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LIVING LEGUME MULCH AS AN EFFECTIVE AND IMPROVED APPROACH IN INTEGRATED SOIL MANAGEMENT IN INTENSIVE ORGANIC APPLE ORCHARDS

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Abstract

The aim of international research project of European Union "DOMINO" was to develop and examine an innovative management strategy in intensive organic fruit orchards: 1) dynamic "living mulches" in the row, such as cash crops with vegetative organs and the sod with legumes between the rows for weed control; 2) fertilization by recycled soil amendments and leguminous crops to increase resource use efficiency and improve ecosystem services, and 3) partly closed covering net systems to support non chemical pest and diseases control.

The content of NH_4^+ during the second season – 2020 was an increase for on row and inter row forage pea and for inter row white clover variants, because of the leguminous crops sown there. The data for phosphorus for 2020 and 2021 show a clear increasing trend for Golden B variety, which is clearly visible in 2021. Values of K_2O for 2020 and for 2021 increase significantly about 2–3 times which meets the requirements for good soil availability. Calcium leads Golden B for inter row white clover variant and for magnesium content for the same variant. The two leguminous crops provided the trees with Mg very well.

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The highest content of iron in the forage pea variant on row for Golden B and for Granny Smith varieties.

Key words: living mulch, leguminous crops, soil management, intensive apple orchards, soil analysis, macro elements

Introduction. In the research project "DOMINO" of the European Union with the participation of five member countries – Italy, France, Germany, Poland and Bulgaria, as well as Switzerland, where the world's first Research Institute for Organic Agriculture was founded in 1973, the following main aims were set:

- Reducing external inputs in intensive orchards and vineyards for pest control, fertilization and improving the productivity and sustainability of agro-ecosystems;
- Increasing biodiversity in orchards and vineyards, as well as adapting plant protection strategies to modern requirements;
- Introducing adapted fertilization strategies to effectively use recycled waste from organic materials. These new management practices such as living mulches will give us the possibility of additional income from the sown second crops in the plantations such as green mass or dry hay;
- The role of leguminous crops is well known for fixing nitrogen through their root system, thereby enriching the soil with this essential macro element for plants; Industrially produced nitrogen fertilizers are quickly washed away by rainfall and irrigation water and go into rivers and other water bodies, and from there into drinking water. In this case, intensive nitrogen fertilization increases the content of nitrates in plant production, and through it reaches consumers. Oxidized nitrogen exists in two forms as nitrite (NO_2) and nitrate (NO_3), and the ammonium ion (NH_4^+) is undesirable in rivers and other bodies of water because it is toxic to fish. The toxicity of nitrates is known, while nitrite is 10 times more toxic. No less toxic are nitrosamines ($N - N = O$), which also cause cancer [1].

In this study we aim to develop and ameliorate the living mulch of leguminous crops in an intensive apple orchard. The novelty was to determine whether these crops would be able to replace industrially produced nitrogen fertilizers, as well as other artificial fertilizers containing phosphorus, potassium and other macronutrients. The worldwide trend for the so-called "no till" technology, which preserves the structure and fertility of the soil, is well known. In this regard, we have tested how far the two leguminous crops could replace industrially produced fertilizers and avoid mechanized inter-row tillage and weed control between trees. From the soil analyses, it was found with which macro and microelements they enrich the soil. The conditions for nitrification of the organic mass of the used leguminous crops were also established.

Materials and methods. The experimental organic apple orchard is privately owned and is located on the land of the town of Perushtitsa, Plovdiv region with coordinates 42°03′N and 24°32′E and 184 m above sea level. It was established in March 2016 on an area of 3.3 ha. The apple varieties Golden B, Fuji and Granny Smith are planted on M26 rootstock at spacing of 3.50×1.25 m (2285 trees/ha) with four rows of each variety. The rows are oriented north-south, and the trees are trained according to the free spindle system. The soil is sandy, alluvial meadow. The orchard is covered with a black anti hail net with mesh size 7×4 mm. It is irrigated with drip system, and the row is naturally grassed and mowed periodically when the grass reaches about 15 cm, which is left in place for mulch. The experimental plot has an area of 2.53 ha.

The experiments have been carried out in the period of 2019 to 2021. In the spring of 2019, a weather station "Meteobot" was installed, which measures the necessary indicators, and with additional sensors – temperature and humidity of the soil at a depth of 15 and 30 cm.

