Organic apple tree nutrition: Comparison of different organic fertilizers, application timing and rate, and soil management techniques: results of a 5 year field study

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Abstract

In order to provide nitrogen to the soil, in organic farming only organic fertilizers and soil conditioners are allowed. The mineralization of these products is slow, and therefore problems in nitrogen supply may arise exactly when the plants require high amounts of nitrogen.

In this study, different organic fertilizers and soil conditioners, application timing and rate, and soil management techniques were compared in the open field. The soil mineral nitrogen (SMN), the nitrogen content in leaves, the increase in tree trunk circumference, and the total yield was measured for 15 different treatments including untreated control over a period of 5 years.

Among the different fertilizers, best results in terms of total yield (kg/tree) over the entire study period were obtained with Azocor 105, a commercially available organic fertilizer, followed by the combined use of compost + Nutristart (liquid vinasse) and the conventional reference fertilizer ammonium sulfate. In the trials, in which different application timing and rate of Azocor 105 were compared, one single early spring application at the recommended field rate resulted in highest yield. Applying higher total amounts of fertilizer, but splitted over time (3 spring applications), did not provide any additional value in terms of yield. Among the different soil management techniques, the highest yield was achieved by using ploughing and brushing.

Keywords: organic apple, organic fertilizer, organic soil conditioner, application timing and rate, tillage techniques

Introduction

In apple orchards nitrogen supply in spring is frequently a limiting factor, as low soil temperatures may impair the activity of the plant roots. The trees thus mobilize their own nitrogen reserves stored in the stem and roots. During and shortly after bloom, when nitrogen demand is highest, the trees' own reserves may become exhausted. The nitrogen supply from the mineralization of soil organic matter is not yet sufficient due to the low soil temperatures. It is therefore important to supply the plants timely in spring with fertilizer nitrogen (Aichner and Drahorad, 2004).

Soil nitrogen mineralization is a microbial process and as such dependent on environmental conditions. The main factors affecting mineralization are temperature, soil humidity and chemical/physical soil conditions (Schachtschabel *et al*., 2002).

The Research Centre Laimburg – Sector Organic Farming (Ora, South Tyrol, Italy) has been testing organic fertilizers and soil conditioners for several years. In order to obtain more detailed information on the behaviour of fertilizers in the soil and on their nitrogen release rates, laboratory studies conducted under controlled conditions had been performed (Kelderer *et al*., 2008). In these studies, data on the nitrogen mineralization rate of different fertilizers and soil conditioners, commercially available in South Tyrol, were collected. As a follow-up of these laboratory studies, open-field studies have been set up since 2009, in order to test and compare different fertilizers, application timing and rate,

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and tillage techniques. The field studies aimed at optimizing the nitrogen and nutrient supply to apple plants in organic farming. The results of 5 years of field studies are presented.

Material and Methods

The studies were conducted in two different apple orchards, representative for apple cultivation in South Tyrol. Details on the study orchards are provided in Table 1.

Table 1: Study site and orchard description.

Study site	Cultivar	Height (m a.s.l.)	Rootstock	Row x plant spacing	Year of planting
Latsch	Golden Delicious	700	M9	3.2 x 0.75 m	2009
Laimburg	Braeburn	220	M9	3.2 x 0.8 m	2009

A randomized block design with 4 replicates of 7 plants each per treatment was used. Assessments were conducted only on the 5 central plants of each plot.

In June 2009, before the beginning of the trial, a soil analysis was carried out in both study orchards. According to the results of this analysis, the soil of the study orchard Latsch was a sandy loam, and with pH of 6.5, a low carbonate content, and 4.8 % of organic matter. The soil of the study orchard Laimburg was sandy silt, with pH of 7.8; a high carbonate content, and 3-4 % of organic matter.

The studies in the study orchard Latsch lasted from 2009 to 2013, while in the study orchard Laimburg, investigations were interrupted in 2012 due to inconsistent results because of several reasons. Bad plant quality was one of the major problems. In fact, the trees showed stunted growth over the first two years, and considerable variability in tree development. A further problem was the frost in spring 2012, which destroyed almost the whole harvest from the experimental orchard.

