Work package 4: Report on Soil and Plant Nutrition Data 2020

The partners, University of Hohenheim (UHOH, Germany, coordinator of the work package (WP), INHORT (Institute of Horticulture, Poland), LAIM (Research Centre Laimburg, Italy) and FGI (Fruit Growing Institute, Bulgaria), continued their work in WP4. In designing the field trials in this WP, each partner (FGI, INHORT, UHOH) focused on alternative fertilizers and waste materials present in the different regions of the trial location. In addition, each partner used a control plot with zero fertilization and a plot fertilized with horn grit or animal manure as a control. The amount of N applied in the trials depended on the productivity / yield level of the apple production system in the different countries / regions. These field trials were continued in 2020. LAIM performed incubation experiments in microcosms in 2018 and 2019 and pot trials in 2019 and 2020 to gain a better understanding on the N dynamics of the fertilizers used by the partners and open field pot trials with selected fertilizers. In addition, in 2020 a selection of fertilizers tested in incubation experiments and field trials were tested in pot trials at FIBL. UHOH performed an additional pot trial to test the impact of S-containing plant production products which are widely used in organic fruit growing on nutrient and heavy metal mobility and plant availability.

Most important outcomes of the trial year 2020 provided by the consortium partners in WP4

FGI

The trials were carried out on a private farm in the Plovdiv region (42º 03' N and 24º 32'e and 184 m above sea level. The apple trees (varieties "Golden B" and "Granny Smith") were planted in March 2016 on sandy fluvisols at spacing 3.50x1.25 m on M26 rootstocks and in rows with North – South orientation. The training system is free spindle, irrigation is done through drip irrigation and soil management relies on the mulch from the inter row transferred to the tree row. The orchard is covered with a hail protection net with a mesh size of 7x4 mm. For the study, 3 trees in 8 replicates were used for six treatments: white clover grown in the inter row forage pea grown in the inter row, forage pea grown in the tree row, fertilization with horn grit and liquid organic fertilizer Lumbreco from red Californian worms (*Lumbrecus rubella*) of Bulgarian origin – one liter of concentrate dissolved in 150 l of water. 10 liters of the solution were used per tree in row and the untreated control. The sowing of legumes took place in the first week of April and they were killed when the height of the plants was about 15 cm. The fertilization was done two times at BBCH stages 53 and 73 as half of fertilizer at each time.

In 2020, the climatic conditions were difficult. During the bloom stage in the first decade of April, a frost event occurred. The summer season was very hot (July to August between 37.3 and 39,9ºC) and with very low rainfall (July – 18 mm, August – 9.5 mm and in September – 2.5 mm).

After the application of Lumbreco NH_4^+ showed the highest level – 86.67mg N kg^{-1} probably due to the high content of total N in Lumbreco (1800 mg N l^{-1}), followed by horn grit with 84.9 mg N kg^{-1} and white clover in the inter row with 74.3 mg kg^{-1}.

The leaf analysis showed that the content of N (2.6%) was highest in the horn grit treatment, followed by Lumbreco and forage pea in the inter row. The leaf content of P (0.3%) and Ca (2.4%) was highest for the treatment forage pea in the inter row and in the tree row.

The content of Mg in the leaves was higher than the optimum level (0.4%, Gorbanov, 2018) in the treatments with forage pea, white clover, Lumbreco and horn grit.

The highest number of fruits per tree was harvested in the horn grit treatment in G. Smith (71 fruits) and for cv. Golden B in the treatment white clover in the inter row (68) fruits. The use of forage pea and Lumbreco resulted in a harvest of 62 and 50 fruits, respectively. For Granny Smith the highest number of fruits was found in white clover and forage pea in the inter row, with 71 and 64 fruits.

The application of Lumbreco resulted in the highest fresh mass of fruits for Granny Smith with 149.8 g, followed by horn grit for both cultivars (141.67 and 140.33 g).

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 can be classified as first class and for Granny Smith as Extra class.

The overall yield is not at an optimal level because of the frost event during bloom. The use of horn grit resulted in the highest yield in G. Smith for 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 on a lower level. For this variety, 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}.

The growth of shoots was highest for cv. G. Smith for forage pea in the tree row and for Lumbreco. For Golden B, the highest shoot growth was found in the horn grit treatment followed by Lumbreco and forage pea in the tree row.

After two years of trials at FGI, the following conclusions can be drawn. The legumes forage pea and white clover can be used as an inter row living mulch in organic apple orchards, as they provide necessary nutrients for the apple trees. In addition, forage peas were also used successfully as a living mulch in the tree row.

The liquid fertilizer Lumbreco can also be used as fertilizer as sufficient N can be provided to the plant by its application.

