Deliverable 4.8: Final Report on new fertilization management to improve soil fertility and health in intensive organic orchards

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1. Introduction

Intensive organic fruit production in Central Europe shows several characteristics that differ from traditional organic farming systems e.g. mixed farming of arable crops and ruminants: 1) fruit orchards are perennial crops that are usually grown for about 25 years (e.g. for apples) or even longer (e.g. for pears), preventing the use of crop rotations for pest and disease control and soil improvement, 2) legumes as a major N-source for N-fixation are very difficult to be included in these cropping systems and c) as fruit farms are highly specialized, no animal husbandry is practiced and, therefore, organic manure as the corner stone for organic fertilization systems is not available. Consequently, intensive organic fruit orchards are highly dependent on external inputs of pesticides and commercial organic fertilizers. A wide range of such fertilizers e.g. horn grit, dried poultry manure, stillage or other residues from food production are permitted in organic farming according to Annex 1 of the current EU-Regulation on Organic Food and Farming (European Commission Reg. 889/2008). However, these inputs are currently under discussion in the organic sector and nutrient inputs from intensive conventional animal husbandry are considered to be contentious inputs that should be phased out (BioAustria, 2014, Demeter 2021, Oelefse et al. 2013). This situation has created the need to develop new fertilization strategies based on non-contentious inputs from different sources: farm internal resources (e.g. clover based), recycled nutrients from organic farming or urban sources (e.g. biogas digestates) or plant based sources from (organic) agriculture (e.g. grain legumes as living mulch in the tree row).

A second challenge of organic orchard fertilization consists in imbalanced nutrient budgets: Depending on the regional production systems, phosphorous (P) inputs are either negative (e.g. in Southern Tyrol - Alber et al. 2020) or positive (e.g. in Southern Germany - Möller and Zikeli, unpublished). In the latter case, a deficit in potassium (K) budget was also observed. These imbalances result from a stoichiometric mismatch between the composition of the organic multi-element fertilizers (e.g. poultry manure) used in organic fruit production and the harvested products.

The third challenge for organic apple production systems in Central Europe results from the seasonal nitrogen (N) demand of the crop: N demand in apples is highest around flowering and fruit set, while later in the season a low soil N level is needed to avoid excessive canopy growth which results in a high disease pressure. Unfortunately, during spring time, soil N availability is rather limited due to low soil temperatures that minimize soil microbial activity and N mineralization. This implies that the fertilizers used in organic apple production should be able to mineralize fast even at low temperatures in order to release nutrients and meet the crop demand, with little residual N in the later growing season.

Taking all these challenges and aspects into consideration, the overall objective of work package 4 in the project DOMINO was to test different alternative fertilizers and fertilization strategies (recycled nutrients, clover grass based materials, leguminous intercrops and non-contentious commercial fertilizers) and verify their applicability in organic fruit production.

2. Synthesis of the results

2.1 Overall research approach

To get more detailed information on nutrient budgets in organic apple orchards, a case study was conducted in the Alte Land region (Lower Saxony, Germany). Semi-structured interviews with organic apple growers and soil analyses of selected orchard sites were performed in order to verify how the fertilization practices affect the level of soil nutrients.

The test of several alternative sources of organic fertilizers was carried out in field trials on organic apple located in Switzerland (FIBL), Italy (LAIM), Bulgaria (FGI), Poland (INHORT)

and Germany (UHOH). As production intensities differed between the locations, different target N levels were applied by the project partners. In addition, since the sources of alternative fertilizers differ depending on the European region, the choice of the fertilizers was based on the product availability for local farmers. In Germany, for instance, access to commercially produced biogas digestates and composts is easy for organic growers, but this is not the case in Bulgaria. However, a common standard fertilizer, horn grit, was used on all sites in addition to an unfertilized control to allow for a multi-site comparison.
At FGI, INHORT and UHOH field trials in intensive apple orchards were done for two (FGI) or three years (INHORT, UHOH), testing the fertilizers under conditions of local cultivation practices. Moreover, in order to better understand the N dynamics, incubation (LAIM) and pot trials (FIBL, LAIM) were carried out.

2.2 Synthesis - Case study on nutrient budgets in intensive organic apple orchards (UHOH)

In 2019 four farmers in the Altes Land region in Lower Saxony were interviewed and data was collected on inputs (fertilizers and pesticides) and output (yield) per orchard for five consecutive years to calculate field nutrient budgets. Also, soil samples were taken in their orchards in the tree row and the inter row and analysed for pH, C_{org}, N_t, P, K and Mg contents. The data was merged with data collected in a previous project in Southern Germany. In total, 19 farmers were interviewed.