In addition to different fertilizers (Tab. 2), also different application timing was tested (Tab.3): spring and autumn. In spring, the 1st fertilizer application was conducted at beginning of bud break (BBCH 07), while autumn applications were carried out at the end of October. Furthermore, as far as spring applications are concerned, some spring treatments consisted in just one single fertilizer application, while others had a 2nd and/or 3rd fertilizer application at a time interval of 4 weeks between applications. And finally different tillage techniques were compared such as a simple self-made disk plough combined by the brushing machines Aedes (Dueville, Italy), the crumbling machine Ladurner (Lasa, Italy) and manual weed mower to mulch the weeds in the row.

In both study orchards, the following parameters were assessed:

- Soil Mineral Nitrogen (SMN): one mixed consisting in 8 soil sample per plot was collected along the row underneath the trees at a depth of 0-30 cm, and brought to the laboratory in order determine the soil mineral nitrogen content. Each year, a total number of 4 assessments was carried out: the 1st assessment was conducted just before the 1st fertilizer application in spring (preliminary assessment), the 2nd 4 weeks after the 1st spring application, the 3rd 4 weeks after the 3rd spring application, and the 4th before the autumn application (final assessment) in October.
- Leaf nitrogen concentration (%): leaf analyses were performed in the laboratory on 50 leaves per plot taken an the middle of 1 year old shouts twice a year, but only the data collected in June/July are reported;
- Leaf colour measurements: at the end of June, leaf colour was measured on 25 leaves per plot by using a Minolta CR-300 Chroma Meter;

- Total yield and tree trunk circumference: at harvest, all fruits were collected from the 5 central plants within each plot, weighed and the yield in kg/tree over the entire study period was calculated. At the same time, the circumference of the trunks of the 5 central trees within each plot was measured, and the mean increase in trunk circumference over the entire study period was calculated. Results on yield are reported only for the study orchard Latsch, but not for the study orchard Laimburg because of inconsistent results observed in the latter orchard already during the first study years, and because of complete harvest destruction due to heavy late frost in 2012.

For each treatment and assessment (preliminary assessment, assessment after 1.application of fertilizer, assessment after 3rd. application of fertilizer and final assessment), the mean values of SMN, nitrogen concentration in leaves, and leaf colour for the different treatments were calculated by using all data collected during the years of the trial.

In each study site, 15 treatments in total (untreated control included) were tested. The treatments were assigned to 3 different groups in order to better compare and evaluate the effect of different factors:

Group 1: fertilizers and soil conditioners

In this group, different fertilizers and soil conditioners (one single spring application) were evaluated in comparison to an untreated control (Table 2). The tested products were: ammonium sulphate, a chemical fertilizer, which has been included as conventional reference treatment; compost from Ecorott S.r.l. (Ora, Italy) with a high content in manure; Azocor 105, an organic fertilizer manufactured by Formet S.p.A. (San Pietro di Morubio, Italy) and consisting of soya, maize oil cake, and horn and feather meal formulated as pellets; Nutristart, produced by Lessafre (Parma Italy) and consisting of liquid vinasse; liquid biogas manure from the biogas plant in (Aldein Italy) and consisting of fermented liquid manure; Agrobiosol, produced by Sandoz GmbH (Kundl, Austria) and consisting of fungal biomass formulated in granules. The fertilizers and soil conditioners were applied by hand concentrated on the tree strip. A more detailed description of the fertilizers tested can be found online at http://www.laimburg.it/de/obstbau/1204.asp.

Table 2: Group 1: tested fertilizers and soil conditioners.

N.	Treatment (formulated product)	N. applications/ year	Timing	g N/tree (1st year)*	g N/tree (2nd year)*	g N/tree (3rd year)*	Tillage type
1	Untreated control	-	-	-	-	-	ploughing-brushing
2	Ammonium sulfate	1	spring	16	20	24	ploughing-brushing
3	Compost	1	spring	1 kg	2 kg	2 kg	ploughing-brushing
4	Compost + Azocor	1	spring	1kg +16	2kg +19	2kg +23	ploughing-brushing
5	Azocor	1	spring	16	20	24	ploughing-brushing
11	Compost + Nutristart	1	spring	1kg +16	2kg +19	2kg +23	ploughing-brushing
12	Compost + liquid biogas manure	1	spring	1kg +16	2kg +19	2kg +23	ploughing-brushing
13	Agrobiosol	1	spring	16	20	24	ploughing-brushing

* total nitrogen applied in g/tree via fertilizer + compost in kg

Group 2: application timing and rate

In this group, different application timing and rate of the organic fertilizer Azocor 105 were tested in comparison to an untreated control. Details are reported in Table 3. In treatment n. 5 and 6, Azocor was applied once at the recommended field rate. In treatment n. 8 and 9 Azocor was applied respectively 2 and 3 times splitting the recommended field rate, and in treatment n. 10 Azocor was applied 3 times using 50 % more fertilizer in comparison to the recommended field rate.

