MAIZE-LEGUME INTERCROPPING EFFECT ON SOIL PROPERTIES AND CO_2 CONCENTRATION

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Abstract. The EU Greening program requested increasing the area of leguminous crops. The use of legumes as intercrops reduces both wind and water erosion, which has a positive effect on the yield of the main crops. Unfortunately, there is no precise scientific background of legume intercropping technologies in Lithuania. For this reason, a stationary short-term field experiment was started in 2022 at the Experimental Station of the Vytautas Magnus University Agriculture Academy (VMU AA), Lithuania (54º52′ N, 23º49′ E). The experimental soil is a silty loam Planosol (*Endohypogleyic-Eutric – Ple-gln-w*). The experiment consisted of maize (*Zea mays* L.) with legume intercrops, with a total of 6 treatments: 1. Inter-row loosening (control 1, K1); 2. Inter-row mulching with weeds (control 2, K2); 3. Faba bean intercropped (LUP); 4. Crimson clover intercropped (PUD); 5. Persian clover intercropped (PED); 6. Blue-flowered alfalfa (MEL) intercropped. Contrary to expectations, the slow development of the intercrops did not halt the physical erosion of the soil caused by the uneven precipitation. During the growing season, soil microstructure particles increased, and structural durability deteriorated. The CO_2 concentration in the soil depended more on the amount of precipitation and the type of intercrops, but the highest soil CO_2 concentrations at the beginning and the end of the growing season were in the control plots K1 and K2 without intercrops.

Keywords: *Zea mays* L., legume intercrops, soil properties, GHG.

Introduction

Maize (*Zea mays* L.) is a common crop in Lithuania and abroad. In 2022, 53,000 ha of maize were declared in Lithuania [1]. The potential uses of maize are wide. It has been grown in Lithuania for many years as animal feed, but with a warming climate, likely, that maize will increasingly be grown for cereals in Lithuania [2].

Multi-cropping is a type of crop production in which two or more different crops are grown simultaneously in the same field [3]. This is how more sustainable agricultural systems can be created, where it is possible to increase biodiversity, reduce damage from diseases, pests, and weeds, reduce the need for mineral fertilizers, and maintain soil fertility and quality [4]. This is particularly relevant to the Green Deal 2023-2027, which requires a significant reduction in the use of fertilizers and plant protection products. However, these requirements are very difficult to implement. This is due to several reasons: wheat and oilseed rape remain the most demanded crops, accounting for almost 50% of the total declared area of agricultural land in 2022 [1]. This makes it almost impossible to establish a crop rotation that maintains adequate phytosanitary periods, which leads to faster soil degradation and an increase in the spread of diseases and pests. Growing more crops together can increase the organic carbon, nutrient content, biological stability of the soil, etc. [5].

Intercrops play a really important role in agricultural systems by reducing soil erosion, enriching the soil with nutrients, helping to control some weeds and pests, etc. However, it is important to realize that the number of crops that can be grown as intercrops is quite large and they all have different functions and benefits [6]. Intercrops containing legumes play a very important role in enriching the soil with biological nitrogen. Nitrogen fertilization rates can be reduced in the following year when growing the main crops. However, studies have shown that intercropping results in a faster mineralization rate, so intercropping should be done one month before sowing to optimally supply the main crop with nutrients [7]. However, even if no intercropping is done and direct sowing is done, intercrops still mineralize and enrich the soil with nutrients, but at a slower rate. The undecomposed crop residues cover the row spacing and thus inhibit soil erosion and weed growth [8]. However, the cultivation of multi-crops is still relatively unexplored, even though there is a great deal of latent potential in this area [3].

The aim of this study was to assess the influence of monomial and binomial maize and legume agroecosystems on soil structure, persistence, and soil CO_2 concentration.

Materials and methods

A stationary short-term field experiment started in 2022 at the Experimental Station of the Vytautas Magnus University Agriculture Academy (VMU AA) (54º52′ N, 23º49′ E). In this study, the data of 2023 is presented. Experimental soil is a silty loam (45.6% sand, 41.7% silt, 12.7% clay) Planosol (*Endohypogleyic-Eutric – Ple-gln-w*) [9]. Soil pH_{HCl} ranged from 7.3 to 7.8, total nitrogen content – from 0.08 to 0.13%, humus content – from 1.5 to 1.7%, mobile phosphorus content – from 189 to 280 mg kg^{-1}, mobile potassium content – from 97 to 118 mg kg^{-1}, mobile sulfur content – from 1.2 to 2.6 mg kg^{-1} and magnesium content – from 436 to 790 mg kg^{-1}. The water regime was regulated by closed drainage and the microrelief was leveled. The topsoil was 27–30 cm thick.

