The influence of biological nitrogen and organic fertilizers on crop productivity in arable land under organic farming conditions

Aušra Arlauskienė, Lina Šarūnaitė, Lithuanian Research Centre for Agriculture and Forestry

LITHUANIAN RESEARCH CENTRE FOR AGRICULTURE AND FORESTRY

Introduction

Organic farming is specific because it depends on the cycles of the elements of nature, which can limit the uptake of plant nutrients. Compared to conventional farming, organic farming systems have advantages in terms of environmental impacts, including biodiversity and soil quality, however, they often also yield lower returns. Improving the productivity of organic farming systems is essential for the development of more sustainable production and the protection of resources on which future production depends. It is not easy to do this in organic arable farms, where a large part of the nutrients is taken away with the sold products. In such farms, plant residues (aboveground and belowground) are the main source of soil organic carbon (SOC) and some nutrients. Legumes occupy an important place in ecological agrosystem. They are grown to accelerate the cycling of nitrogen and other nutrients and to increase the availability of these nutrients to other plants in the rotation. This helps to balance plant nutrient requirements and avoid soil depletion. Their management is complex and their use in crop rotation is often insufficient. In this study, we aim to assess the impact of various methods of sowing and utilization of legumes and granulated cattle manure, and their combinations on the productivity of rotation sequence and the flows of productive and non-productive organic matter.

Materials and methods

The experiment was carried out during 2013–2015 (optimal conditions) and 2015–2017 (dry conditions) periods at two eexperimental sites of Lithuanian Research Centre for Agriculture and Forestry. The first site was established at the Joniškėlis Experimental Station on a clay loam *Endocalcaric Endogleyic Cambisol* (Clayic, Drainic) (WRB, 2014), the second–at the Institute of Agriculture in Akademija, Kėdainiai district on a loam *Endocalcaric Epigleyic Cambisol* (Drainic, Loamic) (WRB, 2014). At Akademija site the topsoil layer (0–25 cm) contains 19 clay particles, silt– 29 and sand 52%, at Joniškėlis – 27.0, 50.2 and 22.7% clay, silt and sand, respectively. The main crops were oats (cultivar 'Migla', with a seed rate of 5 million ha^{-1}), peas (cultivar 'Simona', with a seed rate of 1.2 million ha^{-1}), spring wheat (cultivar 'Vanek', with a seed rate of 6.0 million ha^{-1}), spring barley (cultivar 'Noja', with a seed rate of 5.5 million ha^{-1}) and a mixture of oats and peas (1:1 seed ratio). Red clover (cultivar 'Arimaičiai', 2013 and 2015) and white clover (cultivar 'Nemuniai', 2014 and 2016) were grown as undersown cover crops with a 10 % reduction in seed rate. Granulated cattle manure was calculated per plot at a rate of 1744 kg ha^{-1} or 48.1 kg N ha^{-1}. The field was cultivated twice in spring; before the last cultivation, granular cattle manure (GCM) fertilizer had been applied, and cereals were sown. The crops were sown at the end of April. On the same day after cereals sowing and rolling, the oats were undersown with red clover and spring wheat – whit white clover for green manure. Immediately after harvesting, the plots without intercrop were cultivated with disc harrows, and the cultivation was repeated 3–4 weeks later. In mid-October, the entire experimental field was ploughed after the clover plots had been disced. In the field experiments, the plants were grown according to organic farming standards.

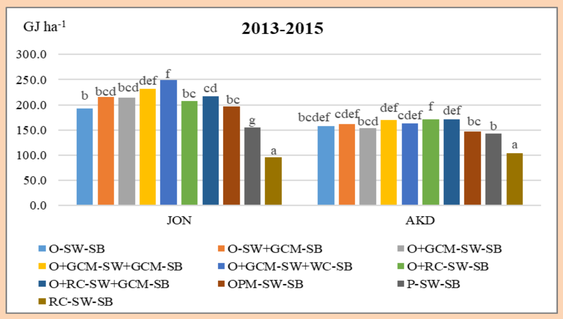
Crops and organic manure used in the rotation sequence for the 2013–2015 and 2015–2017 periods

