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The influence of organic fertilizers on nutrient balance, yield, soil nutrient and organic matter - results of a 10-year field study

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Abstract

Nutrient availability is an important factor in apple cultivation and, especially in organic production, the use of organic fertilizers can lead to a deficit or excess of individual nutrients, and one-sided nutrient supply can affect production. Therefore, fertilization measures should be adapted to the crop to avoid negative inputs into the environment. Therefore, soil tests are carried out regularly in apple cultivation to check the fertilization measures that have been carried out and, in addition, the calculation of the nutrient balance can also be used.

In this study, seven different treatments were applied to the apple variety 'Golden Delicious' over a period of 10 years. In addition to an unfertilized control and a conventional variant with ammonium sulfate, three different organic fertilizers were used. On the one hand, one variant was fertilized with compost and a second variant with a combination of compost + Nutristart, while on the other hand the fertilizer Azocor 105 was applied. The fertilizer Azocor 105 was used in three variants, comparing the methods of mulching and tillage for weed control with the conventional method, ploughing and brushing. Overall, both nutrient balances and yields were evaluated, as well as the results of N_{min} analyses. In addition, the results of the soil analyses of 2009 and 2019, for the evaluation of the P, K, Mg and organic matter in the soil, were used.

The evaluations show that the nutrient balances are unbalanced for all variants, and no significant difference can be found between the variants in terms of yield. However, a tendency towards higher yields can be observed for the ammonium sulfate and Azocor 105 variants. In the results of the N_{min} analyses, significant differences between the variants can be observed in some years, while the P, K, Mg and organic matter in the soil was increased mainly for the variants compost and compost + nutristart. Finally, the fertilizer Azocor 105, compared to the other organic fertilizers, was found to have the most positive effects on yield and nutrient availability.

Keywords: Nutrient balance, organic fertilization, apple cultivation, organic matter.

Introduction

Fertilization is an important factor in apple production, and N is the most important element because it controls essential physiological processes such as flower bud formation, shoot growth, yield, and internal and external fruit quality (Aichner et al. 2004).

In organic apple production, no mineral, easily soluble fertilizers are allowed for N fertilization, and for the nutrients P, K, Mg, mineral fertilizers may only be used from supply level B onwards. Therefore, organic fertilizers are the basis for fertilization in organic apple production. Through an experiment on N mineralization, Kelderer et al. (2008) already showed that there are strong differences between the organic commercial fertilizers in terms of N mineralization and nutrient release. However, since high-quality fruit at a high yield level should also be produced in organic apple production, the organic fertilizers must provide N, P, K, and Mg to the trees in a sufficient ratio. However, in addition to providing sufficient nutrients, high nutrient surpluses should not occur so that fertilizers are used sustainably and negative inputs to the environment from leaching are avoided.

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Therefore, in this study, different fertilization methods and tillage techniques were compared regarding their nutrient balance and yields as well as nutrient and organic matter content in the soil. The aim was to find out whether the respective fertilizer has a positive effect on nutrient availability as well as yield and whether the nutrient balance is balanced. Thus, the sustainability and practicality of the fertilization methods can be evaluated to provide decision support for future fertilization strategies in organic apple production.

Material and Methods

Experimental Design:

The experiment was established in 2009 in Vinschgau (39021 Latsch; 46°36'41.2"N 10°51'54.3"E) at an altitude of 700 m (a.s.l.). For this purpose, apple trees of the variety 'Golden Delicious' were planted on the rootstock M9, at a spacing of 3.2 m by 0.75 m and with a planting density of 3750 trees per hectare and managed according to organic farming methods. From the soil analysis at the beginning of the experiment, it was found that at the experimental site, the upper soil (0 - 20 cm) with an organic matter content of 6.4% is a highly humic, loamy sandy soil and the subsoil (20 - 40 cm) with an organic matter content of 4.9% is a humic, loamy sandy soil. With a soil pH of 6.2 and a low to medium carbonate content, this site is ideally suited for apple production. During the trial period, precipitation averaged 589 mm, which was above the long-term average, and in addition to natural precipitation, the plant was optimally supplied with water by drip irrigation. The average temperature was 10.9 °C, with temperature fluctuations between 38 °C and -13 °C.

The experimental plot was divided into plots with five evaluation trees and two border trees each, and each variant had four replicates randomly distributed in the plot. A total of seven different experimental variants were evaluated. In addition to the control as a reference for all variants, the conventional variant with ammonium sulfate served as a comparison between conventional and organic fertilization. The organic fertilizers used were compost, Nutristart and Azocor 105 with different nutrient compositions. (Table 1)

Each year, tree cut was performed according to standard professional practice and then the cut wood was chipped in the tramline and thus remained in the plant. For weed control, variants 1/2/3/5/11 were ploughed in the spring and then brushed four times during the year. Variant 14, on the other hand, was only mulched and no tillage was performed by mowing four times a year with a string mower. Variant 15 was hand hoed a total of four times a year; otherwise, no further tillage took place there. All variants were always fertilized at the same time in spring, with fertilizer rates varied between 37.5 and 169 kg total N/ha (Table 2). The higher N applications in variants 3 and 11 are because the N bound in the compost is released very slowly. In a study by Amlinger et al. (2003), it was observed that only 5-15% of the total N is released in the first year and 2-8% in subsequent years. For this reason, a N release of 10% per year was assumed for compost in this study and the maximum permitted amount of 90 kg total N per ha (9000 kg compost per ha) was fertilized.