The objectives pursued with the case study were as follows: a) to explore if current fertilization strategies in intensive organic apple production lead to imbalanced nutrient budgets depending on the production intensity and b) if these imbalances affect soil parameters, in particular plant available nutrients.

Based on the data collected from farmers, highest imbalances were found for Ca and S. If inputs of base fertilizers (manure, compost) were higher, surpluses of Ca and K occurred. However, these imbalances did not affect soil nutrient contents. However, differences of soil nutrient contents were found between tree row and inter row. This shows that the transfer of nutrients within the orchard is more pronounced than the effect of imbalanced nutrient supply. The results also imply that nutrient mining can occur before it can be detected by soil analysis. For this reason, nutrient budgeting can be recommended to monitor and improve soil fertility before negative effects emerge.

2.3 Synthesis of the incubation trials (LAIM)

Incubation experiments were carried out in microcosms to gain a better understanding on the N mineralization dynamics of the tested fertilizers and their impact on selected soil parameters. In summer 2018 twelve organic fertilizers (bone and horn meal, two stillage extracts, clover pellets, pea seeds, two biogas digestates, clover pellets, clover grass silage, green waste compost, green waste compost + biochar (8:1 v/v) and a mushroom substrate) were tested. Besides periodic mineral N (N_{min}) quantifications, contents of micro-organisms and heavy metals were analysed and after the incubation, soil nutrient contents were determined.

Among the twelve products, the two digestates showed a faster mineralization rate, and they released the largest amount of mineral nitrogen. The two stillages well mineralized well, but both required more time than the biogas digestates to reach high mineralization levels. Clover pellets showed a minimal influence on N_{min}. Clover grass silage and mushroom substrate immobilized N and released only a small amount of it after more than one month. Green waste compost released only a low quantity of N_{min}, which was even lower when compost and biochar were mixed. The addition of clover grass silage, biogas digestate pellets and mushroom substrate slightly increased pH, while the addition of biogas digestates, pea seeds, one of the two stillages, bone and horn meal decreased it, but these effects were only minor (pH 7.5 ± 0.2). Soil organic matter content increased with all the treatments, while it remained quite constant (+5 %) in the control microcosms. As expected, the organic carbon pool increased, as all the tested substances contain mainly organic matter. Phosphorous and magnesium increased in all the microcosms, particularly with the application of clover pellets, the two biogas digestates and the two composts.

In the incubation trial, only biogas digestates released N fast enough to be considered suitable fertilizers to substitute horn meals / grits and stillage in organic apple production.

2.4 Synthesis of the pot trials (LAIM and FIBL)

The pot trials were conducted for two years at LAIM (2019 and 2020) and for one year at FIBL (2020) in order to assess the mineralization dynamics of alternative fertilizers and their effect on apple tree growth and leaf nutrient content. However, the first trial year at LAIM was characterized by intensive rainfalls, therefore the data was considered not representative. The results presented here are based on the assessment of the second trial year.

At LAIM, two biogas digestates, two stillages, pea seeds and clover pellets were tested and compared with two fertilizers permitted in organic farming and with an unfertilized control. The following alternative fertilizers were tested at FIBL: biogas digestate, stillage, clover-grass pellets, and two green manure treatments, peas and fresh white clover biomass. The alternative fertilizers were compared to a standard organic fertilizer, and an unfertilized control. On both locations, an amount of fertilizer equaling 8 g N per tree was applied, except for clover (FIBL), where 480 g fresh biomass was applied to the pots (= 2 g N). The organic fertilizers application was split at FIBL in two applications: three weeks prior to full bloom and four days after full bloom. The pea seeds were sown mid-March and the above ground biomass was cut and mixed into the soil four weeks later. At LAIM, the fertilizers were applied three, five and eight weeks after the planting in the first year to avoid possible root damages caused by the excess N. The pea seeds were sown three weeks after the tree planting and the seedlings were cut and mixed with the soil after five and seven weeks. The soil sampling for the mineral nitrogen analyses was done ten, twelve and sixteen weeks after the tree planting.

At FIBL, N_{min} analyses (N-NO3 and N-NH4) were performed immediately after the first (31st of March), and the second (21th of April) fertilizer application and after three (12th of May) and nine (24rd of June) weeks after the second application; except for the peas and fresh clover treatment where the second and third analysis were performed two weeks later (5th of May and 26th of May) due to a later incorporation date (14th of April).