INHORT

In 2020, as in previous years, the same fertilizers (horn grit, dry animal manure, clover-grass pellet, stillage and liquid biogas digestates) were applied in the orchard at the end of April. The same level of fertilization (70 kg Nha^{-1}) was applied as in the previous years, distributing the fertilizers in the tree strip. The NPK and Nmin content in the soil was monitored during the season together with the assessment of soil biodiversity performed by evaluating microbial activity (Biolog method) and nematode populations. The soil samples for these analyses were randomly taken with a soil auger at 0-20 cm depth from each treatment four times during the season: just before the fertilizers' application, and then 2.5, 13 and 20 weeks after application. To evaluate the effect of the fertilizers on leaf nutrient content, leaf samples from current-year shoots from the central section of the tree were collected randomly from each plot at the end of July and analyzed according to standard methods. At the end of the season (28 September 2020) the fruit yield was also assessed.

The initial soil chemical analysis showed a low nutrient content and strongly suggested fertilization. The untreated control displayed a significant decreasing trend in the Nmin content in the soil until the beginning of autumn. Addition of dry manure and clover pellets only slightly postponed the onset of the decrease. Fertilization with horn grit, biogas digestate or stillage induced an initial rapid increase in Nmin content in comparison to the untreated control and the increased level was maintained during the whole season. The most visible changes in Nmin content in soil were observed after stillage and biogas digestate applications.

On the other hand, plots treated with either dry manure or stillage presented elevated total P and K contents in the soil after the fertilizers' application (or even before the application, as for total K analysis, due to fertilization history and soil pedological characteristics) during the whole monitoring period when compared to untreated control and other treatments. However, the leaf macro and microelements analysis did not show significant differences between treatments, which was paralleled by a comparable fruit yield among all treatments.

Changes in microbial diversity and activity were calculated from the results of the Biolog Eco Plate analysis testing the microbiome potential with 31 different carbon sources. The results showed a significant increase in both, microbiological activity and diversity, after stillage application in comparison to the untreated control. Thus stillage, as a rich source of proteins and wide spectrum of macroelements, could introduce different compounds to the soil which could stimulate bacterial diversity and activity.

The effect of the fertilizers on the nematode community was assessed using the following parameters and indices: abundance, distribution of trophic groups, maturity index (MI), and plant parasite index (PPI). Bacterial feeders were particularly favored in soil treated with clover pellet and horn grit, fungal feeders were favored in soil fertilized with horn grit, and plant feeders were favored in soil fertilized with stillage. The highest share of omnivores was observed in soil treated with clover pellets, while the predators were enhanced in soil receiving horn grit. However, the greatest biodiversity in the nematode community was found in soil fertilized with stillage and horn grit. The addition of clover pellets, biogas digestate and manure reduced the biodiversity of nematodes compared to the control. The highest value of the plant parasite index was observed in soil fertilized with manure and clover pellets.

The effect of inoculation since the nursery phase of apple trees with a P-solubilizing rhizobacterium and a mycorrhizal fungus, alone or in association, was assessed in a second trial that was established in a newly planted orchard in 2019. The plants receiving the bacterium were also treated in the orchard, though the application was not repeated for the mycorrhizal fungus (this not being necessary due to the continuous colonization of new roots by the established fungus). The following plant growth parameters were measured together with the determination of the nutritional level of the trees by leaf diagnostics: shoot number, total and average shoot length, trunk diameter growth and the frequency of shoot length classes. At the end of the 2020 season, no statistically significant differences emerged between the three treatments and the untreated control. However, the analysis of frequency of different classes of shoot length revealed that in all treatments the most abundant class was between 6 cm to 15 cm, but the mixed inoculum presented a certain number of shoots with a higher growth (length >40 cm), which did not develop with the other treatments. In the leaf analyses, no statistically significant differences between the treatments could be found for both micro and macro elements.

LAIM

In 2020 the pot trial started earlier, to be more representative for the practice, as apple trees' nitrogen demand is higher in the weeks directly before and after bloom. Furthermore, the pot trial was replicated at FiBL with some modifications. The challenge was to find organic fertilizers that bring sufficient mineral nitrogen into the soil in a short time with low temperatures in early spring. At LAIM, the pea sowing was done on the 13th of March and the seedlings were cut and mixed with the soil on the 3rd of April. On the same day, the first of three fertilizer applications was done. The second and third applications were done on the 16th of April and 6th of May respectively. To monitor plant available N in the soil, analysis for N-NO3 and N-NH4 were taken immediately before the first (31st of March), second (15th of April), third (5th of May) fertilizer application, and after ca. three (20th of May) and seven (23rd of June) weeks from the last application. The results were extremely different from the ones observed in 2019, but this was expected as one of the most important parameters required for optimal organic mineralization, i.e. temperature, drastically differed from the previous year. During the first extraction, before the first N input of 2020, no difference to the previous year was found. The second extraction, performed two weeks after the first fertilization, showed a strong increase of Nmin for the two biogas digestates and the two stillages. The stillages showed very similar N level in all the extractions, while 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 brought lower levels of bioavailable N to the soil, reached the peak already during the first extraction, and then started to decrease. Biogas digestate pellets and organic fertilizers used as reference took more time to markedly increase the level of mineral N, but reached the same levels of the best performing biogas digestate and the two stillages. Peas, contrary to what was observed in 2019, showed the lowest level on Nmin in all the extractions performed. Unfortunately, a large part of the above-ground biomass produced by the peas was eaten by insects or wild animals and thus lost. The same happened with the seeds before and during the germination phase, some of the pea seeds were found out of the pots, or in the wrong one, probably transported by small mammals like mice and voles. Due to these damages, it is not possible to compare the results of the pea treatments with the other treatments of the trial.