Soil Tests:

Soil tests were taken in June (2009) and April (2019) from soil layer 0 - 20 cm using a Pürckhauer gouge auger. In the process, 500 g of soil were taken from each plot and analyzed according to VDLUFA regulations. On the other hand, the N_{min} - soil samples were taken every year, four weeks after fertilization, and 300 g of soil were taken for analysis according to VDLUFA regulations. In the laboratory, an extraction of the field-moist soil samples was prepared with a 0.0125 molar solution of calcium chloride and photometrically determined. Nitrate-N (NO^{3-}) and ammonium-N (NH^{4+}), as well as N_{min} content, the sum of nitrate- and ammonium-N, were determined. Since the N_{min} content was given by the laboratory in mg/kg of dried soil, the results still had to be converted to kg/ha. For the conversion, the average dry matter of the soil of 74 % and, according to the guideline values for mineral soils, a density of 1.4 g/cm^3 were used.

Table 1: Description of the experimental variants: Treatments with abbreviations and composition of fertilizers, as well as manufacturer and nutrient content in fresh matter (in %); analyses were performed by the agriculture chemical laboratory Laimburg.

No.	**Treatment (fertilizer/soil management techniques)**	**Abbrev.**	**Composition**	**Producer**	**Proportion of nutrients in the fresh mass (%)**			
					N	**P**	**K**	**Mg**
1	Control	Contr	-	-	-	-	-	-
2	Ammonium sulfate	Amsul	Ammonium nitrogen	Siriac S.r.l.	21,0	0,0	0,0	0,0
3	Compost	Comp	Green waste, pomace, cattle manure, biowaste, stone meal	Ecorott S.r.l.	1,0	0,2	0,9	1,8
5	Azocor 105	Azo	Soy, corn press cake, horn meal, poultry feather meal (pellet)	Fomet S.p.A.	10,4	1,8	1,2	0,3
11	Compost + Nutristart	Comp +	see No. 3					
		Nutr	Vinasse (liquid)	Lievitalia	3,5	0,1	4,5	0,1
14	Azocor 105 / Mulching	Azo - Mul	see No. 5					
15	Azocor 105 / Tillage	Azo - Til	see No. 5					

Table 2: Year of fertilization and total N fertilization rate in kg N/ha, by variant.

Year of fertilization	**No. 2/5/14/15 kg N/ha**	**No. 3 kg N/ha**	**No. 11 kg N/ha**
2009	60	37,5	37,5 + 56,25
2010	75	90	90 + 79
2011	90	90	90 + 79
2012	90	90	90 + 79
2013	90	90	90 + 79
2014	60	90	90 + 51
2015	60	90	90 + 51
2016	60	90	90 + 51
2017	60	90	90 + 51
2018	60	90	90 + 51
2019	60	90	90 + 51

Nutrient balance:

The nutrient balance was calculated according to the simplified soil balance, since some material flows such as nitrogen fixation, emissions and immissions, denitrification, erosion, leaching, volatilization, and the weathering of minerals could not be determined and were therefore not considered (Bachinger et al. 2004). The nutrients N, P, K, and Mg of the individual fertilization methods were calculated.

For the calculation of the nutrient balance, the results of the experimental trees of each variant (20 trees) were extrapolated to one hectare (3750 trees) since the quantity calculations in the balance always refer to one hectare. In the balance calculation, the stored amount of nutrients in the roots and in the scaffold of the apple trees was used (Friedrich 1993) (Table 3). The sum of the removal by the harvest quantities and storage in the roots and scaffold of the apple trees was then compared to the nutrient supply by the fertilization. Nutrient supply from fertilization was calculated from the amount of fertilizer applied (Table 2) and the percentage of each nutrient in the fertilizer (Table 1).

Table 3: Mineral uptake of apple trees by the growth of the trunk substance, per hectare and year. (Friedrich 1993)

Plant part	**Uptake in kg/ha**			
	N	**P**	**K**	**Mg**
overgrown shoots and roots	15	3	12	2

Statistics:

The IBM® SPSS® Statistics program (version 27) was used to perform the statistical analyses. The test for normal distribution and the test for variance homogeneity were used to check whether a one-factor analysis of variance (ANOVA) may be performed. If a statistically significant difference ($p < 0.05$) was then seen, a post hoc test (Tukey HSD) was then performed so that it could be seen between which variants there was a significant difference. If there was no normal distribution of the data, the Kruskal-Wallis test was applied with a pairwise comparison.