The stillage application resulted in the highest increase in N_{min}, followed by the biogas digestate, both higher than the standard fertilizer (Fig. 1). The N_{min} did not change for the peas in the first five weeks and then showed a slight increase. The clover-grass pellets and the two applications of fresh white clover biomass all resulted in a N immobilization within the first four weeks followed by a slight N release. Leaf nutrient content was assessed and showed the highest nitrogen content in leaves of the pea treatments, followed by the standard fertilizer, whereas the fresh clover and biogas digestate treatments and the control showed the lowest N content. A negative correlation was found between high N content of the leaves and P and K content. No differences were found for Ca and Mg.

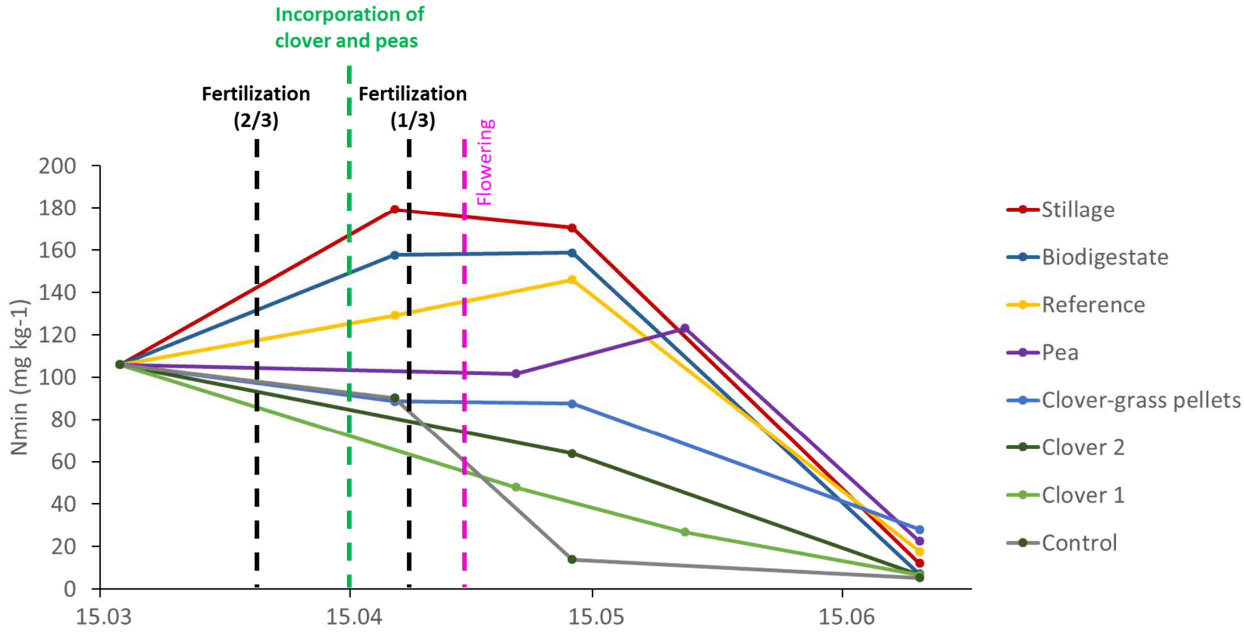

Fig. 1. Soil Nmin contents measured in the pot trials for the tested fertilizers at FiBL, Switzerland

In 2020, at LAIM, the pea sowing took place on 13th of March and the seedlings were cut and mixed with the soil on the 3rd of April. On the same day, the first aliquot of the fertilizers was applied to the respective plots. The second and third application were done on the 16th April and the 6th May, respectively. To monitor N_{min} in the soil, analyses of N-NO3 and N-NH4 were done immediately before the first (31st of March), second (15th of April) and third (5th of May) time of fertilizer application and after ca. three (20th of May) and seven (23rd of June) weeks after the last application.

For the first N_{min} analysis, before the first N input of 2020, no differences resulting from previous years' treatments were found (Fig. 1.). The second sampling, performed two weeks after the first fertilization, showed a strong increase of mineral nitrogen for the two biogas digestates and the two stillages. The two stillages had similar N levels in all the extractions, while the two biogas digestates mineralized quite differently: The first one mineralized well and kept the level of mineral N high until the last extraction, while the second one provided lower levels of bioavailable N to the soil, reaching the peak already during the first extraction, then steadily decreasing. Clover pellets and the standard fertilizers used as reference took more time to significantly increase the level of mineral N, but reached the same levels of the best performing bigas digestate and the two stillages. Peas, contrary to what was observed in 2019, showed the lowest level of N_{min} in all extractions performed. However, this was likely due to bird damages that were observed in the plant stand, which significantly reduced the number of pea plants and their development.