The experiment consists of growing maize (*Zea mays* L.) (hybrid P7034) with plants of the *Fabaceae* family: faba beans (*Vicia faba* L.) (variety "Trumpet"), crimson clover (*Trifolium incarnatum* L.) (variety "Kardinal"), Persian clover (*Triffolium resupinatum* L.) (variety "Rusty"), blue-flowered alfalfa (*Medicago sativa* L.) (variety "Giulia"). A total of 6 treatments:

1. Inter-row loosening (control 1, K1);
2. Inter-row mulching with weeds (control 2, K2);
3. Faba bean intercropped (LUP);
4. Crimson clover intercropped (PUD);
5. Persian clover intercropped (PED);
6. Blue-flowered alfalfa intercropped (MEL).

The field experiment is carried out in 4 replications. The plots are arranged in a randomized manner. The initial size of the plot is 18.4 m^2 and the reference size is 18 m^2. The total number of plots in the experiment is 24. The year of establishment of the experiment is the year of establishment of the black fallow.

In autumn, before the experiment was set up, the soil was plowed with a plow and a Kverneland semi-screw plow. In spring, when the soil had reached physical maturity, it was cultivated with a KLG-4 composite cultivator to a depth of 3-4 cm. On the same day, mineral fertilizer NPK 5:15:29 was spread. The fertilizer rate was 300 kg·ha^{-1} (Table 1).

Table 1

Agrotechnical measures and their timing

No.	Agrotechnical measures	Timing
1	Autumn ploughing	After the harvest of the intercrop
2	Spring pre-sowing tillage	After the physical maturity of the soil
3	Basic (minimum) fertilization with NPK fertilizer	Before sowing
4	Sowing	Immediately after pre-sowing cultivation
5	Inter-row loosening and sowing of intercrops	After maize has germinated
6	Inter-row loosening, chopping, and spreading of intercrops and weeds	According to the need 2–3 times, but no later than when maize reaches a height of 70-100 cm
7	Harvest	After the maize has finished growing

After fertilization, up to 3 days later, the maize will be sown with a Kverneland Accord Optima pneumo-mechanical drill with a row spacing of 45 cm, and with a dotted spacing of 21 cm between seeds. After germination, the inter-rows were loosened, and the 6 rows were sown with a hand-held greenhouse sowing drill and the bean intercrops were sown. The edge rows of the intercrops are about 1-2 cm away from the maize. The sowing of maize and intercrops is carried out according to the prescribed sowing rates: maize – 27-30 kg·ha^{-1}, faba bean – 200 kg·ha^{-1}, Crimson clover – 30 kg·ha^{-1}, Persian clover – 18 kg·ha^{-1}, blue-flowered alfalfa – 20 kg·ha^{-1}.

Maize inter-rows are loosened, intercrops and weeds are cut and chopped 2-3 times during the maize growing season until the maize reaches a height of 50-70 cm. In 2023, the operation was carried out 2 times because of the slow development of the seedlings due to drought. The intercrops were cut with a modified Stihl FS-550 hand-held shrub-cutter, using a designed and manufactured operator-loadreducing trolley with a protective hood, which spreads the biomass evenly in the crop inter-row and protects the crop from mechanical damage. Intercrops are cut when they reach a height of 20–25 cm. The green mass of the intercrops and weeds is spread in the maize inter-rows. The inter-rows are manually loosened (Treatment 1). After harvesting, the remaining crop residues will be plowed in with a plow with a semi-screw plowshare at a depth of 20-22 cm. Pesticides are not used in the agricultural technology. The biomass will be harvested manually at the end of the maize growing season (when the grains reach the beginning of hard maturity).

In terms of precipitation, the territory of Lithuania is in the zone of surplus moisture. The average annual precipitation is 600-650 mm and evaporation about 500 mm. The warm season lasts 230-260 days. The spring of 2023 was cool and dry, resulting in poor germination of the bean intercrops. In June-July there was often a lack of moisture and heat, which resulted in sluggish intercrop biomass growth. August was exceptionally hot and rainy, reminiscent of a tropical climate and favorable for the development of plant biomass (Table 2).