Oats (O)	Spring wheat (SW)	Spring barley (SB)
Oats (O)	Spring wheat + GCM (SW+GCM)	Spring barley (SB)
Oats + GCM (O+GCM)	Spring wheat (SW)	Spring barley (SB)
Oats + GCM (O+GCM)	Spring wheat + GCM (SW+GCM)	Spring barley (SB)
Oats + GCM (O+GCM)	Spring wheat + WC (SW+WC)	Spring barley (SB)
Oats + RC (O+RC)	Spring wheat (SW)	Spring barley (SB)
Oats + RC (O+RC)	Spring wheat + GCM (SW+RC)	Spring barley (SB)
Mixture of oats and peas (OPM)	Spring wheat (SW)	Spring barley (SB)
Peas (P)	Spring wheat (SW)	Spring barley (SB)
Red clover (O)	Spring wheat (SW)	Spring barley (SB)

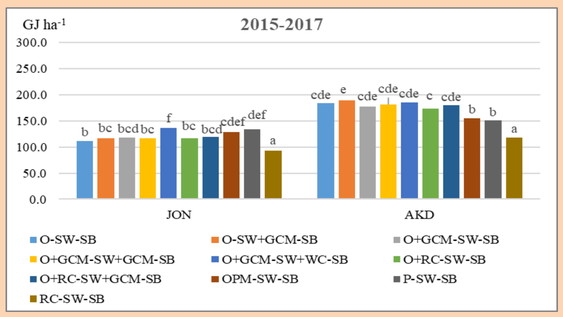
Note. GCM - granulated cattle manure; RC – red clover, WC – white clover

Results

Productivity of cereals

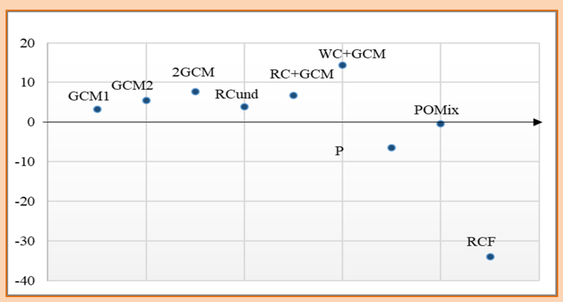


a) Plant growth in optimal conditions



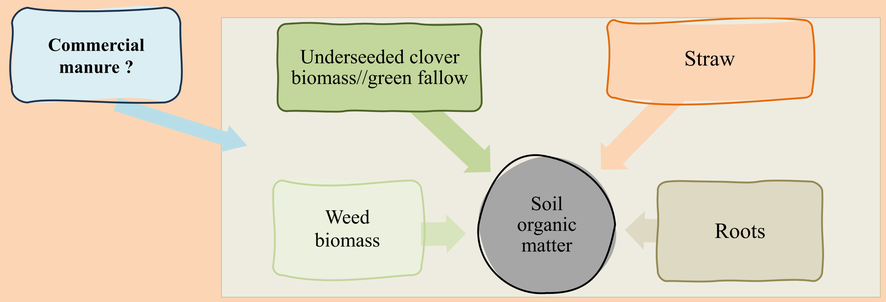
b) Plant growth in dry conditions

The amount of total energy (GJ ha^{-1}) accumulated in the cereal grain yield

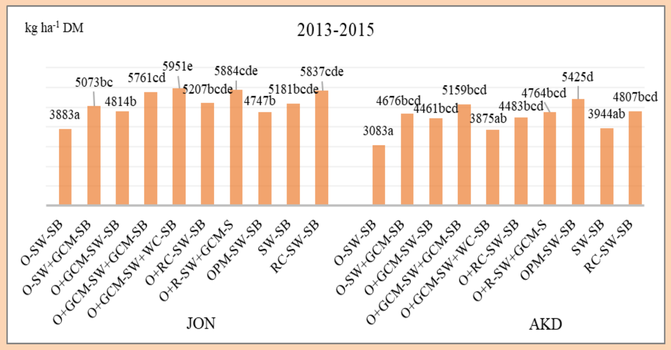


Comparison of the effect of forage legume intercrop and granulated cattle manure on cereal yields (yield increase %), Note. GCM1 - fertilized in the first year of crop cultivation, GCM2 - fertilized in the second year of cereal cultivation, 2GCM – fertilized twice in GCM, RCund - RC undersown, RC/WC +GCM – clover undersown and fertilized GCM, POMix - pree-crops mixture of oats and peas, P – pree-crops peas, CRF - pree-crops RC for green manure.