The mineral nitrogen content of control leaves was lower when compared to the fertilized pots, and together with the pea treatment did not reach an adequate level of N in the leaf tissues. Curiously, the highest level of phosphorous was observed in the leaves of unfertilized pots, and a significant negative correlation between N and phosphorous (P) in leaf tissues was found. No significant differences were found for potassium (K), calcium (Ca) and magnesium (Mg) between treatments and control. Also, no significant differences were found for pH, acidity, total suspended solids and mineral nutrient content of the fruits, but when the mineral nutrients were classified by nutritional classes (Aichner et. al., 2004) some differences were evident.

For what concerns soil analyses, only clover pellets and one of the two biogas digestates significantly increased the total N content. Some slight K and P excess was found with most of the fertilizers, but in the case of the stillages and one of the biogas digestates the excesses resulted more pronounced.

For the pot trial at FiBL, six treatments were identical to LAIM (one biogas digestate, one stillage, clover-grass pellets, peas, a standard organic fertilizer, and an unfertilized control), and additionally two treatments with fresh white clover biomass were tested. As for LAIM, 8 g of N per tree were applied. The organic fertilizer applications were split into two applications: three weeks prior to full bloom (31st of March) and four days after full bloom (21st of April). The pea seeds were sown mid-March and the above ground biomass was cut and mixed into the soil after four weeks. The soil sampling for the mineral nitrogen analyses was done ten, twelve and sixteen weeks after the tree planting. To monitor plant available N in the soil, analysis for N-NO3 and N-NH4 were done immediately after the first (31st of March) and the second (21th of April) fertilizer applications, and after ca. three (12th of May) and nine (24rd of June) weeks from the last one. For the peas and fresh clover treatments, the second and third analyses 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 soil Nmin, followed by the biogas digestate, both higher than the standard fertilizer, which came third. The soil Nmin didn’t change for the peas in the first five weeks and then showed a slight increase. The clover-grass pellets and the two fresh white clover applications all resulted in nitrogen immobilization within the first four weeks followed by a slight nitrogen release. Leaf nutrient content was assessed and revealed the highest nitrogen content was in the leaves of the pea treatments, followed by the standard fertilizer, whereas the fresh clover and biogas digestate treatments and the control showed the lowest nitrogen content. A negative correlation was found between high N content of the leaves and the P and K content. No differences were found for Ca and Mg.

From the pot trial at FiBL it can be concluded that biogas digestate and stillage can provide good amounts of nitrogen around apple bloom, since they lead to a fast and high release of mineral nitrogen shortly after application. Peas can be an interesting source of nitrogen for later in the season as they release some nitrogen around five weeks after incorporation. Fresh white clover biomass, as for example cultivated in the tree inter-row and cut and applied to the tree strip, or clover-grass pellets cannot provide sufficient nitrogen used alone, but can be a complementary source. In conclusion, liquid products like biogas digestate and stillages mineralized well and fast, even when temperatures were low, as expected in springtime. The substrate used for the biogas digestate production directly influences the mineralization potential, and the biogas digestate, even when produced from the same biogas plant, might differ between different years, due to the natural heterogeneity of the feed materials. This was evident observing the different C and N ratio of one of the two biogas digestates, which showed a C/N ratio of 3 in 2018 and 2019 and 10 in 2020.