Results

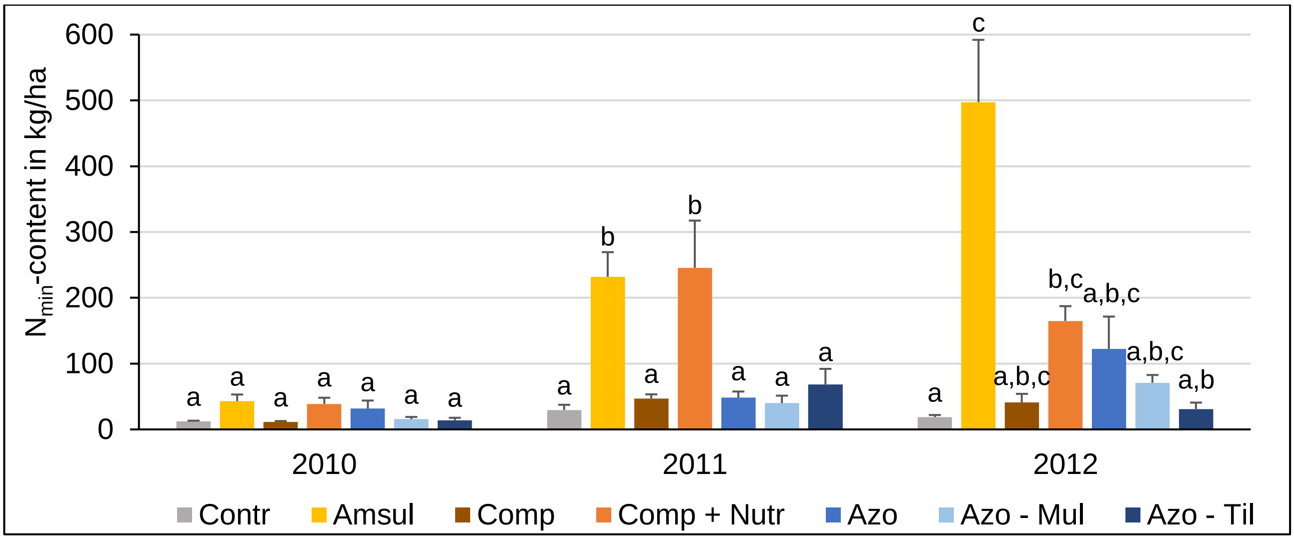

Figure 1: Influence of fertilization on N_{min}-content in 2010 - 2012; four weeks after fertilization, in soil layer 0 - 20 cm (kg/ha).

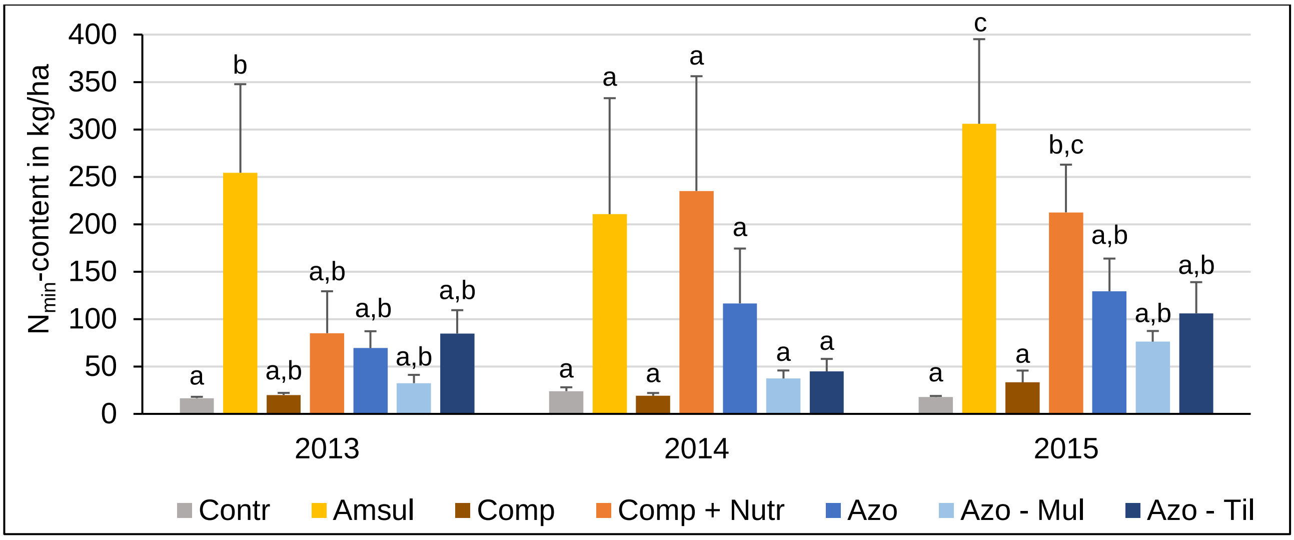

Figure 2: Influence of fertilization on N_{min}-content in 2013 - 2015; four weeks after fertilization, in soil layer 0 - 20 cm (kg/ha).