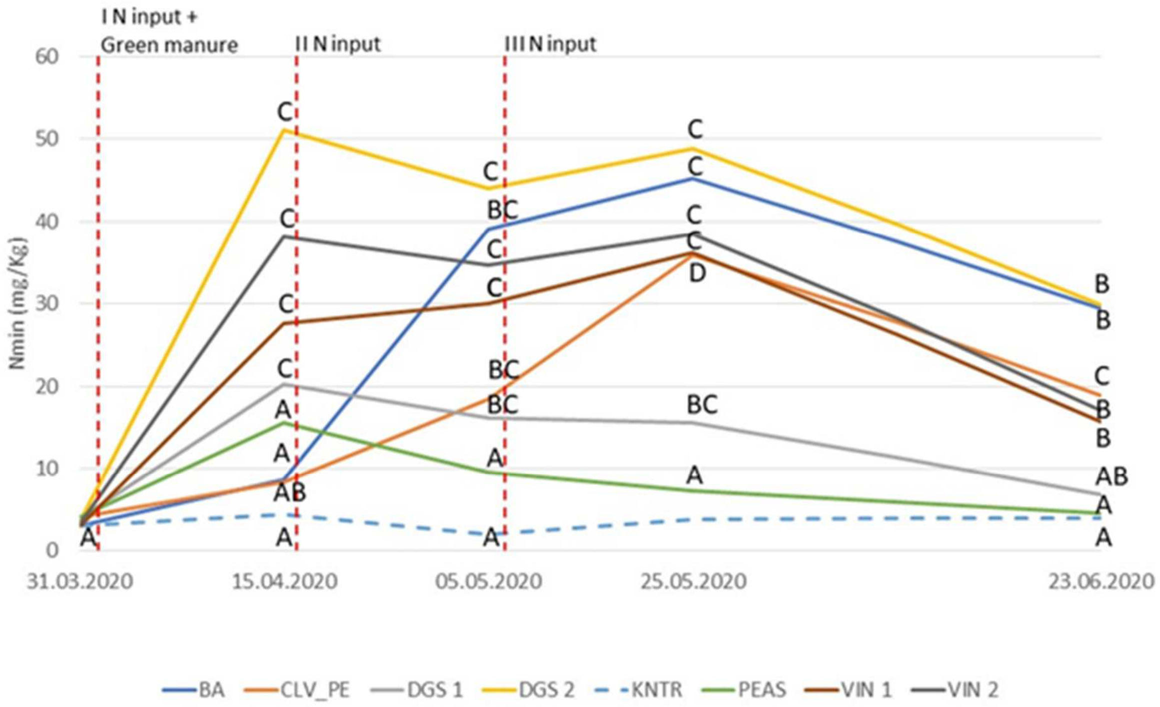

Fig. 2. Soil Nmin contents measured in the pot trials for the tested fertilizers at Laimburg. BA= organic fertilizer as reference, CLV_PE=clover-grass pellets, DGS 1=digestate 1, DGS 2=digestate 2, KNTR=control, PEAS=peas, VIN 1=stillage 1, VIN 2=stillage 2.

N content of the leaves of the control plants at LAIM was lower when compared to the fertilized pots, and, together with the green manure treatment (peas), it did not reach an adequate level of N in the leaf tissues. Curiously, the highest level of P was observed in the unfertilized pots leaves, and a significant negative correlation between N and P in leave tissues was found. No significant differences were found for K, Ca and Mg between treatments and control. No significant differences were observed for fruit quality parameters (pH, acidity, total soluble solids and mineral nutrient content). However, when the mineral nutrient contents were ranked according to nutritional classes some differences emerged.

Picture pot trial Laimburg

Pictures pot trial FIBL

2.5 Synthesis of the field trials (INHORT, UHOH, FGI)

All three field trials had the objective to assess the effect of alternative fertilization practices on fruit yield and quality.

At UHOH and INHORT a 3-year field trial (2018 – 2020) was carried out with different varieties (Santana on rootstock M9, planted in 2014 at UHOH and Topaz on rootstock M9, planted in 2011 at INHORT). At FGI, a two years' trial was conducted on a private farm using the apple varieties Golden B and Granny Smith (rootstock M26, planted in 2016).