Table 2

Meteorological conditions during vegetative season

Month	Per 10-days period			Per month	Long-term average
	I	II	III		
Average air temperature of 24 hours, ˚C					
IV	5.6	10.0	9.8	8.5	6.9
V	8.4	14.1	15.3	12.6	13.2
VI	15.0	18.0	18.9	17.3	16.1
VII	17.2	19.0	17.4	18.0	18.7
VIII	19.1	22.2	19.3	20.2	17.3
Precipitation rate, mm					
IV	7.8	6.7	12.2	26.7	41.3
V	0.0	14.3	0.0	14.3	61.7
VI	1.1	47.4	15.5	64.0	76.9
VII	20.0	3.8	13.0	36.8	96.6
VIII	40.1	5.9	50.2	96.2	88.9

For the determination of the soil structure and its durability, samples shall be taken after sowing, before inter-row loosening, and before harvesting, in a soil layer of 0 to 25 cm in at least 4 to 5 places in each field. An average sample shall be taken. A Retsch sieving machine (Retsch Lab Equipment, VERDER Group, the Netherlands) and a set of sieves are used for the analyses. To determine the CO_2 concentration in the soil, a 20 cm diameter ring is hammered into each plot in spring, and 3 measurements are taken at the beginning, middle, and end of the growing season. Determination is done by IRGA (Infra-Red Gas Analyzer). A portable soil respiration system LI-8100A with camera 8100-103 is used.

The data were statistically evaluated using the computer program ANOVA [10]. Differences between the averages of treatments marked with different letters (a, b, c, …) are significant, $P < 0.05$. The calculations were carried out at the Vytautas Magnus University Agriculture Academy.

Results and discussion

Soil structure and its durability. Soil structure is classified according to the size of the aggregates, as follows: 1. Megastructure (aggregates larger than 10 mm in diameter); 2. Macrostructure (aggregates between 0.25 and 10 mm in diameter); 3. Microstructure (aggregates smaller than 0.25 mm).

Soil structure is formed when the top layer of soil is broken down by the roots of growing plants into crumbs. Tillage, frost, and macrofauna (moles, earthworms, etc.) all contribute to crumbling. The structure of the soil is affected by various factors. It can decompose for mechanical, physicochemical, and biological reasons. The best structure is crumbly, with aggregates 0.5–5 mm in diameter. This soil has many empty spaces between the aggregates – pores – which account for up to 50% of its volume. The pores are filled with air and water, creating favorable soil moisture and air regime for plant growth. A soil is structured when at least 50% of its structure is crumbly. In structured soils, the microstructure is no more than 5%. Higher levels of dust structure make soils more susceptible to erosion by wind and water because the dust structure is not stable. Also, after heavy rainfall, the soil surface is stretched and crust forms as it dries. Higher levels of megastructure in soils impair the quality of sowing operations and germination of crop seeds. More clods in the seedbed reduce the contact between seed and soil. According to many studies, the percentage of megastructures in the seedbed should be no more than 35-40% and the percentage of large clods (larger than 50 mm in diameter) should be up to 5% [11].

In our experiment, **at the beginning of the vegetative season**, megastructures in the 0-25 cm soil layer ranged from 20.2 to 33.5% (Table 3). It was the highest in the control fields, but the differences were not significant. The fact that the differences found are not significant indicates that the soil chosen for the experiment is of similar quality. Macrostructure was predominant in the soil, ranging from 61.9 to 73.4%. It is encouraging that the soil contained more than 50% of valuable macrostructure. Such soil is structured. The microstructure (dust) in the soil was more than 5% in some of the fields, but this was normal at the beginning of the experiment. We expect that after three years of the experiment, the soil will have less dust particles.

Table 3

Soil structure and its durability at the beginning of the growing season

Treatment	Megastructure (>10 mm), %	Macrostructure (0.25-10 mm), %	Microstructure (<0.25 mm), %	Structure durability, %
K1	31.6a	62.5a	5.9a	31.7a
K2	33.5a	61.9a	4.6a	37.7a
LUP	20.4a	73.4a	6.2a	39.0a
PUD	20.2a	73.3a	6.5a	38.9a
PED	28.0a	64.6a	6.7a	28.6a
MEL	30.2a	62.8a	7.0a	30.8a

Note: K1 – inter-row loosening (control 1); K2 – inter-row mulching with weeds (control 2); LUP – faba bean; PUD – crimson clover; PED – Persian clover; MEL – blue-flowered alfalfa. Differences between the averages of treatments marked with the same letter (a) are insignificant ($P > 0.05$).