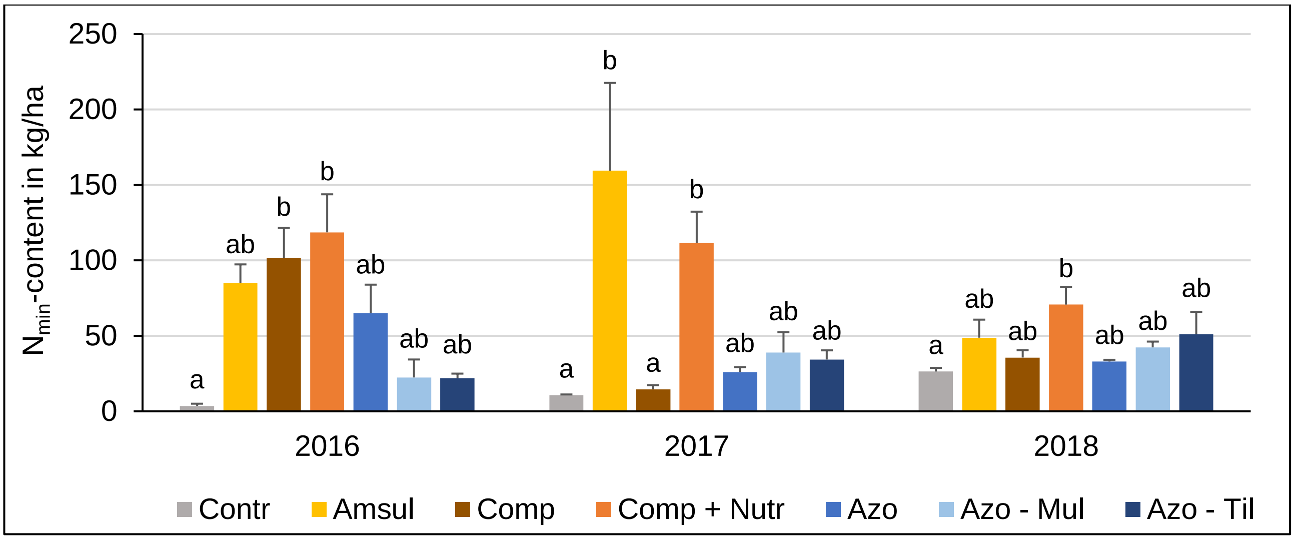

Figure 3: Influence of fertilization on N_{min}-content in 2016 - 2018; four weeks after fertilization, in soil layer 0 - 20 cm (kg/ha).

Through statistical analysis of N_{min} content, a significant difference was found between groups a and b in 2011 ($p < .041$), 2013 ($p = .011$), 2016 ($p < .029$), 2017 ($p < .039$) and 2018 ($p = .027$). In 2012, a significant difference was found between groups a and c ($p = .008$), a and bc ($p = .048$), ab and c ($p = .041$), and in 2015 between a and c ($p < .003$), a and bc ($p < .036$), ab and c ($p < .05$). In 2010 and 2014, there was no significant difference in N_{min} content between the variants. (Figure 1 - 3)

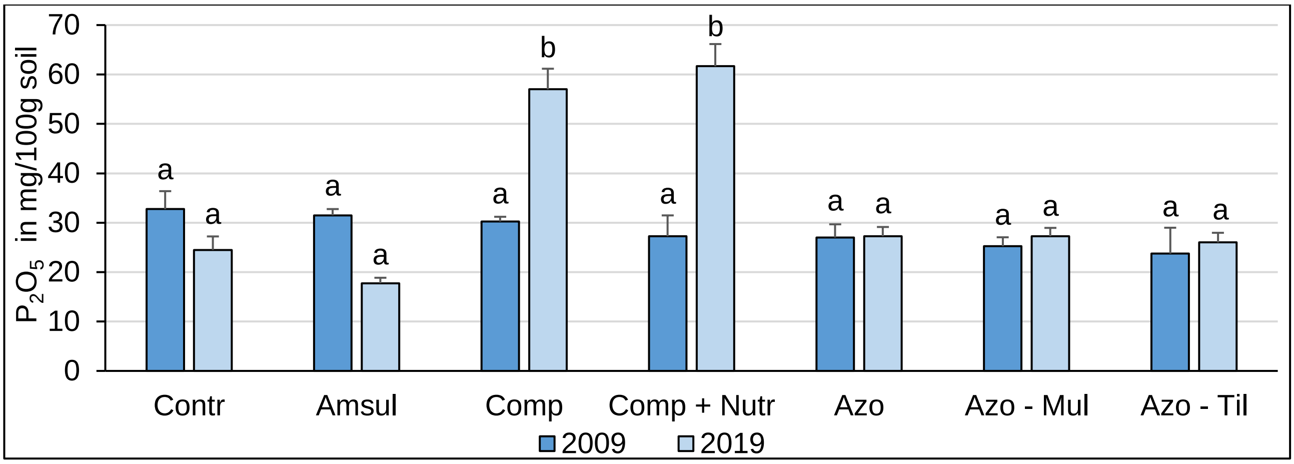

Figure 4: Influence of fertilization on phosphorus content (P_2O_5) in the upper soil layer (0 - 20 cm) over the period 2009 - 2019.

At the beginning of the experiment in 2009, there was no significant difference in the P content in the soil between the individual variants. Through the influence of fertilization, the P content changed, because in 2019 the variants compost and compost + Nutristart had a significantly higher P content than all other variants. A significant difference was found between group a and b ($p < .001$) (Figure 4). When comparing the P contents with the supply levels (LTZ Augustenberg 2009), in both 2009 and 2019, all variants could be allocated supply level E and thus there was a P oversupply.