The fertilizers tested by INHORT and UHOH were similar: Biogas digestates (a different source for each location), stillage from yeast production (INHORT) and from sugar beet production (UHOH), clover-grass pellets and horn grit. At UHOH, clover grass silage and spring and winter peas as mulches in the tree row were compared in addition. The alternative fertilizers were compared to a standard organic fertilizer (granulated cattle manure in case of INHORT, horn grit at UHOH), and an unfertilized control. Target N fertilization levels were 70 kg ha^{-1} at INHORT and 25 kg ha^{-1} at UHOH based on local farming practices. Fertilizer application was done at flowering at both locations and during the same period, the stands of winter peas

sown the previous October and summer peas sown in March were incorporated at UHOH. Nutrient budgets were calculated at both sites.
At FGI, white clover grown in the inter row, forage pea grown in the inter row, forage pea grown in the tree row, horn grit and the liquid organic fertilizer Lumbreco from red Californian worms (*Lumbrecus rubella*) were tested. The sowing of legumes took place in the first week of April and the resulting green manure was incorporated in soil when the height of the plants was about 15 cm. The fertilization was done twice at BBCH stages 53 and 73 with half a dose of the fertilizer at each time.

At all locations, N_{min} content of the soil was determined during the growing season. Leaf samples were collected at the date recommended by local extension services for macro and micro nutrient analysis. At harvest, yield and fruit quality parameters (the latter only at UHOH) were determined. Plant available P and K in the soil were determined before the trial and then annually using the local extraction methods in order to provide data for local growers.

In addition, at UHOH, on-farm trials were done for two years on three farms in the Heilbronn, Freiburg and Lake Constance region testing peas, silage and compost as fertilizers. Soil samples were taken for N_{min} analysis 4 to 6 times during the vegetation period.

At UHOH, mineral nitrogen reached the highest values in spring and early summer for the winter pea treatments, followed by horn grit and biogas digestates. The lowest values were measured in the soil treated with silage and the unfertilized control. For the winter peas a shift in the timing of the N peak was detected, which was related to the time of biomass incorporation in the soil. The field budgets indicated a potassium deficit in all the treatments, being highest in horn grit and peas. The biogas digestates showed the smallest K deficit due to their higher K:N ratio and also showed the most balanced nutrient supply among all fertilizers used. The highest surpluses were found in the compost treatments for Mg and Ca. Leaf nutrient analysis showed no significant differences between fertilized and unfertilized plots, revealing a sufficient nutrient supply for N, P, Mg, Ca, Fe and even for K despite the negative nutrient balance. However, in the third trial year, deficiencies were detected for Mn, Zn and B content. Yield levels in the different treatments showed no significant differences compared to the standard fertilization. However, tendencies for lower yields could be observed in the pea and silage treatments.

In the on-farm trials the temporal shift in the soil N peak due to different mulching dates of peas was not as clear as on the experimental site. A difference between the experimental field trial and the on-farm trial emerged concerning silage: The N_{min} levels were equal to, and later in the year, even higher than the control treatment that received a stillage.

UHOH: Figure xx: Fertilizers used in the field trials (top left to down right): Horn grit, stillage, biogas digestate, compost, silage, clover grass pellets, spring and winter peas

UHOH : Summer (left) and winter peas (right) in the tree row before mulching in April.

UHOH: Apple orchard at harvest.

At INHORT, the addition of dry manure or clover pellets did not increase N availability in comparison to the unfertilized control until late in the season. Only the application of the stillage and dry manure increased P and K levels in soil during the whole season in comparison to all other treatments. Even though only minor effects were observed on the macro and microelements content in leaves, an increasing trend could be detected particularly for N content. The yield, which was affected in two seasons by frost events in spring time, showed no statistical differences between the treatments when considering the annual production. However, a slight increase was observed in trees treated with the horn grit when considering the cumulative yield after three years.

Fig. XX: The experimental organic apple orchard at INHORT

At FGI, after the application of Lumbreco, a high level of $NH4^+$ occurred in the soil, probably due to the high content of total N in the solution, followed by horn grit and white clover in the inter row. The overall yield in the trial year was not at an optimal level because of the frost events during bloom – minus 2.1°C (2 April) and minus 5,7°C (8 April). The use of horn grit resulted in the highest yield in Granny Smith with 23.0 t ha^{-1}, followed by Lumbreco (21.3 t ha^{-1}) and white clover (18.8 t ha^{-1}). The yield of Golden B was generally lower compared to Granny Smith: the use of white clover in the inter row resulted in a yield of 16.9 t ha^{-1}, followed by Lumbreco with 15.5 t ha^{-1} and horn grit with 14.7 t ha^{-1} (Fig 5).

