Comparison of different tree nutrition strategies for organic apple growing: long-term and additive effects of compost, N-fertilizer, foliar fertilizer and bio-dynamic preparations on tree growth, yield, fruit quality and soil fertility

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Abstract

Organic apple growers often have yields that are 15-30 % below the average of conventional growers, and that are not explainable by losses due to insufficient plant protection measures. Thus, worldwide, a tendency can be observed that organic fruit growers are intensifying fertilization. The question is, whether this really can improve the yields and which side effects occur on fruit quality and soil. On the other hand it is stated that improving soil fertility with compost and/or bio-dynamic preparations can also stimulate nutrient mineralisation. However, quantitative data showing these single and combined effects on tree performance are scare.

In an orchard with two-years old 'Topaz' apple trees on rootstock 'M27' we carried out from 2001 to 2007 a full factorial trial testing the factors i) biowaste compost (8000 kg ha-1,y-1), ii) commercial organic N-fertilizer (10 % N; 40 kg N h-1,y-1), iii) foliar N-fertilizer (as molasses, 5 % N-content; 14 kg N ha-1,y-1). In all possible combinations 9 treatments resulted. Additionally, 2 sub-treatments with bio-dynamic methods were tested: iv) application of the same compost but prepared by the bio-dynamic method with and without foliar application of the bio-dynamic preparation 500 and 501.

With respect to yield, fruit weight, inner fruit quality, and mineral content of the fruits only rarely significant treatment effects occurred. Only by tendency, organic matter content, aggregate stability and microbial activity were improved in the plots receiving compost. Conclusions to optimize tree nutrition measures depending on spatial soil conditions could be drawn.

Keywords: apple, organic, fertilization, compost, bio-dynamic

Introduction

In Europe and many other countries the market and production of organically produced fruit is still expanding (Weibel *et al.* 2013).

In general organic apple growing yields are often 15-30 % lower than in conventional production, and often the reasons are: i) a not sufficiently effective plant protection regime against diseases and pests, ii) too strong weed competition or iii) distinct alternate bearing. However, also in cases where the limiting factors mentioned seem to be sufficiently controlled, yields in organic orchards are lower than in conventional or IP systems (Weibel 2002). As a reaction, many organic fruit growers try to intensify the fertilization of their trees. However, the trend to intensify tree nutrition in organic apple growing is contrasting to the traditional principle of organic plant nutrition where primarily the soil – not directly the plant - should be "fed" (Lampkin 2002). However, i) the effects of this intensification on fruit yield and quality is not scientifically studied, and even if yields would increase, there is

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a severe risk for diminishing fruit quality which would not be compatible with the high consumer expectations on the inner quality of organic apples; ii) organic fertilizers are usually much more expensive, even if it is farm yard manure its purchase and application is labour intensive. Thus, also the question on the economic efficiency of intensification measures must be raised; and finally iii) it is a primary goal of organic agriculture to increase and sustainably conserve soil fertility on a high level while growing food produce of high inner quality. Nevertheless, the effects of an intensified organic tree nutrition management on soil fertility and its correlations with yield and quality performance of apple trees have rarely been reported scientifically. Consequently, there is also a considerable lack of knowledge for advising practical growers on how they could fertilize their orchards to optimize all issues together: yield, fruit quality, costs and soil fertility.

To contribute to these questions, and in the frame of the ISAFRUIT project (Task 5.1.7) of the 7th EU-Framework Program, we carried out a long-term full factorial experiment in a commercial organic orchard in Switzerland (KOB trial) with application of compost, commercial N-fertilizer, foliar N-fertilizer and bio-dynamic preparations in 11 different combinations.