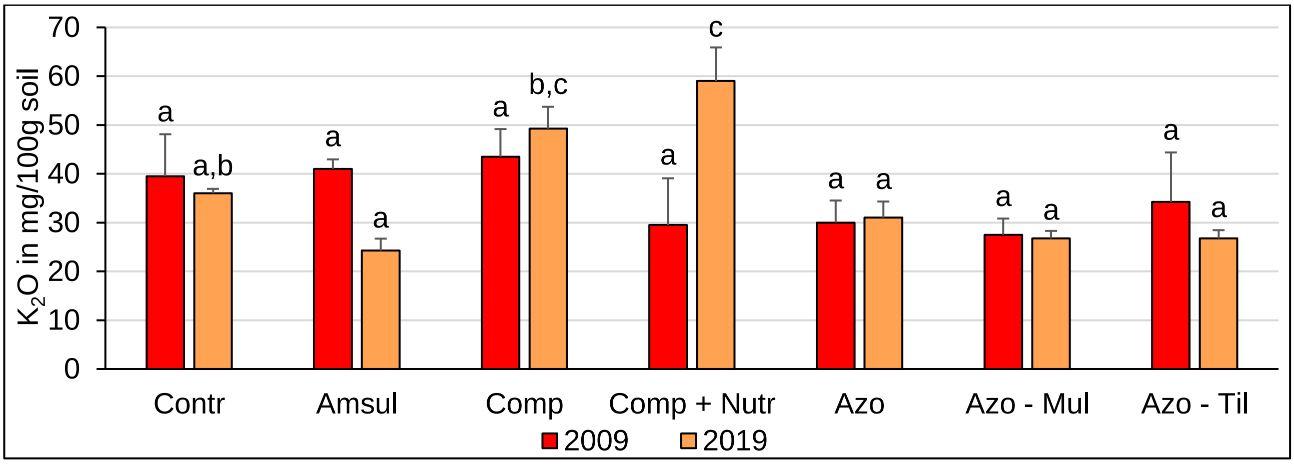

Figure 5: Influence of fertilization on potassium content (K_2O) in the upper soil layer (0 - 20 cm) over the period 2009 - 2019.

At the beginning of the experiment in 2009, there was no significant difference in soil K content between the different variants. In 2019, there is a significant difference between groups a and c ($p < .001$), ab and c ($p = .003$), and a and bc ($p < .026$). There is no significant difference between groups a and ab, ab and bc, and bc and c. When comparing the K contents (Figure 5) with the supply levels (LTZ Augustenberg 2009), in 2009, all variants can be assigned supply level E. In 2019, the ammonium sulfate variant could be assigned supply level C and all other variants could be assigned supply level E.

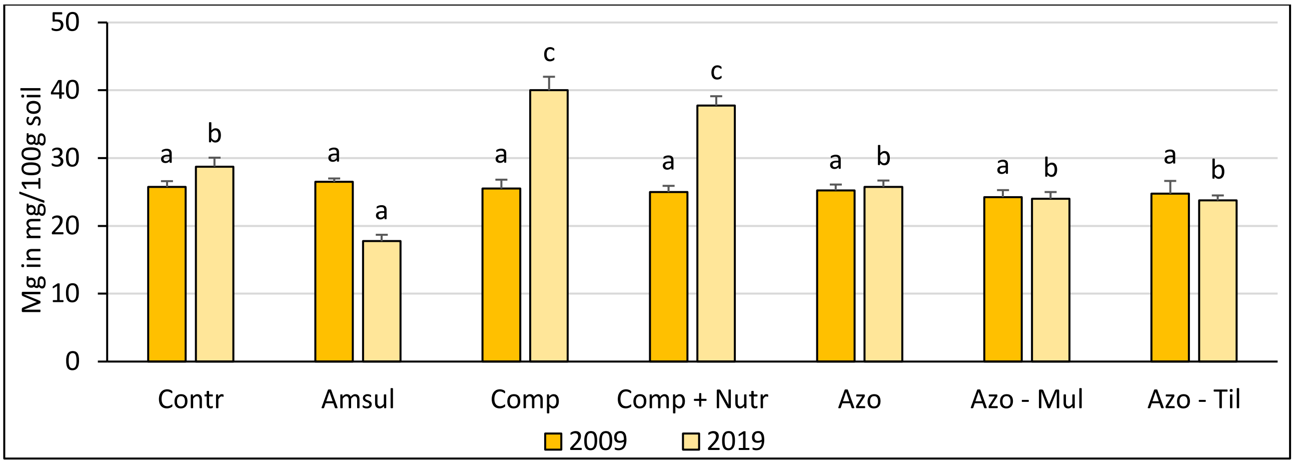

Figure 6: Influence of fertilization on magnesium (Mg) content in the upper soil layer (0 - 20 cm) over the period 2009 - 2019.

At the beginning of the experiment in 2009, there was no significant difference in soil Mg content between the different variants. The analysis results from 2019 show a significant difference between groups a and c ($p < .001$), b and c ($p < .001$), and a and b ($p < .038$). When comparing the Mg contents (Figure 6) with the supply levels (LTZ Augustenberg 2009), all variants could be assigned to supply level E in both 2009 and 2019.