The leaf analysis showed that in all fertilizer treatments, nutrient contents were at optimum levels, except Mg which was slightly (0.4%) higher than the optimum (Gorbanov, 2018) in the treatments with forage pea, white clover, Lumbreco and horn grit.

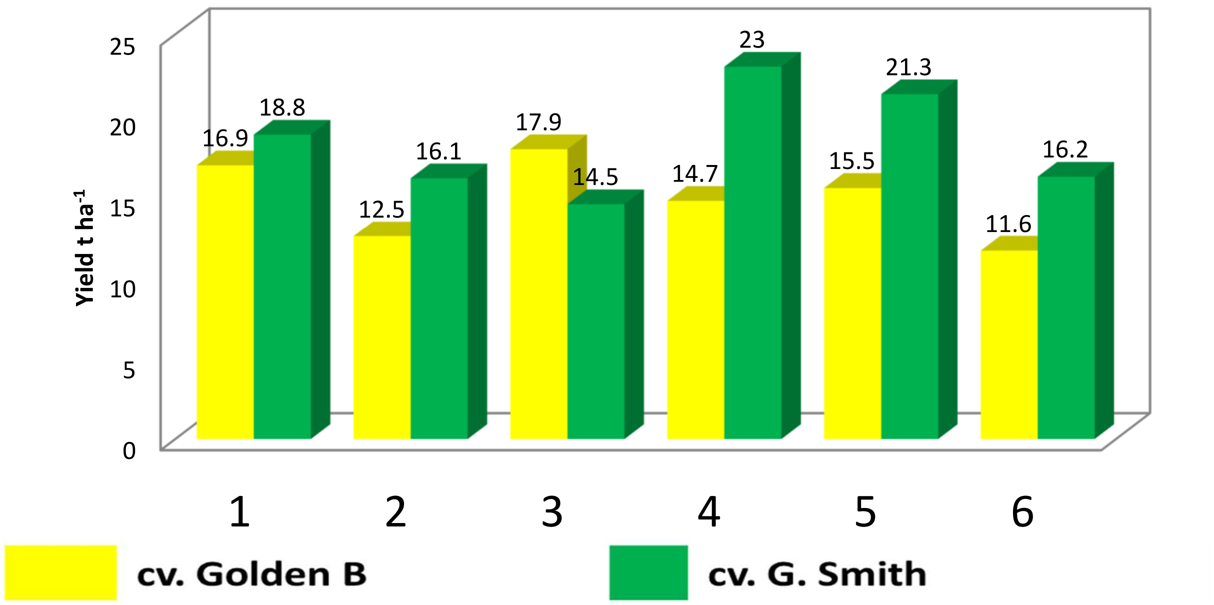

Fig. 5: Apple yield of the varieties Golden B and Granny Smith depending on the different fertilization treatments for 2020. Treatments: 1. White clover inter row, 2. Early forage pea inter row, 3. Early forage pea on row, 4. Horn grit, 5. Lumbreco, 6. Control

The application of Lumbreco resulted in the highest average fruit weight for Granny Smith with 149.8 g, followed by horn grit for both cultivars (141.67 g and 140.33 g, for Golden B and Granny Smith, respectively). The diameter of the fruits of Golden B varied from 60.61 mm for the control up to 64.05 mm for the Lumbreco treatment and for Granny Smith from 62.25 mm in the control to 69.24 mm in the Lumbreco treatment. According to the National fruit standards, Golden B fruits could be classified as First class and Granny Smith as Extra class.

FGI: Experimental apple orchard - cv.”Golden B” before harvesting

FGI: Early forage pea between trees before mulching in May 2020

3. Discussion

3.1. Potentials of the tested fertilizers to substitute contentious inputs

Based on the pot and field trials, it can be concluded that all fertilizers tested can be used as nutrient source in intensive organic apple orchards as differences in yield levels were low or non-existent. However, N availability from peas and clover-grass based fertilizers depended strongly on application dates and times of incorporation, which can result in insufficient N availability during the period of intensive plant demand. This was confirmed by the incubation trials that showed N immobilization for these fertilizers. However, as peas were used as dry grains and not as fresh biomass for the incubation trial, a better performance of this fertilization strategy could be observed in both pot and field trials. Based on the results of the pot trial at FIBL, N release from peas as intercrop in the tree row reached the highest levels five weeks after incorporation. If local weather conditions allow for the seeding of winter peas or a very early seeding of spring peas, N release after incorporation can reach a sufficient N supply during flowering. On the contrary, leguminous cuts from the inter row didn't supply sufficient N during bloom, but could serve as a N source later in the season. Clover grass silage showed similar N dynamics, but due to its storability, application would be more flexible compared to grass cuttings from the inter row. This allows to plan an earlier application e.g. in autumn of the previous year. Whether this result would provide an improved N availability in spring was not tested in the current research and warrants further research. The results of the application of clover grass pellets differed substantially between the different locations of the field trials as well as in the pot and incubation trials. A slow N release in the incubation and pot trials was observed, while at comparatively low N levels (25 kg ha^{-1}) in the German field trial no difference in yield and nutrient contents in the leaves was found. As clover pellets are easy to apply, vegan and of non-contentious origin, they represent a valid option for organic farmers. Nevertheless, further research is necessary to explore the reasons for the diverse N mineralization behavior observed in the incubation, pot and field experiments.