Material and Methods

The field trial has been installed in 2001 in a commercial certified organic orchard of family Vogt planted in 1999 on site without fruit production before. Location: Remigen, Switzerland 47°30.7N/8°11.4E), 390 m a.s.l., av. rainfall 900 mm y^{-1}, av. year temp. 8.4°, the soil is a neutral alluvial para-brown soil of silty clay with signs of pseudo-gley at 40-60 cm depth, the 0-25 cm topsoil initially had a $pH_{H2O}$of 5.4-6.0 and humus content was 3.0 %. Cultivar: Topaz (scab resistant); rootstock was M27 (very dwarfing and therefore estimated to express well fertilization treatment differences); planting distances: 1 m in row, 3 m between row; tree training as free spindle. The alley way is kept green with a mulched grass sod all year round. The tree strip is tilled for weed control 4-5 times over a width of 1 m from April to July with a hydraulically operated Ladurner rotor-tiller device.

Plant protection measures, weed control, crop regulation and pruning were carried out after usual farm practices of family Vogt.

The trial is arranged as a full factorial randomized block design with 3 replication blocks. One plot contains 18 trees and is 18 m long, the first and the last tree were buffer trees. Within each plot 5 representative trees were chosen as measuring trees for all assessments made on the tree organs (see below). The fertilizer factors are i) compost (**K**) from green wastes in form of a commercial, organic certified compost made by SV AG in CH-Bellach, ii) commercial organic N-fertilizer (**O**) with “Biorga Quick” of Hauert GmbH in CH-Grossaffoltern with 11 % total N, iii) commercial organic foliar N-fertilizer (**B**) with “Biorga NK-Vinasse” with 4.5-5 % total N. The 2 control treatments are: “untreated” and “PKCaMg fertilization” equivalent to the compost treatments (to be able to differentiate the organic matter effect from the pure nutrient effect of the compost). Due to the factorial design, n per factor was 9. Additionally there were the two sub-treatments, both with bio-dynamically prepared compost (from the same raw material, treated by Rainer Sax, CH-Gelterkinden) but with and without foliar application of the bio-dynamic preparations 500 (Horn Manure) and 501 (Horn Silica). In total 11 combined treatments were tested (Tab. 1).

Table 1: Factorial combinations of the treatments tested. **K** = Compost (n=6), **O** = commercial organic soil N-fertilizer (n=4); **B** = foliar organic N-fertilizer (Vinasse) (n=4). In V3, V6, V7 and V8 certified organic green waste compost was used. In V4 and V5 bio-dynamically produced compost was used which was made from the same primary material. In the treatments V2, V9, V10 and V11 the equivalent amounts of P, K, Ca and Mg of the compost were applied in form of commercial organic fertilizer.

Treatment no.	Treatment name (factor combination)	Remarks
V1	**– ––**	Untreated control
V2	**– – –PKCaMg**	Untreated control with PKCaMg supplement
V3	**K – –**	
V4	**K_{bd} – –**	Bio-dynamic compost; but fruit production without bio-dynamic preparations 500 and 501
V5	**K_{bd} – –Prep.**	Bio-dynamic compost; fruit production with bio-dynamic preparations 500 and 501
V6	**KO –**	
V7	**KOB**	
V8	**K – B**	
V9	**– O –**	with PKCaMg supplement
V10	**– O B**	with PKCaMg supplement
V11	**– – B**	with PKCaMg supplement

The amounts of fertilizers given were calculated to reach nutrient equivalents concerning PKCaMg between treatments and according to the official Swiss soil-analysis based recommendations (Bertschinger et al. 2003). They reached per ha and year (standard recommendation put in parenthesis): 40 (60) kg N available; 12.2 kg P_2O_5 (20 kg), 13,7 (70) kg K_2O, 19.5 (10) kg MgO, 52 (70) kg CaO. All fertilizer products and composts were applied only on the tree strip which results in a 3-fold concentration of the quantities given. The treatments, therefore represent - for Swiss circumstances - quite a high intensification of tree fertilization.