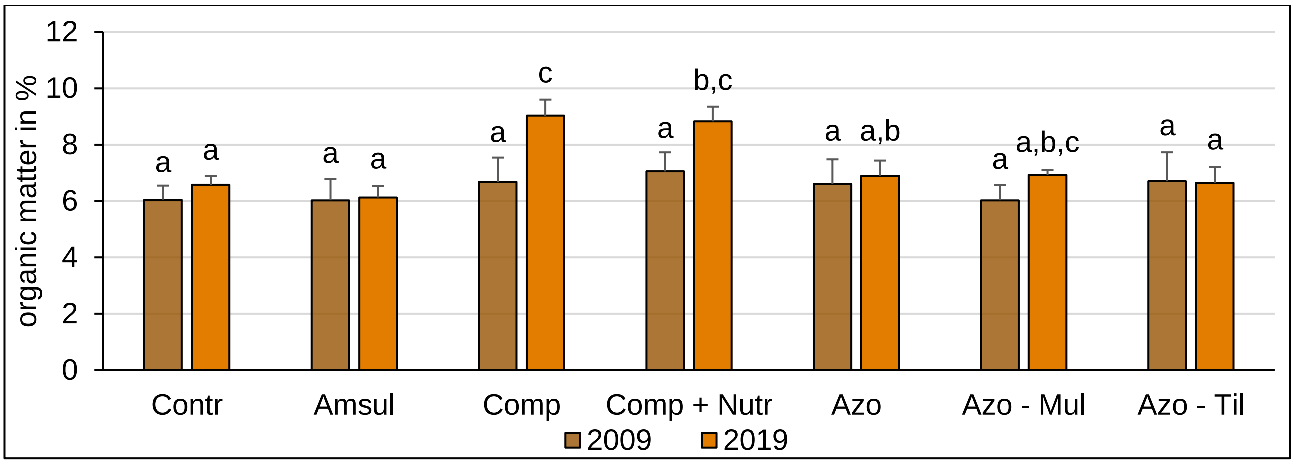

Figure 7: Influence of fertilization on organic matter in the upper soil layer (0 - 20 cm) over the period 2009 - 2019.

For organic matter content, there was no significant difference between the variants at the beginning of the experiment in 2009. In 2019, a significant difference was visible between groups a and c ($p < .023$), ab and c ($p < .05$), and a and bc ($p < .043$). (Figure 7)

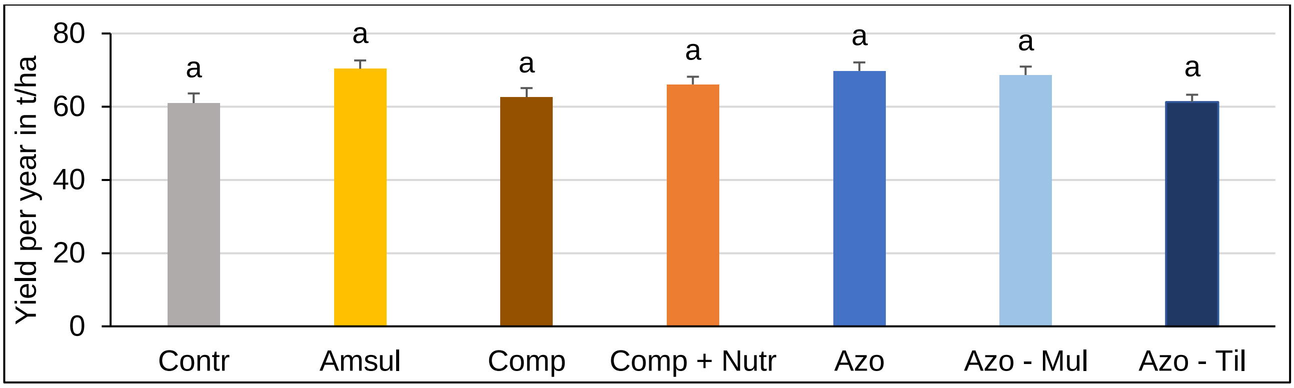

Figure 8: Influence of fertilization on the average annual yield over the period 2010 - 2019 in t/ha

From Figure 8, fertilization has no significant effect on the average annual yield as there is no significant difference between the variants.

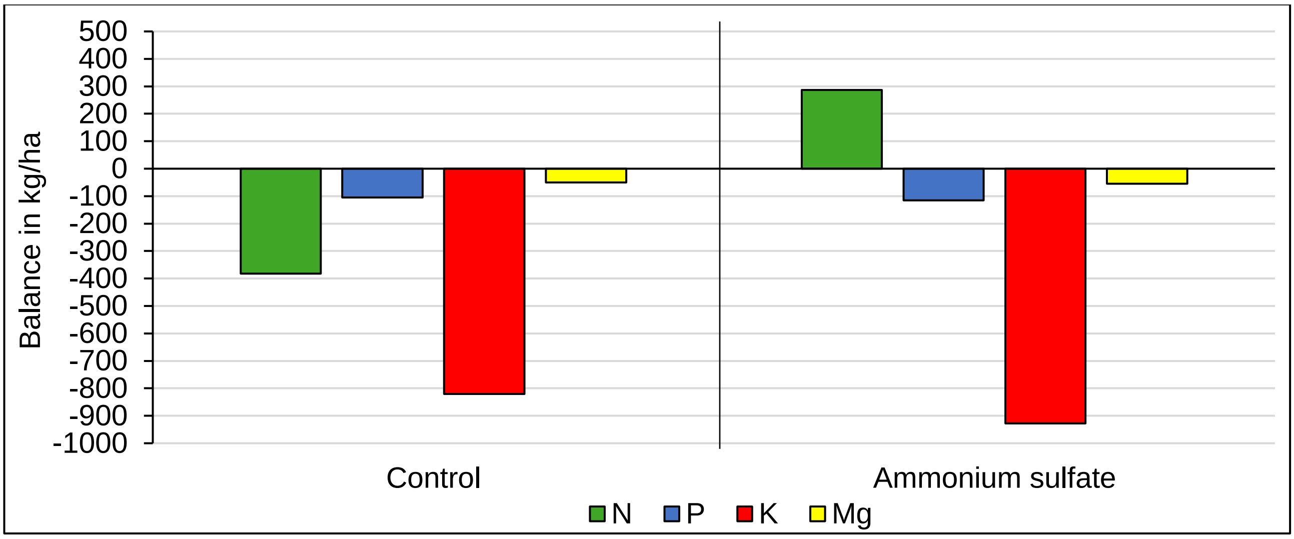

Figure 9: Influence of fertilization on the nutrient balance of the control and variant ammonium sulfate over the period 2010 - 2019.