The liquid fertilizers biogas digestates, Lumbreco and stillage showed very good fits to the N demand of the trees in spring due to a quick N release after application. All three products are rich in NH_4^+ (Möller and Schultheiß, 2014) which determines the fast N release even at low temperatures. Despite these positive results, the use of biogas digestates may be challenging for farmers: The analyses of the biogas digestates used in the pot trials in Switzerland and Italy as well as for those used in the field trials in Poland and Germany showed different C/N ratios for the same kind of product in the different years. Such differences were also confirmed elsewhere (e.g. Möller and Schultheiß, 2014), and appear to largely depend on the composition of the waste materials (e.g. slurry, kitchen wastes, plant materials) used as matrix and the technological treatments of the digestates (e.g. liquid – solid separation, micro filtration, reverse osmosis).

In some countries, well established systems for controls and labelling exist for biogas digestates if they are bought from commercial providers, but in others this is not the case. Moreover, if biogas digestates are acquired from local farmers the exact composition of nutrients is usually not available. In addition, if the organic farmer is participating in a quality control system (e.g. Global GAP), additional analyses on pathogenic bacteria maybe necessary. Such information may be available when digestates are sourced from commercial providers like communal waste management corporations, but it is not if they are acquired from farmers. If these issues are solved from a legal perspective, biogas digestates can be recommended as a valid option for integrating rural – urban nutrient cycles into organic apple production.

Stillage from conventional sugar production is currently widely used in organic farming due to its properties as liquid fertilizer that can be used in fertigation systems. However, even though the production process would limit the presence of contaminants, it is considered to be a contentious input as contamination with pesticides from conventional production might occur (Malusà and Tosi 2005). A similar issue can be raised for stillages deriving from other production processes (e.g. yeast production) which are using molasses from sugar production as the growth substrate for the microorganisms. In this case, the addition of other substances necessary to balance the nutrient content of the microorganisms' growth medium (e.g. phosphates) can further increase the controversy about using these products in organic farming.

Considering all the mentioned pros and cons, it can be concluded that using fertilizers based on legumes (clover grass silage, clover biomass from the inter row or peas mulching on the row) reduces soil contamination risks in comparison to other sources (biogas digestates, stillages, composts) and enhances farm internal N cycles leading to an overall higher N efficiency in organic fruit growing systems.

3.2 Effect of alternative fertilizers on nutrient budgets

None of the alternative fertilizers is a single-nutrient fertilizer, therefore, there is no one-size-fits-all solution for fertilization in intensive organic apple orchards. Based on the findings in DOMINO, a balanced fertilization strategy should introduce the concept of "alternation" of inputs/fertilizers/practices in order to benefit from the different nutrient sources, their diverse nutrient contents and mineralization ratio. Such approach would limit the risk of creating nutrient imbalances in the soil, better matching the trees' nutrients requirements with their temporal and quantitative availability in the soil.

When comparing the nutrient composition of the fertilizers, biogas digestates and clover products can reduce the K deficits, which was documented in the German case study, as they present a similar nutrient composition to the harvested apples compared to the currently used contentious inputs. Nevertheless, fertilization with potassium salts may still be necessary from time to time depending on the nutrient status of the soil. So far, it is not clear how the small scale differences between plant available nutrients with enrichments in the tree row and deficits in the inter row for P and K affect long-term soil fertility in organic fruit orchards. It is also not clear if this pattern is found in other European countries as well.

Keratin based products like horn grit are permitted by the EU Regulation for Organic Food and Farming (EU 2008) and have the benefit of supplying only N and S, but no P that tend to be enriched in soils of organic fruit orchards. However, due to its origin from conventional animal husbandry, the organic fruit growing sector will have to resort to different solutions in the time to come. Besides the fertilizers tested in DOMINO, wool pellets might be an additional solution as these fertilizers are usually derived from more extensive animal husbandry systems. However, as high amounts of S-containing plant protection products are used in organic fruit growing, it is not clear how the addition of S-containing fertilizers affects soil properties.

