0175\ cNES,$$

where TE is expressed in MJ kg^{-1}, cP (crude protein), cR (crude fat), cFi (crude fibre), and $cNES$ (crude non-nitrogen extracted substances) are expressed in g kg^{-1} (Jankauskas, Jankauskienė, 2000).

RESULTS

Comparison of total energy productivity is presented in Table 1. The data suggest that the difference between fertilized and unfertilized parts of the site of the field crop rotation was on average 39.4%, i. e. made up 243.49 GJ. Grassland phytocenosis was characterised not only by higher productivity but also by smaller differences between fertilized and unfertilized parts of the site. The difference was 30.5% and made up 219.99 GJ. In the phytocenosis of the abandoned land the total energy accumulated over 10 years amounted to 199.29 GJ, i. e. this cenosis was significantly less effective in terms of energy. The energy accumulation was calculated only from biomass of grasses, excluding young pine trees (Fig. 2). Having processed the initial taxation data in

Fig. 2. Fallow (III) and afforested (IV) SES on the 10th year of transition from arable land

Table 1. **Comparison of productivity in various phytocenoses (GJ ha^{-1}), D. Lygainiai, 1995–2004**

Gross energy, GJ	I a	I b	II a	II b	III	IV
During 10 years	614.97	371.48	802.69	604.7	199.29	874.91
Difference in GJ from plot I La	–	–243.49	187.72	–10.27	–415.68	259.94
Difference in % from plot I La	100.0	60.4	130.5	98.3	26.7	142.3

Balance of biogenic elements in various stationary sites (Table 2) was calculated including clover and lucerne nitrogen fixation (during the whole experimental period 140 kg ha^{-1} in I a, 96 kg ha^{-1} in I b, 798 kg ha^{-1} in II a, and 549 kg ha^{-1} in II b sites respectively)

Table 2. **Average annual balance of nutrients kg ha^{-1} in experimental plots, D. Lygainiai, 1995–2004**

Experimental plot	N	P	K	Ca	Mg
I a	–17.7	12.0	–33.9	22.5	–12.3
I b	–58.0	–11.9	–84.7	–13.1	–6.1
II a	11.1	26.8	–12.0	–29.6	–8.5
II b	–29.5	–9.1	–68.1	–56.4	–5.8
III	–19.0	–2.6	–19.4	–5.3	–1.2

a young pine tree forest site, we determined the volume of pines and the total amount of accumulated energy. The view of site IV is presented in Figure 2. The energy evaluation gives a clear answer to the question why natural abandonment of unused land is worse than seeding of the same land with perennial cultivated grasses or afforestation. Comparison of the total productivity of the entire experimental period of 10 years suggests that a largest amount of energy (142.3% of the total energy) is accumulated in the phytocenosis of a young pine forest, compared with that of the fertilized field as a control treatment for energy accumulation. It is noteworthy to observe, that from unfertilized grassland nearly the same amount of total energy was accumulated as from the fertilized crop rotation field, while the productivity of the abandoned land makes up only one fourth of this amount.

It was revealed that the chosen fertilization level allowed us to maintain positive balance of P and Ca in the field crop rotation, and positive balance of N and P in the grassland cenosis (Table 2). It was determined that conventional field crop rotation is characterised by the highest requirement for nutrients, compared with phytocenoses of cut grassland (more intensive removal of Ca only) or fallow. In the unfertilized field cenoses, annual nutrient losses per ha amounted to 58.0 kg of N, nearly 12 kg of P and about 85 kg of K. In grassland phytocenosis (with lucerne dominating) the greatest shortage is of Ca, and in the case of no fertilization the deficit of K significantly increases (about 5.6 times), whereas in cut natural swards (on temporarily abandoned land) the annual nutrient losses can make up around 19 kg ha^{-1} N and K, about 5 kg ha^{-1} Ca, a few kg ha^{-1} of P and Mg.

DISCUSSION

Under the conditions of conventional farming, organic matter mineralizes intensively, biogenic elements are removed with the yield, and organic fertilization or incorporation of plant residues large amounts of which are left after perennial grasses serve as a counterbalance for these processes. Approximately 19% of agricultural soils in Lithuania are low productive soils (sandy and eroded soils) (Žekonienė, 2002). The assessment of fecundity and grouping to non suitable, to agricultural use and low productive ones is still discussed. The latest results published on renaturalisation in Lithuania are discussing drained soils (Kvaraciejus, 2000) and afforestration of arable land (Armolaitis, Aleinikovienė et al., 2005). The authors presented detailed data on soil properties, however, the cycling of energy and biogenic elements were not discussed, and the issues of managing low productive soils cannot be solved without that knowledge. Comparison of the phytocenoses tested revealed that afforestation (874.9 GJ per 10 years) and establishment of a sward with a well-adapted species composition (604.7–802.7 GJ ha^{-1} per 10 years) were the most effective measures in terms of energy. The productivity of all the types of agrocenoses was several times higher than in the phytocenose of abandoned land (199.3 GJ ha^{-1} per 10 years). It was found out that the productivity reduction trends were as follows: young pine forest → cultivated grassland → fallow, and the fertilized systems were more productive (about 32.2%) among them. Comparison of nutrient balances demonstrated that non-fertilised agrophytocenoses have more negative balance of N, P, K and Ca in comparison to the fertilised sites, with the exception of Mg (Fig. 3). The grassland fertilised and non-fertilised sites balance differences in comparison to field rotation fertilised and non- fertilised sites balance differences were the same for N (101%), higher for P (150%) and K (110%), but lower for Ca (75%) and Mg (44%). This information could be taken into account during planning of low productive soils management.