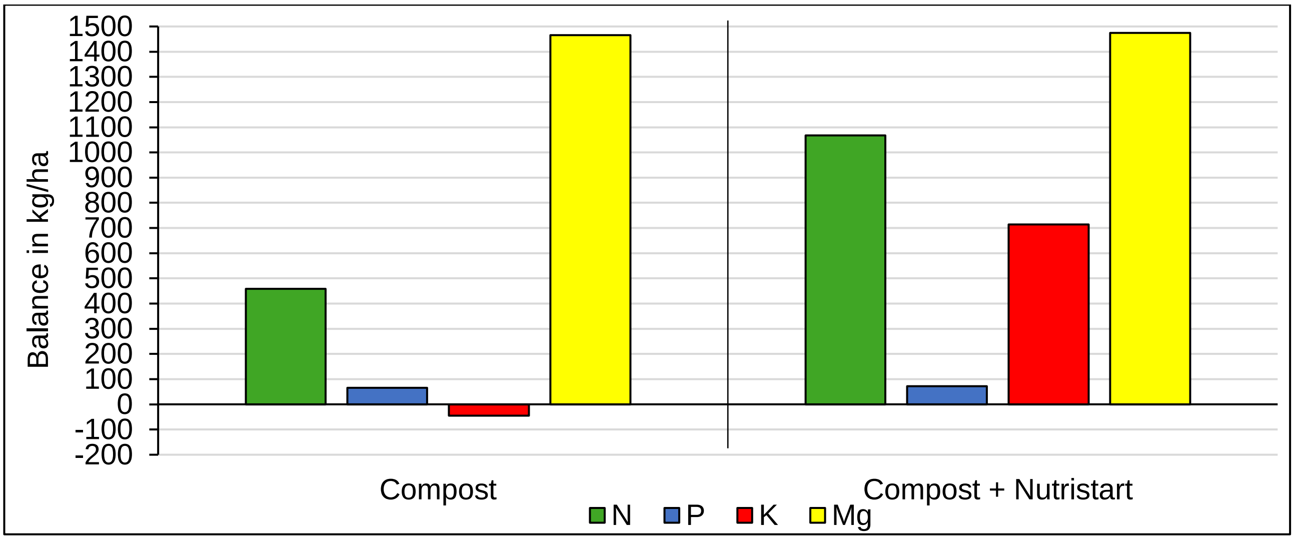

Figure 10: Influence of fertilization on the nutrient balance of the variant compost and compost + Nutristart over the period 2010 - 2019.

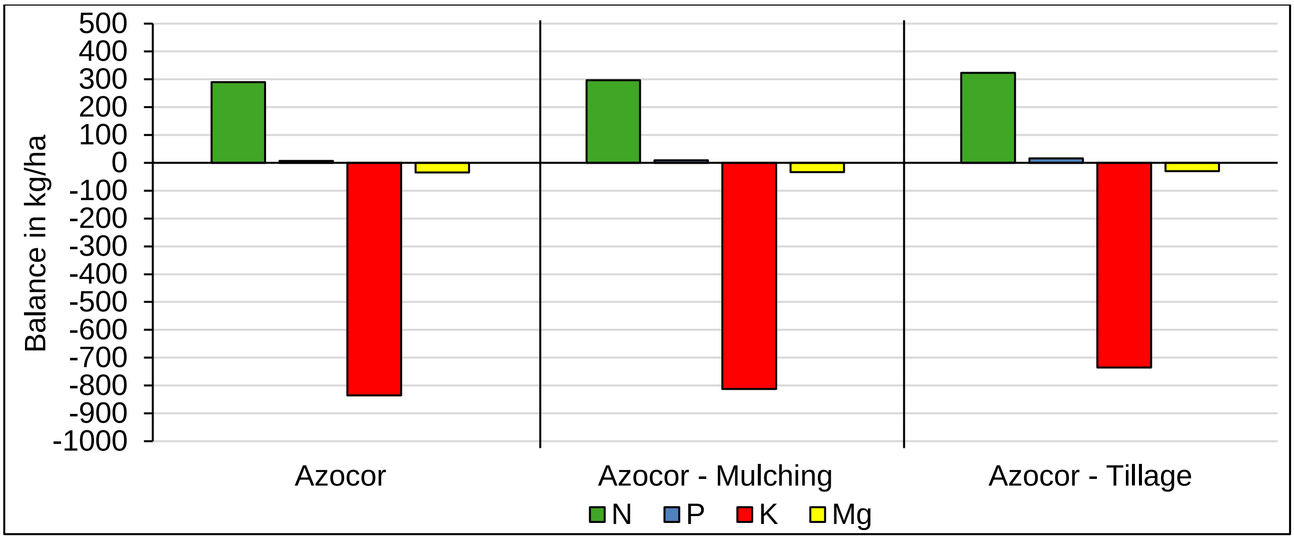

Figure 11: Influence of fertilization on the nutrient balance of the variants Azocor 105, Azocor 105 (mulching) and Azocor 105 (tillage) over the period 2010 - 2019.