Assessments

Soil: For standard soil analysis to assess PKCaMg contents 5 soil cores from 1-25 cm soil depth were taken for a mixed sample in the tree strip not closer than approx. 30 cm from the stem and the edge of the alley way, and analysed in 1:10 vol. water and NH_4-Ac EDTA extract for available and "reserve" nutrient content (Bertschinger et al. 2003). To assess the mineralized N-content, the soil samples were put in a cool box immediately after sampling. The analysis was done photometrically with a 1:4 extraction in 0.01 M CaCl2-solution (NM-Ex method described by FAL *et al*. 1996). N_{min} was assessed 3-4 times during the seasons of 2003, 2006 and 2007.

Yearly stem circumferences were measured at 30 cm above ground as indicator of the vegetative bio-mass growth. Harvest was done tree-wise on all measuring trees in 3 to for picks depending on ripening stage of the fruits. The number of fruits and their total weight per tree were noted. The fruits were stored at 92 % r.h. and 2 °C until analysis. Yield data are shown from 2004-2007 as then the soil/plant equilibrium was installed. Specific yield was calculated by dividing yield per tree (kg) by its stem circumference (cm) at the beginning of the same year. Alternate bearing is expressed as absolute percentage of the difference between the yield of a year and the following year from the sum of the yields in both years.

Leaves and fruits: samples were taken after cell division stage of the fruits, the so called T-stage when stem and bottom of the fruit are forming a T, and at harvest time. From each plot and the 5 measuring trees per plot 28-36 leaves from the middle of representative 1-year old shoots in the central zone of the canopy were collected. In the lab, the leaves were measured for SPAD (chlorophyll index with Minolta device), washed with 3 % citric acidity distilled water, rinsed and dried to weight constancy at 105 °C. The fruits for mineral analysis and fruit quality measurements were sampled during yield assessment (40 per plot). They were measured for firmness with a standard penetrometer (Fruit Tester 327, by Wagner USA-Greenwich), soluble solid content (Brix, Refracto 30PX by Mettler Toledo in CH-Greifensee), malic acid content with Titrator DL67 by Mettler Toledo in CH-Greifensee. To measure mineral content of the fruits they were peeled, uncored, sliced, dried at 72 °C and grind. Analysis was carried out by a certified laboratory (GGML-ZV in NL-Graauw) by spectrophotometry for N and P, and by mass-spectrophotometry for K, Mg, Mn, Fe and B.

Microbial biomass, Microbial bound carbon and nitrogen (C_{mic}, N_{mic}): On sub-samples of the samples described above the chloroform-fumigation-extraction method (CFE) after Brookes *et al*. 1985 and Vance *et al*. 1987 was applied. The soil was sieved to 2 mm.

Additional measurements (data not shown in this paper): 1) Repeated measurements of photosynthesis in the field with a portable device; 2) dehydrogenase activity, fluorescein-diacetat hydrolysis (FDA) and ATP content were additional parameters to differentiate soil microbial activity; 3) soil penetration resistance with a portable penetro-logger; 4) aggregate stability with the shaker apparatus after Murer and soil aggregate quality after the FAL method; 5) fruit quality was also assessed with the gas-discharge-visualisation method.

The statistical analyses were carried out with software “JMP” (v.5.0.1.2; SAS Institute Inc., Cay USA). The data were systematically analysed as an orthogonal full factorial design applying an ANOVA Type 1 model with the factors block, compost (K), organic soil N-fertilizer (O), organic foliar N-fertilizer (B) and sub-treatments. In order to include properly also the sub-treatments into the model (according to Piepho *et al.*, 2006) all treatments different from V2, V4 and V5 where set as V0. The data entered were the means per plot (n=33).

Results and Discussion

In this article, only a selection of data are shown and described. An extended and more detailed article on the study is in preparation for a peer reviewed journal.