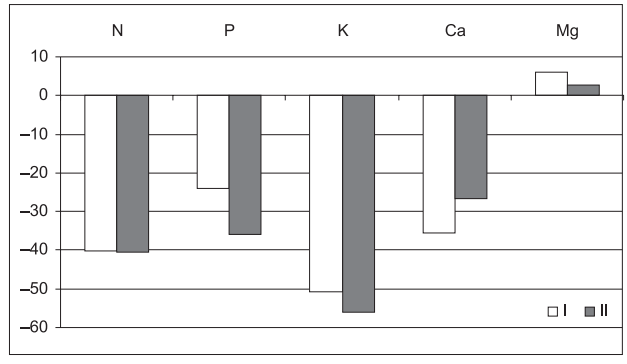

Fig. 3. Annual balance of nutrients (kg ha^{-1}) in non-fertilised sites in comparison to the fertilised sites (I and II SES)

Summarising the data generated during the ten-year experimental period, the transformation of field crop rotation soil into various phytocenoses can be described as a complex of factors that have a great effect on the turnover of energy and biogenic elements. It is noteworthy to mention, that restriction of farming and an increase in temporarily abandoned land exert not only negative effects on agriculture (farming) being developed nearby since perfect conditions are created for weed, disease and pest occurrence and spread, since such renaturalization method is also the least effective one from the energy viewpoint.

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NENAŠIŲ, BUVUSIŲ ŽEMĖS ŪKIO NAUDMENŲ TRANSFORMAVIMO BŪDAI

S a n t r a u k a

Straipsnyje apibendrinti 10 metų trukmės Lietuvos žemdirbystės instituto Vokės filiale atlikti tyrimai, palyginant įvairius mažo našumo dirvožemių tvarkymo būdus. Siekiant įvertinti šių būdų privalumus ir trūkumus buvo apskaičiuoti biomasėje sukaupta energija bei biogeninių elementų balansas priesmėlio paprastame išplautžemio dirvožemyje įrengtose tyrimų aikštelėse. Tyrimų rezultatai atskleidė, kad fitocenozės tipas turėjo įtakos maisto medžiagų apytakai ekosistemoje, didžiausiu biogeninių elementų poreikiu pasižymi lauko sėjomainos fitocenozė. Netręšiant čia per metus prarandama vidutiniškai 58,0 kg azoto, 12 kg fosforo ir 85 kg kalio iš hektaro dirvožemio. Nustatyta, kad savaime apželiančiose (dirvonuojančiose) fitocenozėse sukaupiama ženkliai mažiau biomasės nei kultūriniuose žolynuose bei apželdinant mišku (apie 3–4,4 karto). Transformavimas į minėtas fitocenozes buvo ypač efektyvus produktyvumo atžvilgiu (per 10 metų sukaupiama 605–875 GJ ha^{-1}). Kelis kartus produktyvesnės negu natūralios dirvono fitocenozės buvo abi tirtos agrofitocenozės (pievų bei lauko sėjomainos). Pagal produktyvumą, mažėjančia eile fitocenozes galima surikiuoti šia tvarka: apželdintos mišku (pušynas), kultūrinių pievų, dirvono fitocenozės. Ženkliai produktyvesnės tarp jų buvo tręšiamos fitocenozės (apie 32,2%).

Apibendrinant 10 metų tyrimo duomenų visumą, žemės ūkio naudmenų transformaciją galima apibūdinti kaip veiksnių kompleksą, darantį didelį poveikį energijos ir biogeninių elementų apytakai. Svarbu pažymėti, kad žemdirbystės apribojimas bei dirvonuojančių žemių išplitimas daro neigiamą poveikį šalia plėtojamai žemdirbystei, nes sudaro puikias sąlygas vystytis ir plisti piktžolėms, ligoms ir kenkėjams, ir energetiniu požiūriu toks renatūralizacijos būdas yra mažiausiai efektyvus.

Raktažodžiai: dirvonavimas, apželdinimas mišku, renatūralizacija, biogeninių elementų balansas