Comparing the nutrient balances (Figure 9 - 11), all fertilized variants show a positive N-balance in contrast to the control. Especially the variant compost + Nutristart shows a high positive N balance. The P balances are in the positive range between 6 and 72 kg/ha for all fertilized variants, except ammonium sulfate. In the K balance, all variants, except the variant compost and compost + Nutristart, show high negative balances. While in the variant compost the K balance is almost balanced, in the variant compost + Nutristart a high positive K balance can be seen. The Mg balances are similar and almost balanced in all variants except compost and compost + Nutristart. The very high positive Mg balances can be seen in the variant compost and compost + Nutristart, which is primarily due to the high Mg content in the compost (Table 1).

Discussion

<u>Nutrient availability:</u>

The results show that the ammonium sulfate and compost + Nutristart variants have a high N_{min} content in the soil and thus provide a lot of N to the plants. This indicates rapid N release or better solubility in the soil. In contrast, the compost variant had very low N release because compost releases N very slowly with an N mineralization rate of 2.9 % in 60 days (Kelderer et al. 2008). In 2016, a very high N_{min} content was found in the compost variant, but since low N_{min} contents were found in all other years, the compost variant has the highest risk of N deficiency during the highest demand of the apple trees. Since even in the control yields averaged 61 t/ha (Figure 8), it can be assumed that a high microbial conversion of the organic matter present in the soil ensures sufficient N supply even without fertilization at this location. This assumption is confirmed by the statement that under the South Tyrolean weather and soil conditions 100 to 200 kg N/ha are supplied annually from mineralization (Aichner et al. 2004). It should be noted that during the study, N undersupply was found in the control in two years. The Azocor variants mostly had a much lower N_{min} content than the ammonium sulfate and compost + Nutristart variants, suggesting moderate N release. No significant difference was found between the Azocor variants, indicating that tillage technique had no effect on N availability in this study.
Soil P content increased in the compost and compost + Nutristart variants during the trial period and was significantly higher in 2019 than in all other variants (Figure 4). A conclusive explanation for this could be the supply of large amounts of organic matter. This is because

the decomposition of organic matter produces acids that attack the hardly soluble P compounds and make P partially available to plants again (Keppel et al. 1998).
The results of the soil analysis (Figure 5) show high K values, especially for the variant compost + Nutristart, which can be explained by the higher K content in the fertilizer Nutristart (Table 1). Since only in the variant ammonium sulfate in 2019 the supply level C and otherwise in all variants the supply level E was observed, enough K was provided to the apple trees and there was no K undersupply of the apple trees.
The Mg content in the soil was very high in all variants at all times and therefore all variants could be classified in supply level E (Figure 6). In addition, a strong increase in Mg content was observed in the compost and compost + Nutristart variants, which can be explained by the high Mg content in the fertilizer. According to Keppel et al. (1998), excess Mg in the soil could cause deficient Ca uptake and thus affect fruit quality. Therefore, in the variants compost and compost + Nutristart, due to the antagonistic effect between Mg and Ca, stippling could occur.

Organic matter content:
The results of the soil analysis show that the variants compost and compost + Nutristart have a significantly higher organic matter content in contrast to all other variants (Figure 7). Fertilization with compost and the associated increase in organic matter content can positively influence biological activity, soil structure as well as nutrient availability (Fischer 2002). However, it should be noted that N mineralization of compost takes a long time, as shown by the results of N_{min} analyses (Figure 1 - 3), so low N (11 - 48 kg/ha) was released (except in 2016) and no significant increase was observed over the 10-year period. According to Aichner et al. (2004), with compost only 35 % of the N is available to plants in the year of application and a total of 70 % of the N is mineralized, while the rest is bound in the soil as permanent humus. In contrast, with the variant compost + Nutristart, enough N is available at the time of the highest N demand and thus in this variant the positive properties of compost and rapid N release of the Nutristart are combined.

Yields:
The calculation of the average annual yields shows that there is no significant difference in the yields (Figure 8). It was found that the control as well as the variant compost and Azocor 105 (tillage) tended to have a lower yield than the variant ammonium sulfate and Azocor 105. However, regarding the yields, it does not play a decisive role which fertilizer and which tillage technique is used. The decisive factor for the similar yields of the variants could be the adequate N supply of the apple trees, due to the natural N release of the soil (Aichner et al. 2004).

Nutrient balance:
After calculating the nutrient balances, no fertilizer method can be described as optimal, since either a high negative K balance or high positive Mg or K balances occur (Figure 9 - 11). In addition, the nature of the respective fertilizer plays a decisive role, since the nutrients are available to the plants at different rates, depending on the solubility and conversion rate of the fertilizer. Especially with organic fertilizers there are large differences, because the organic fertilizers need more time for mineralization and thus provide the nutrients over a longer period, while the crystalline, easily soluble ammonium sulfate is quickly available to plants (Kelderer et al. 2008).

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