In any case, "diversification" and integration of nutrient sources can be recommended as the best strategy for fertilization management of intensive organic apple orchards. This would also provide an additional ecological service creating a positive impact on soil microbial and microfauna biodiversity.

3.3 Other sustainability related aspects of alternative fertilizers

The current discussion on contentious inputs in organic farming shows that the sustainability of inputs is gaining importance along the whole production chain. Therefore, this aspect has to be taken into account when alternative fertilizers, including all those tested within the project, are assessed.

In terms of contaminants that might be introduced in organic fruit orchards, biogas digestates and stillages might pose a certain risk. For biogas digestates, the risk of contamination with pesticides and heavy metals is low, if they are derived from kitchen waste or based on plant materials from conventional sources (Möller and Schlutheiß, 2014), as well as when they are derived from substrates of organic farms, e.g. clover grass and/or slurry. Commercial products are also tested for human pathogens, therefore the contamination risk in this regard is very small. For macro plastics and other macroscopic impurities, thresholds are laid down in the

European Fertilizer Regulation (EU Reg. 1009/2019) for commercialization of biogas digestates and composts. However, the risk is unclear and cannot be assessed properly in case of contamination with micro plastics, as no official testing procedures have been defined so far.

Extracts from vermi-compost seem to be unproblematic in terms of contamination and as the composting material needs to be adjusted to the needs of the earth-worms, such products seem to be an acceptable fertilizer for organic farming systems considering that vermi-compost itself is currently already permitted by the EU Regulation 889/2008.

The perception of the use of stillage as a fertilizer in organic farming differs in the different European countries. In Germany, for instance, the stillage from sugar production is seen more and more critical due to the risk of pesticide contamination, even though such levels would be way below any threshold. In other countries, the stillages are still well accepted fertilizers in organic farming systems.

Clover grass pellets are uncritical in terms of contamination, but their production process involves a high energy use for drying and pelleting of the material. Whether these fertilizers are acceptable from a sustainability perspective will largely depend on the source of energy (fossil or renewable) used in the production process. Therefore, the production process needs to be transparent to allow for an informed decision by the users. Clover grass silages are unproblematic from this perspective as well as leguminous material from the inter row and have low contamination potentials as well.

In case of peas grown as intercrops, contamination risks are low and energy use during production is of minor importance. However, using peas raises a different question: Grain legumes are an important protein source for humans and animals, therefore competing uses exist that might be more relevant from an ethical perspective than using such grains as a fertilizer, in particular because seeding densities must be high in order to provide sufficient nitrogen.

4. Overall assessment of the alternative fertilizers

Our research work showed that the alternative fertilizers tested can substitute existing fertilizers: for an overall evaluation see Tab. 1. In any case, fertilization strategies have to be adapted in order to reach a more balanced nutrient budget. This can only be achieved if different fertilizers are used within the single growing season and/or during several years. It must be underlined that the use of legume based fertilizers is largely location-dependent and more knowledge intensive than the current use of contentious inputs as mineralization of plant based material has to be synchronized with tree crop needs by adopting different application times and incorporation methods. In addition, application procedures with current and new machinery need to be tested under different farming/cropping systems as it may be difficult to apply certain fertilizers (e.g. silage) with existing machinery (Tab. 1). Application costs as well as costs of purchasing or costs for producing the fertilizer itself need to be taken into account to assess the overall suitability of these fertilizers. Indeed, some of the fertilizers tested (e.g. clover pellets) are currently still too expensive for the use in commercial organic fruit production (Tab.1.).

Finally, even when using non-contentious alternative fertilizers, various trade-offs in terms of sustainability exist (e.g. concerning biodiversity and realization of nutrient cycling), which have to be appraised by each farmer according to his real or perceived conditions.

Table 1: Overall assessment of alternative fertilizers

Fertilizer	**N-availability**	**Complexity of Fertilization strategy**	**Compatibility with Machinery**	**Costs**	**Contamination risk**	**Competing uses**	**Energy Use**
Biogas digestates	o/+	o	o	-/o	o/+	--	--
Stillage	o/+	o	o	o	+	--	?
Clover pellets	-	o	o	++	-	--	++
Clover grass silage	--	++	--	+	--	--	?
Peas (intercrop)	o/-	++	o	+	-	++	--
Legumes inter row	--	++	-/o	-	--	--	--

(-- much less, - less, o same, + higher, ++ much higher than the current standard fertilizer)

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