Variants of the experiment: 1. White clover inter row (between the rows); 2. Early forage pea inter-row; 3. Early forage pea on row (between the trees), and 4. Control – no sown leguminous crops. Each variant included three trees in eight replicates for both cultivars, or a total of 24 trees for each cultivar per variant including the control.

In mid-March, winter pruning of the apple trees was carried out according to the requirements of the training of free spindle system. Weed control between the trees was periodically mechanized.

The two legume crops were sown in the first week of April, and the disking was done during the bloom period, when the largest green mass with a high nitrogen content was formed [2].

The cover crops inter row is not well-known practice at our fruit orchards [3]. According to Popov [4], to restore soils, it is necessary to use green mass for fertilization and mulching with nitrogen-fixing plants from the Legume family, which form a large amount of plant mass, and which quickly decompose in the soil. In addition, he considers the alternative of replacing herbicides with plants possessing allelopathic agents, since the problem of the emergence of resistance of weeds to herbicides that leave toxic residues in the soil, i.e. pollute the environment, is also discussed in parallel with the possibility of suppressing weeds with competing plants.

Control of the main fungal diseases and the codling moth was carried out by six treatments with colloidal sulphur and Ginko® dispensers at a dose of 500 pieces/ha.

Results and discussion. The mean daily temperatures recorded during the summer months were between 20 and 26 °C, with maximums reaching 37 °C and 40 °C. The optimal temperatures for normal photosynthesis in apple are between 22–24 °C, and high summer temperatures above 35 °C cause physiological stress

in apple trees, as a result of which photosynthesis stops and increased evapotranspiration begins [5].

In 2019, the relative humidity was between 60 and 80%, and in 2020 and 2021, around 70–80%. The season in 2019 was very dry because in April, May, August and September the rainfalls were less than 5 mm for the indicated months. The situation is similar in 2020, when the amount of rainfalls in July is 18 mm, for August 9.5 mm, and only 2.5 mm in September. In 2021, the season was extremely dry – from March to October, the precipitation was less than 1 mm on average for each month, and the relative humidity in July and August was low – about 55%.

The temperature at 15 cm depth in 2020 increased from 10 °C in April to 20 °C in August, then decreased its values until October. The temperature change was similar at a depth of 30 cm, where the maximum reached 25 °C. These relatively high temperatures can be explained by the high summer temperatures of the season as well as the light sandy soil. The data on soil moisture at 15 and 30 cm show the same trend as the temperature, where the humidity at both depths is between 80 and 90%, and at the second one – 78–90%. This humidity is slightly above the optimal values 75–85% [6] because the drip irrigation system, whose flow rate is 4 l/h, worked almost continuously.

The soil temperature at 15 cm depth of 10 °C in April 2021 reached close to 27 °C in August, then decreased its values to 19.6 °C in October. The temperature was similar at a depth of 30 cm, as here in July the maximum reached 29 °C. These relatively high temperatures can be explained by the season's high summer temperatures, almost no rainfalls, and the light sandy soil. The data on soil moisture at 15 and 30 cm depth show the same trend as the temperature, as here the humidity at both depths has close values – between 89 and 94%, and at the second depth the difference is expected to be more significant – from 74 to 97%.

Temperatures around 25 °C accompanied by optimal humidity and good aeration are favourable for increased nitrification processes in the soil. Under these conditions, in the warm summer months, the mineralization of organic nitrogen compounds proceeds intensively, which improves the nitrogen nutrition of fruit plants [6].

Nitrification is the process by which microorganisms convert ammonium to nitrate to obtain energy. Nitrification is most rapid, when the soil temperature is between 20 and 30 °C, moist and well aerated [7].

In well-aerated soils and at pH above 6.2, the process of nitrification of nitrogen proceeds intensively and the main part of ammonium nitrogen is converted into nitrites [6].

During the last weeks of March and October in 2019–2021, soil samples were taken to determine the content of nutrients in the experimental plot at a depth of 0–30 cm.