N-mineralisation and N-content in leaves

The dynamic of the mineralised Nitrogen (N_{min}) in the Ah-horizon of the tree strip showed highest values in spring in the treatments organic N-fertilizer plus compost (KO-) with around 70 kg N_{min} ha^{-1}; biowaste compost without N-fertilizer reached in average 40 % lower amounts (50 kg ha^{-1}); whereas unfertilized plots and those with bio-dynamic compost showed lowest values (35 kg ha^{-1}) (data not shown). To a lesser extent, with differences up to 9 % the same ranking of treatment effects became apparent in all years when looking at the N concentrations of the leaves sampled at T-stage, however not in those sampled at harvest (data not shown).

Tree growth and yield

At the end of the experiment after 7 yearly applications of the different treatments, the stem circumferences varied without a significant difference: between 135.2 without foliar-N (B-) and 138.5 mm with commercial N-fertilizer (O+) (data not shown). As for the accumulated stem circumference growth there was no significant factor influence but a significant interaction showing that the application of compost (K) in combination with commercial N-fertilizer (K*O ++) was significantly above K*O -+ and K*O +- (Tab. 2).

Table 2: Average yield per tree from 2004-2007, stem circumference growth, specific yield, and average fruit size. Mean values per factor, significance tests and least significant differences (LSD). Grey cells: cases of significant differences (p <0.05). Cases with p < 0.10 (tendency) are marked in bold letters. (K = compost, O = organic soil N-fertilizer, B = organic foliar N-fertilizer).

Parameter, unit (means) Factor	**Av. yield 04-07 kg/tree,year**	**Av. spec. yield 04-07 kg/cm stem cir.fer.**	**Bi-annual bearing index 04-07**	**No of fruits 04-07**	**Av. fruit weight 04-07 g**	**Growth of stem circ. 04-07 mm**	
K-	9.36	0.79	36.8	86.28	109.94	K*O -/-	21.2 ab
K+	9.43	0.80	39.3	86.74	113.06	K*O -/+	20.3 b
O-	9.34	0.78	35.3	86.47	111.63	K*O +/-	20.0 b
O+	9.45	0.80	40.8	86.55	111.38	K*O +/+	24.5 a
B-	**9.89**	**0.85**	**33.6**	89.72	112.48	B-	22.2
B+	**8.90**	**0.74**	**42.4**	83.30	110.53	B+	20.8
LSD 0,05	***1.12***	***0.08***	***7.0***	***9.80***	***3.92***		***3.4***
ANOVA							
K	ns	ns	ns	ns	ns		ns
O	ns	ns	ns	ns	ns		ns
B	**0.0780**	**0.0830**	**0.0168**	ns	ns		ns
Interactions	ns	ns	ns	ns	ns	K*O	**0.0329**

The average absolute and specific yields per tree from 2004-2007 showed no significant factor influence or factor interactions (Tab. 2). Without foliar-N (B-) with 9.89 kg per tree and 0.85 kg per cm stem circumference was by tendency (p = 0.083) 13 % higher than B+ with 8.90 kg per tree and 0.74 kg per cm stem circumference. The reason for this might be a certain thinning effect of the molasses at early season application because also the average number of fruits per tree without foliar N fertilizer (B-) was 7.2 % lower compared to 89.7 at B+. Additionally, without foliar N (B-) the average index of bi-annual bearing was significantly 21 % better (33.6) compared to 42.4 with B+ (the lower the index the less bi-annual bearing). Neither the average number of fruits per tree nor the average fruit weight were significantly influenced by the fertilization factors (Tab. 2).

Standard fruit quality

There were only rarely significant fertilization factor influences (alone or in interaction) to be found. Example-wise data of 2007 – a year with relatively high yield and treatment differences – are described and shown in table 3. The single fertilization factors had no effect neither on Brix, flesh firmness, malic acidity content, fruit size or quality index. However, at the interaction K*O it could be seen that K*O +/- with 7.19 kg/cm^2 had significantly but only 5 % less firmness than the other K*O combinations. This effect was not consistent over the years.