UHOH

The trial on testing alternative fertilizers in an organic apple orchard was continued at the Competence Centre for Fruit Growing (KOB) in 2020. In this last trial year the same 11 treatments were tested as in 2019 (unfertilized control, horn grit and stillage as commercial fertilizers, clover-grass pellets, clover-grass silage, liquid biogas residues, two treatments with compost (25 kg N and 5 t dry matter ha^{-1}), spring peas and winter peas (with two incorporation dates). The fertilization level was 25 kg N ha^{-1}, except for the one compost treatment in which a higher rate was used according to local famers' practices. Winter peas were sown in the tree row in October and incorporated in the soil either in March or April. Summer peas were sown in March and incorporated in April, together with all the other fertilizers, as in the previous years. Prior to tillage, the germination rate and the biomass of the peas were determined. The trunk circumference of the trees was measured in the winter season every year. Blooming intensity and fruit set were estimated. Leaf samples were collected in July for SPAD measurements and analyses of the nutrient status (N, P, K, Mg, Ca, Na, Zn, Fe, Mn and B). Based on leaf analyses there was a slightly lower N content in the unfertilized treatment, and nutrient deficits could be found for Mn, Zn and B. Mineral N content of the soil (N_{min}) was determined at 9 dates during the growing season between March and October. Besides N_{min}, S_{min} was also determined. Simultaneously, soil moisture was measured by Time-Domain-Reflectometry. N_{min} in the soil showed highest values from May to July; the highest was in the treatments with winter peas (92 and 84 kg N_{min} ha^{-1} tree row) and the 5 t ha^{-1} compost (87 kg N_{min} ha^{-1} tree row), and the lowest was in the silage (41 kg N_{min} ha^{-1} tree row), compared to 45 kg ha^{-1} as the highest value of the unfertilized control. S_{min} levels were more similar in all treatments, with the highest values from May to July (32 – 48 kg S_{min} ha^{-1} tree row). At the time of harvest, yield and fruit quality were determined in the apples, i.e. size, weight, color, sugar and acid content, starch degradation, fruit firmness and nutrient concentrations (C, N, P, K, Mg, Ca, and Na). In comparison to 2018 and 2019, acid and sugar content (10.3 °Brix) were lowest in 2020, starch degradation and fruit firmness (6.6 kg cm^{-2}) were similar to 2019. There were no significant differences to the control treatments (unfertilized, horn grit and stillage) in the fruit quality and yield level in the third trial year. The fertilization with stillage resulted in the highest yield (19.6 kg per tree), while the lowest yield levels appeared in the treatments with silage, spring peas and the later incorporated winter peas (17.5 – 17.6 kg per tree).

The three on-farm trials which were initiated in 2019 with the partner FÖKO e.V. continued in 2020. Compost, peas or silage were tested in the farmers´ orchards. N_{min} in the soil was analyzed at five to six dates during the trials. A noticeable difference to the field trial at KOB could be seen in the on-farm-trial with silage, whereas the N_{min} levels were equal to and later in the year even higher than in the control treatment with stillage.

The pot trial on the effect of S on nutrient and heavy metal mobility and availability in the soil was started in November 2019 and ran until November 2020. Five different soils from the Lake Constance and "Altes Land" region in Germany were chosen, and three levels of S (0, 40, 80 kg S ha^{-1}) were applied on the soils, followed by leaching events simulating rainfall. The element content of N, K, Ca, Mg, S, Cu and Zn were measured in the eluate after the leaching events. After seven months with six leaching events, rye grass was grown in the same pots to measure nutrient uptake by plants as well. The grass cultivated for twelve weeks with two cuts after six and twelve weeks. Significant differences could be detected in the amount of the leached elements between the different soils as well as the different S application rates.

Conclusions for the first, second and third project year

All trials at the different locations were continued in accordance with the project plan and the data were collected for the third year. No major deviations due to the Covid-19 situation in the different countries occurred. The application of alternative fertilizers resulted in different soil N_{min} contents during the year. However, only few statistically significant differences were found in the third year of trials, similar to the previous years.

As a major conclusion from the work performed it can be stated that, in principle, all fertilizers tested can be used as nutrient source in intensive organic apple orchards. 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 bloom. Biogas digestates may strongly differ in nutrient contents depending on the feedstock of the biogas plant, as could be shown by the analysis of the two biogas digestates utilized in Poland and Germany. However, nutrient availability was fast in both countries and therefore similar to other waste materials like stillage from sugar or yeast production that are widely used in organic apple growing and tested in the trials. Leaf and soil analyses revealed how organic fertilizers expose the trees to possible nutrient imbalances. For that reason, to avoid such imbalances, the fertilization strategy needs to be based on: a) soil and leaf analyses, b) orchard nutrient budgets, c) nutrients content of the fertilizer.

A second major lesson learnt from the trials was that there is no one-size-fits-all solution for fertilization in intensive organic apple orchards. However, a balanced fertilization strategy should introduce the concept of “alternation” of inputs/fertilizers/practices in order to benefit from the different nutrient sources and their differing nutrient contents. Such approaches would limit the risk of creating nutrient imbalances in the soil, better match the trees’ nutrients requirements with their availability from the soil, in particular the timing of the latter. Therefore, “diversification” of nutrient sources is 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.