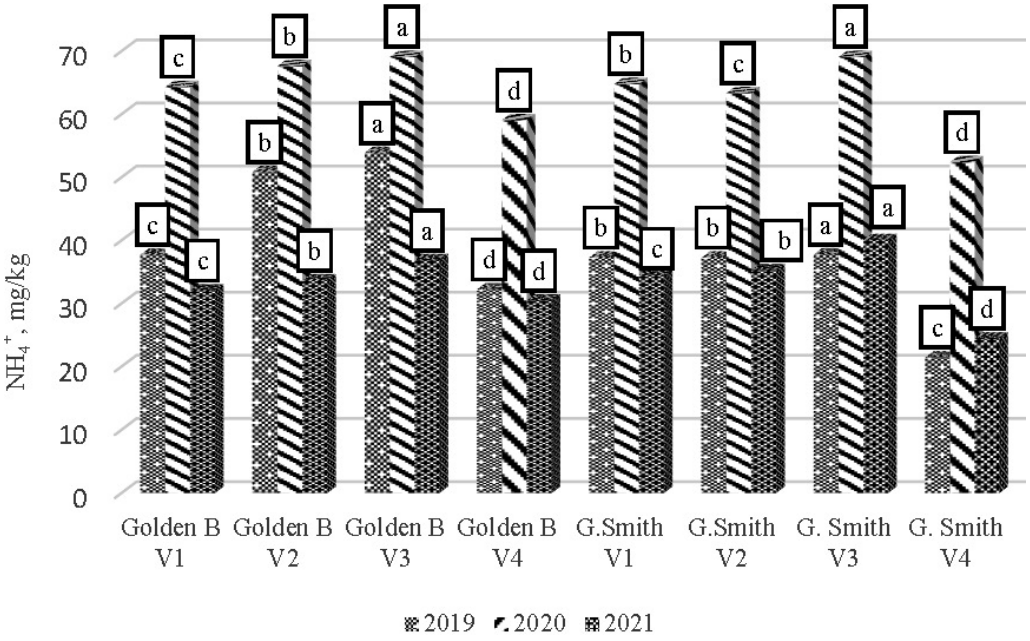


Fig. 1. Soil analysis for NH_4^+ in 2019–2021

The data from the soil analysis in 2019 for the Golden B variety show that for the forage pea option on the row the value of NH_4^+ is 53.86 mg/kg, 50.84 mg/kg for forage pea on the row and 37.75 for white clover inter row at 32.21 mg/kg for the control. In 2020, there was an increase in values for on row and inter row forage pea and inter row white clover which were 69.05 mg/kg, 67.62 and 64.29, respectively, at 59.05 mg/kg for the control variant (Fig. 1).

According to Voinova-Raikova [1], bacteria related to the use of mineral nitrogen predominate in the microflora of the pea rhizosphere, which is explained by the presence of more nitrogen in the root mass of leguminous crops. We should note that in 2021, the values of ammonium cations decreased due to the enhanced extraction of nutrients from the root system during the period from May to October-November and the relatively high density of bearing trees per unit area [2]. In this case, they are from 30.43 mg/kg for NH_4^+ in the control of the Golden B variety to 36.83 mg/kg for forage pea on the row. As expected, the values in the control variant are the lowest, because there are no leguminous crops sown there.

In the case of the Granny Smith variety, NH_4^+ in 2019 was between 37.75 and 21.43 mg/kg, respectively, for forage pea on the row and the control, and in 2020 the contents are expected to increase to 69.05 and 52.38 mg/kg, respectively. For the reasons mentioned above, in 2021 all data were lower, from 24.41 mg/kg for the control variant to 40.03 mg/kg for forage pea between the trees.

From the soil analysis in 2020, it is clear that the ammonium cation (NH_4^+) is 74.29 mg/kg in the white clover inter row, with the lowest values from forage pea on the row – 49.52 mg/kg or less than the untreated one – 68.57 mg/kg, which can be explained by the slower mineralization of nitrogen by the root system of this legume.

Phosphorus is of great importance for increasing the intensity of photosynthesis. According to Stoilov [6], in order to obtain more than 20 t/ha of apple fruits, in the soil the optimal level must be more than 16 mg of P_2O_5/100 g. In 2019 for the Golden B variety, the phosphorus content varied widely – from 10.06 mg/100 g for white clover in the inter row to 19.61 mg/100 g for forage pea on the row. In this case, logically, the third option is very well stocked. The remaining variants, as well as all in 2020, are below the optimum level or between 10.06 to 14.00 mg/100 g, which can be explained by the light sandy soil. The data for 2020 and 2021 show a clear increasing trend, which is clearly visible in 2021, when the values for the first three variants are 17.80, 21.60 and 22.00 mg/100 g, respectively, i.e. the positive role of the two legume crops is present. For the Granny Smith variety, the data is unidirectional, as for the first variety for the three years – 2019 from 12.63 to 15.21 mg/100 g and from 11.50 to 14.10 mg/100 g for 2020, and from 20.60 to 21.60 mg/100 g in 2021, respectively (Fig. 2).