Table 3: Standard fruit quality parameter soluble solids (Brix), flesh firmness, malic acid, fruit size (of fruits analysed) and an empirical quality index at harvest in 2007 (Brix + 2*firmness + malic acid). Mean values per factor, significance tests and least significant differences (LSD). Grey cells: cases of significant differences ($p < 0.05$). Cases with $p < 0.10$ (tendency) are marked in bold letters. (K = compost, O = organic soil N-fertilizer, B = organic foliar N-fertilizer).

Parameter, unit (means) **Factor**	**Fruit Brix harvest 07 %**	**Fruit flesh firmness harvest 07 kg/cm²**			**Fruit malic acid harvest 2007 g/L**	**Fruit size at analysis harvest 07 g**	**Quality index 2007**
K-	12.1	K*O -/-	7.57	a	6.93	127.100	36.28
K+	11.9	K*O -/+	7.43	ab	6.84	135.200	35.72
O-	12.0	K*O +/-	7.19	b	6.85	131.000	35.86
O+	12.1	K*O +/+	7.58	a	6.92	131.000	36.14
B-	12.0		7.47		6.85	130.300	35.95
B+	12.0		7.42		6.92	132.100	36.05
LSD 0,05	***0.3***		***0.25***		***0.27***	***10.19***	***0.89***
ANOVA							
K	ns		ns		ns	ns	ns
O	ns		ns		ns	ns	ns
B	ns		ns		ns	ns	ns
Interactions	ns	**K*O**	**0.0397**		ns	ns	ns
***)**	*means not connected with the same letter are significantly different (p < 0.05)*						

Organic carbon, microbial bound carbon and nitrogen (C_{mic}, N_{mic})

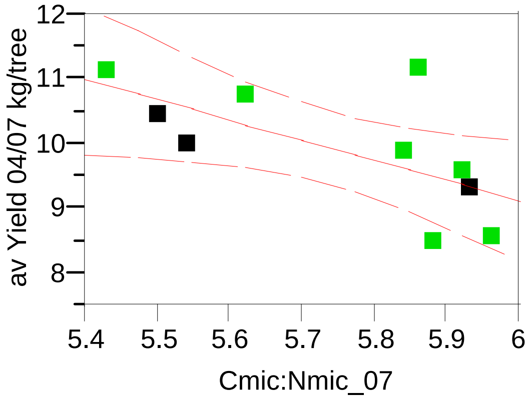
The results shown in table 4 reveal that 7 years of compost application according to the norm and Swiss law which is 25 t DM within 3 years could not increase the amount of organic carbon in the tree strip compared to plots where no compost or organic N-fertilizer was applied (---PK). The values remained stable at around 2.0 % C_{org}. Similarly, with the treatments of the trial, there was no increase or a tillage-induced reduction of the organic carbon content compared to the lateral alleyway (used as a reference to exclude spacial inhomogeneity). In contrast to that, in the buffer row where the farmer applied 5 times higher amounts of compost, there was a clear and significant increase in organic carbon content up to 152 % compared to the alleyway beside. For the microbial bound carbon C_{mic} thereis a similar trend, however, neither between the treatments nor between alleyway and tree strip a significant difference could be found. The C_{mic} contents varied between 520 and 711 µg/g. Concerning the N_{mic} content which is a good indicator of bacterial biomass, the means of all compost fed plots (K+) were by17-31 % higher than in in the plots without compost application (K-). Lower values of the ratio C_{mic}:N_{mic} indicate a more bacterial dominated and thus more actively mineralising soil microbial fauna. The ratio was significantly lowest with 1.94, with the high dosages of compost in the buffer row. The treatments of the trial did not differ significantly among each other, even though in the control plots the highest average with 2.97 could be found. Alike the pattern with C_{mic}, the tree strips, except for high dosage compost with a 25 % decreased C_{mic}:N_{mic} ratio, did not differ from the alleyway.