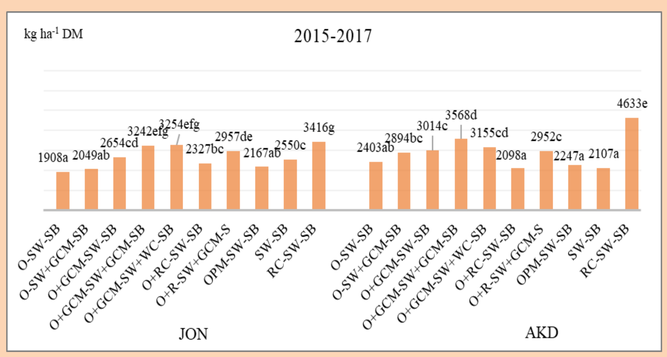
Plant residues



Supply of organic matter in an organic arable farm



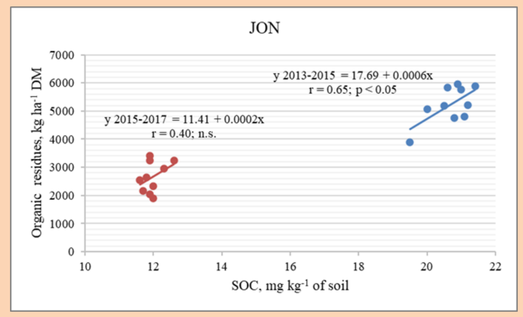
a) Plant growth in optimal conditions



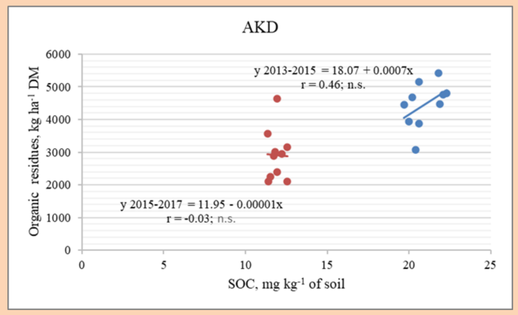
b) Plant growth in dry conditions

The total amount of plant residues (straw, weed and clover aboveground biomass) and commercial manure (DM) incorporated into the soil

Soil organic carbon



b) Clay loam soil (Joniškėlis)



b) Loamy soil (Akademija)

Soil organic carbon in a three-year arable organic rotation dependence (b) on biomass of straw and organic fertiliser incorporated into soil I Joniškėlis (a) and Akademija (b). Note. the 2013-2015 period is marked in blue, the period 2015-2017 is marked in red.

The ratio of plant residues removed from the farm and incorporated into the soil (2013-2015 and 2015–2017)

Means used		Relative number	Examples of means Main crop used
Main crop	Soil improvement measures and frequency of their application over three years		
Straw	-	0.99 ± 0.04 (V = 5.9%)	straw of cereals
	legume undersown	1.18 ± 0.07 (V = 10.0%)	undersown of RC (≈ 1 t ha^{-1} DM)
	commercial fertilizers	1.25 ± 0.08 (V = 10.8%)	GCM (N48)
	1) grain legumes, or their mixtures with cereals 2) legume undersown and commercial fertilizer	1.31±0.09 (V = 11.4%)	mixture of pea and oats, pea, undersown of RC (≈ 1 t ha^{-1} DM) and GCM (N48), undersown of WC and GCM (N48)
	commercial fertilizer twice	1.46±0.07 (V = 7.3%)	GCM twice (2 x N48)
	RC for green fallow	2.56±0.18 (V = 11.65%)	RC for green fallow

It is worth paying more attention to plant productivity in arable organic farming. Higher plant yields mean more plant residues.

Clover biomass and organic manure GCM differ in terms of decomposition intensity and impact on cereal yield. The aboveground mass of forage legume undersown and the amount of N accumulated in it are difficult to predict and depend on meteorological conditions and cultivation agrotechniques. The effect of nitrogenous clover mass on crop yields is short-lived, unlike that of GCM.

According to the positive influence on the yield, the combinations of the measures used were arranged in the following order: GCM+WC (14.3%) > 2GCM (7.7%) > RC+GCM (6.7%). Our research showed that the inclusion of green fallow in the rotation once every three years (RC in main crops) reduced the marketable production in the rotation and was economically unfavourable.

The study has shown that plant yield and SOC were positively influenced by the use of two different means, i.e. the cultivation of forage legume undersown and the application of commercial manure (GCM).

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