K_2O content for Golden B in 2019 ranged from 16.25 mg/100 g for the control to 18.00 mg/100 g for forage pea on the row. In the next two years, the potassium increases significantly about 2–3 times, which meets the requirements for good soil availability [6]. The reduced content of potassium negatively affects photosynthesis in the leaves, as a result of which the sugars in the fruits, their colour and size decrease [5,6]. In this case, forage pea on the row leads with 50.00 mg/100 g in 2021, followed by forage pea inter row – 49.00, and white clover

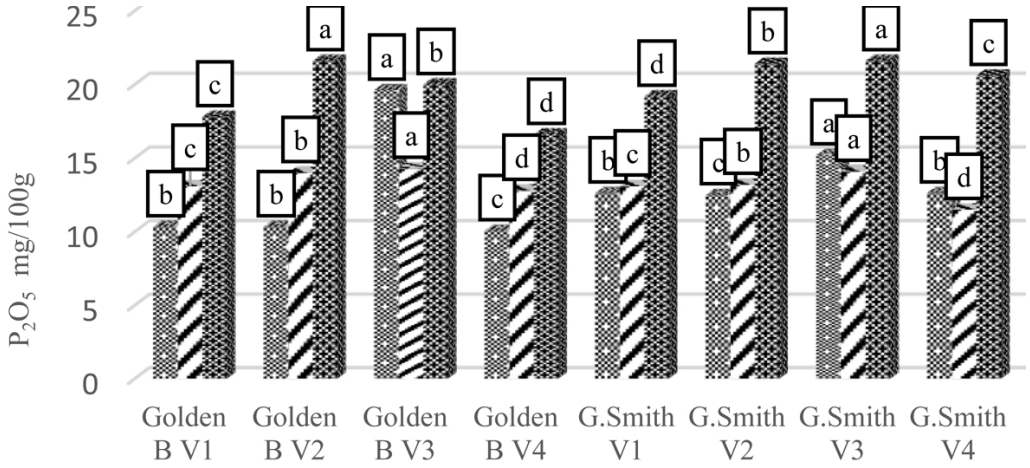


Fig. 2. Soil analysis for P_2O_5 in 2019–2021

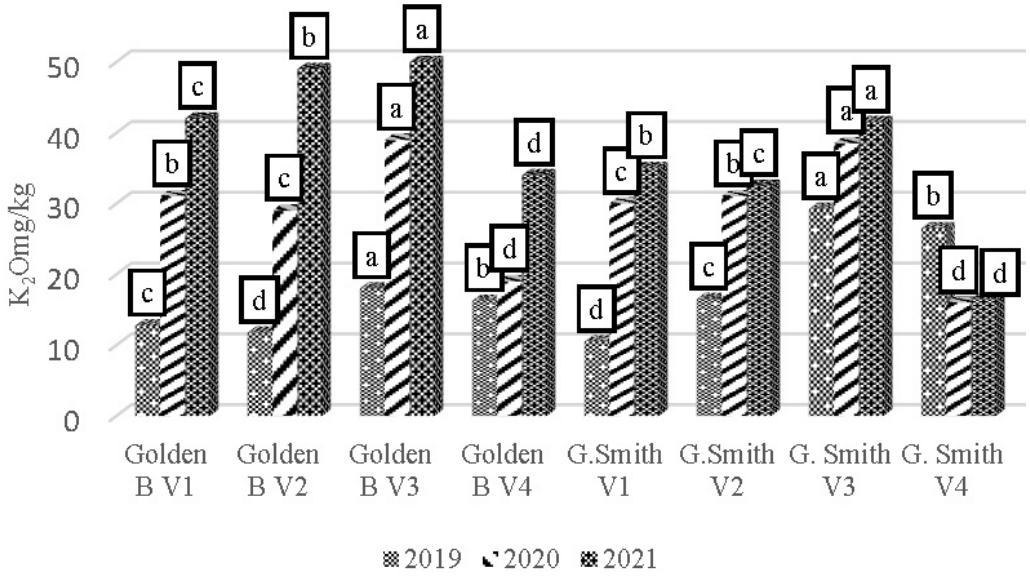


Fig. 3. Soil analysis for K_2O in 2019–2020

inter row – 42.00 mg/100 g, i.e. the obtained results are logical according to the variants (Fig. 3).