Table 4: Contents of organic Carbon (C_{org}) and microbial bound carbon and nitrogen (C_{mic}, N_{mic}) in the tree strips and their lateral alleyways. Grey cells: cases of significant differences ($p < 0.05$, not connected with same letter). Cases with $p < 0.10$ (tendency) are marked in bold letters. (K = compost, O = organic soil N-fertilizer, --PK = untreated control supplied with mineral P-K-Ca-Mg fertilizer equal as brought in with the K+ treatments; "high dose compost": in the buffer rows the farmer applied the 5-fold dosage of compost, representing a kind of extreme reference).

Treatment	Tree strip	Mean of lateral alley ways	Difference tree strip/alley way (%)
Organic carbon %			
---PK	**2.15a**	2.28	**95.3b**
K--	**2.08a**	1.99	**105.2b**
KO-	**2.06b**	2.01	**105.2b**
high dose compost	**3.05a**	2.01	**152.5a**
Cmic µg/g			
---PK	638.7	711.3	90.6
K--	583.0	577.7	103.3
KO-	579.0	569.1	102.9
high dose compost	589.0	520.0	114.1
Nmic µg/g			
---PK	113.0	115.9	**99.0**
K--	98.5	88.5	**116.7**
KO-	103.1	86.7	**120.9**
high dose compost	116.2	92.1	**130.7**
Cmic:Nmic			
---PK	**2.97a**	3.1	**95.7a**
K--	**2.77a**	2.8	**98.4**
KO-	**2.81a**	2.8	**99.1**
high dose compost	**1.94b**	2.6	**74.5b**

Concerning the application of bio-dynamic compost with and without additional application of bio-dynamic horn manure and horn silica (V4 and V5 in Tab. 1) no significant differences in soil, tree and fruit parameters could be found (data not shown).

A correlation could be found indicating that plots (treatments) with lower C_{mic}:N_{mic} ratios (higher microbial activity) also performed higher average yields over 2004-2007 (Fig. 1). This might explain a certain amount of the relatively high special variation which is responsible for relatively rare significant factor effects



av Yield 04/07 kg/tree = 27.84986 - 3.1210055 Cmic:Nmic_07
R^2 = 0.430; n = 10; p = 0.039

Figure 1: Correlation between C_{mic}:N_{mic} ratio of the soil in the tree strip and average yield per plot. Light symbols stand for plots which received compost (K+). Lower C_{mic}:N_{mic} values indicate higher bacterial soil activity.

Conclusion

Interpreting these results, it has to be kept in mind that the recommended and allowed amounts of fertilizers and compost on a hectare basis, were given only on the tree strip, resulting in a 3-fold concentration. Thus, the treatments tested represent (for Swiss circumstances) quite an extreme intensification of tree fertilization. The results of this study clearly show, that tree performance (yield and growth) in an organic orchard system cannot be “boosted” with organic soil N-fertilizer or organic foliar N-fertilizer. Neither the application of compost according to Swiss regulations (max. 25 t DM over 3 years) was able to increase soil fertility, N-mineralisation and thus tree nutrition by an overall significant and for fruit growers relevant magnitude. Soil-borne inhomogeneities as varying thickness of the Ah layer and locally varying severity of water logging often seemed to be more dominating (but here impossible to quantify) reasons for the high variation in tree performance than the applied fertilization factors K, O and B. The results confirm that organic fertilizers hardly can compensate sub-optimal soil conditions, and therefore a specific soil sanitation should be carried out before planting. The results also show that it is recommendable to accomplish the PKCaMg need (according to soil analysis) firstly with compost, also as it conserved the organic matter content in the tree strip whereas it declined where no compost was used. By tendency, the combination of compost and commercial soil N-fertilizer gave best results. Based on the results of this study, we have developed a 5-steps procedure to plan tree nutrition for practical organic apple growers.

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