Soils with more than 50% persistent aggregates are more resilient to the intense precipitation caused by climate change, and water erosion damage is reduced [12]. We can see that at the beginning of our experiment, the durability of the soil structure was only 39%. We expect the durability of the structure to increase because of the positive effect of the intercrops.

At the end of the vegetative season, the megastructures were between 7 and 10% (Table 4). It did not differ significantly between the treatments but had changed significantly since spring. It has decreased more than threefold. Macrostructure quantities were also not significantly different, but they decreased slightly compared to spring. The amount of microstructure in the soil increased 4-5 times. It was significantly higher in the fields with blue-flowered alfalfa –32.1%.

Table 4

Soil structure and its durability at the end of the growing season

Treatment	Megastructure (>10 mm), %	Macrostructure (0.25-10 mm), %	Microstructure (<0.25 mm), %	Structure durability, %
K1	9.7a	52.1a	28.3ab	11.7b
K2	6.8a	63.5a	29.7ab	17.0ab
LUP	7.2a	66.6a	26.2b	17.6a
PUD	9.1a	59.7a	31.3ab	17.3a
PED	9.8a	61.5a	28.7ab	13.6ab
MEL	7.0a	60.9a	32.1a	16.8ab

Note: K1 – inter-row loosening (control 1); K2 – inter-row mulching with weeds (control 2); LUP – faba bean; PUD – crimson clover; PED – Persian clover; MEL – blue-flowered alfalfa. Differences between the averages of treatments marked with different letters (a, b, c) are significant ($P < 0.05$).

We believe that this process was not influenced by the type of intercrops, but rather by the constantly changing meteorological conditions. In particular, the uneven precipitation regime. Of course, the drought also contributed to the slow development of intercrops, which meant that the maize inter-rows were not sufficiently protected. The durability of the soil structure has been particularly compromised during the 2023 growing season. It was significantly worse in the control K1 fields.

Soil CO_2 gas concentration. Soil carbon dioxide concentration is mainly dependent on soil properties, which affect the abundance of microorganisms. As the soil moisture and temperature increase to a certain limit (50% air and 50% water in soil pores are optimal), microorganisms develop more rapidly and release more CO_2. However, if the soil is compacted and has a lot of megastructures that are not permeable to both air and water, it can also accumulate carbon dioxide. Maire et al. [13] pointed out that CO_2 emission mainly depends on the type of crops, climate, and meteorological conditions. In our experiment, carbon dioxide concentrations varied with precipitation and intercrops sown, but the highest soil carbon dioxide concentrations were generally found in the control fields K1 and K2 (Table 5).

Table 5

Dynamics of CO_2 gas concentration in the soil (0–10 cm soil layer), % of total CO_2 concentration in the soil

Treatment	23 May	21 July	18 September
K1	0.28ab	0.11b	0.28a
K2	0.35a	0.13b	0.1ab
LUP	0.20ab	0.16ab	0.13ab
PUD	0.15b	0.29a	0.14ab
PED	0.16ab	0.20ab	0.09b
MEL	0.19ab	0.15ab	0.07b

Note: K1 – inter-row loosening (control 1); K2 – inter-row mulching with weeds (control 2); LUP – faba bean; PUD – crimson clover; PED – Persian clover; MEL – blue-flowered alfalfa. Differences between the averages of treatments marked with different letters (a, b, c) are significant ($P < 0.05$).

In our previous studies, gas concentration in the soil also depended on the soil's structural composition, temperature, and moisture content [14].

Conclusions

1. Contrary to what was expected, the slow development of the intercrops did not stop the physical erosion of the soil due to uneven precipitation. During the growing season, the amount of soil microstructure particles increased by 22-25% points, and structural stability deteriorated up to 22% points.
2. The CO_2 concentration in the soil depended more on the amount of precipitation and the type of intercrops, but significantly the highest soil CO_2 concentration at the beginning of the growing season was in K2 plots (0.35%) with mulched weeds and at the end - in K1 plots (0.28%) without intercrops.

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Author contributions

Conceptualization, K.R.; methodology, K.R., and A.Š; software, K.R., and A.Š; formal analysis, K.R., A.S., A.Š., and J.B.; investigation, K.R., A.S., A.Š, R.K., and K.V.; data curation, K.R., A.S., U.G and A.Š; writing – original draft preparation, K.R., A.S. and K.V.; writing – review and editing, K.R. and A.S; visualization, K.R, U.G.; project administration, K.R.; funding acquisition, R.K. All authors have read and agreed to the published version of the manuscript.

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