K_2O values ranged from 19.05 mg/100 g for the control to 27.62 mg/100 g for the forage pea on the row, which met the requirements for good soil fertility. In this case, as expected, forage pea on the row is leading with 27.62 mg/100 g, followed by forage pea again, but in the inter row, followed by white clover inter row, 25.14 and 24.29 mg/100 g, respectively. These data support the conclusion that mulching increases exchangeable potassium in the soil [6].

Soil analysis for the Granny Smith variety showed that the pH ranged from 7.48 for the inter row white clover variant to 7.75 for the control. In general, these data are close to those for the Golden B variety, i.e. the soil is favourable for nitrification.

The NH_4^+ content ranged from 22.38 mg/kg for forage pea to 17.40 mg/kg for the control. The P_2O_5 are between 21.10 and 30.20 mg/100 g, respectively, for forage pea on the row and 20.0 mg/100 g for the control. The K_2O are from 50.50 mg/100 g for white clover to 43.81 for the control variant. The close values in clover with those of the control are due to the delayed mineralization of organic mass from the root system of white clover during the winter-spring months.

The other main macro element phosphorus has the highest values in the variety Granny Smith with forage pea on row – 0.33% and 0.32% as the same values for Golden B and Granny Smith with peas on row. Golden B with forage pea and white clover follow – with 0.31 % each. The potassium content is logically highest in the variety Granny Smith with pea on row – 1.49%, followed by Golden B with

white clover – 1.36% and with 1.34 and 1.37% for the control variants for both varieties.

Calcium leads Golden B with 2.86% for inter row white clover and 2.75% for inter row pea for the same variety. The values for the two controls were 2.57 and 2.45% for Golden B and Granny Smith, respectively. The great role of calcium in the occurrence of physiological diseases in apple fruits is known due to the antagonism between K and Ca, as well as between Mg and Ca, which is the reason for its deficiency in fruits [6].

The Golden B variety had the highest Mg content with inter row clover at 0.79%, followed by Granny Smith with inter row pea at 0.78 at 0.60 and 0.62% for the Golden B and Granny Smith controls. In this case, the two leguminous crops provided the plants with Mg very well. Because it is known that when its content is below 0.25%, the absorption of phosphates by the plants is difficult.

Iron has the highest values in the forage pea variant on row – 229.58% for Golden B and 157.30% for Granny Smith. They are followed by Granny Smith with clover on row – 127.03% and pea on row for Golden B – 105.5% with 63.8 and 76.2%, respectively, for the controls in both varieties. Without Fe, chlorophyll cannot be formed, so when it is in short supply the leaves become chlorotic.

Conclusions. In this study an effective and improved mulch method was developed by using two leguminous crops white clover and early forage pea. It was found that they provide macro and micro elements to the apple trees in intensive orchards, necessary for the normal course of their vegetative growth, as well as for their good crop by using good fruiting. Additionally, the two leguminous crops enrich the soil with naturally fixed nitrogen and other macro and microelements when the soil temperature at a depth of 20 cm reaches about 25 °C accompanied by good aeration and optimal soil moisture. Under these conditions, nitrification of organic matter in the soil proceeds normally.

REFERENCES

[1] Voinova-Raikova Zh. (1977) Microflora associated with nitrogen in the soil, Sofia, Zemizdat, 92–98, 123–124 (in Bulgarian).

[2] Gorbanov S. (2018) Fertilization of Agricultural Crops, Sofia, Videnov and Son, 134–138, 456–461 (in Bulgarian).

[3] Stamatov I., V. Todorov, K. Gogova, Z. Makariev (1982) Systems for soil management in fruit plantations, Plovdiv, Hristo G. Danov, 24–63 (in Bulgarian).

[4] Popov V. (2013) Agroecology and management of agroecosystems, Academic Publishing House of Agrarian University Plovdiv, 63–68 (in Bulgarian).

[5] Sansavini S., G. Costa, R. Gucci, P. Inglese, A. Ramina et al. (Eds) (2019) Principles of Modern Fruit Science, ISHS, Leuven, Belgium, 341–384.

[6] Stoilov G. (1977) Mineral nutrition of fruit plants and methods for its control, Plovdiv, Hristo G. Danov, 9–19, 31–130 (in Bulgarian).

[7] Johnson C., G. Albrecht, Q. Ketterings, J. Beckam, K. Stockin (2005) Nutrient Management Spear Program, Cornell University Cooperative Extension, Agronomy Fact Sheet Series, Fact Sheet 2.

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