Table 3: Group 2: tested application timing and rate.

N.	Treatment	N. applications/ year	Timing	g N/tree (1st year)	g N/tree (2nd year)	g N/tree (3rd year)	Tillage type
1	Untreated control	-	-	-	-	-	ploughing-brushing
5	Azocor	1	spring	16	20	24	ploughing-brushing
6	Azocor (autumn)	1	autumn	16	20	24	ploughing-brushing
8	Azocor 2x50%	2 x 50%*	spring	16	20	24	ploughing-brushing
9	Azocor 3x33%	3 x 33%*	spring	16	20	24	ploughing-brushing
10	Azocor 3x50%	3 x 50%*	spring	24	32	33	ploughing-brushing

* at a 4-weeks time interval

Group 3: soil management techniques

In this group, different tillage techniques and tools were tested in comparison to an untreated control (Table 4). In all treatments except in the untreated control, Azocor 105 was used for fertilization. In the treatment Ploughing-brushing, the soil was ridged up with a disc plough early in spring, and then brushed with a rotor brush during successive tillage operations. In the treatment Soil incorporation, in addition to ploughing and brushing, the fertilizer Azocor 105 was also lightly incorporated into the soil immediately after application. In the treatment Mulching, the grass was only mown, while in the treatment crumbling, the soil was kept continuously open by using a soil crumbler.

Table 4: Group 3: tested tillage techniques.

N.	Treatment	N. applications/ year	Timing	g N/tree (1st year)	g N/tree (2nd year)	g N/tree (3rd year)	Tillage type
1	Untreated control	-	-	-	-	-	Ploughing-brushing
5	Azocor Ploughing-brushing	1	spring	16	20	24	Ploughing-brushing
7	Azocor Soil incorporation	1	spring	16	20	24	Soil incorporation + Ploughing-brushing
14	Azocor Mulching	1	spring	16	20	24	Mulching
15	Azocor Crumbling	1	spring	16	20	24	Crumbling

The assessed data were compared across treatments using 1-way ANOVAs, followed by Tukey’s Test for post-hoc comparisons of means. All analyses were performed using the statistics program PASW 17.

Results

Group 1 – fertilizers and soil conditioners

At the study site Latsch, before the application of the fertilizers, the SMN content was generally low in all treatments, even though significant differences emerged, with the soil of the plots assigned to the Azocor treatment showing highest (8.42 mg/kg dry weight) SMN content (Table 5).

After the 1st spring application of fertilizer the SMN content had strongly increased in all treatments (Table 5), and the ammonium sulfate showed significantly higher SMN content (146.67 mg/kg dry weight) than all the other tested treatments.

At the assessment conducted after the 3rd spring application, the highest SMN content (32.45 mg/kg dry weight) was recorded for the treatment compost+Nutristart. At the final assessment conducted in autumn, however, no significant differences among treatments emerged.

Table 5: Mean SMN content (mg/kg dry weight) in the different treatments in the study orchard Latsch at the 4 assessments.

Treatment	SMN (mg/kg) - preliminary assessm.		SMN (mg/kg) - ass. after 1. fert.		SMN (mg/kg) - ass. after 3. fert.		SMN (mg/kg) - final assessm.	
Untreated control	4,92	a	14,00	a	8,39	a	10,48	a
Ammonium sulfate	4,79	a	146,67	b	19,86	ab	13,22	a
Compost	4,67	a	25,08	a	9,70	a	13,23	a
Compost+Azocor	7,33	ab	42,75	a	9,17	a	10,68	a
Azocor	8,42	b	51,88	a	15,61	ab	13,63	a
Compost+Nutristart	6,88	ab	59,08	a	32,45	b	16,70	a
Compost+liquid biogas manure	5,17	ab	50,75	a	20,45	ab	14,98	a
Agrobiosol	5,67	ab	66,63	a	22,42	ab	16,06	a

Different letters within the same column indicate statistically significant differences (Tukey’s test: P<0.05).

Also in the study orchard Laimburg, only slight, even though significant differences among the tested treatments emerged at the preliminary assessment, with the plots of the treatment compost+Azocor showing highest SMN content (Table 6). At the successive assessments, the treatment compost+Nutristart always showed the highest mean SMN content (135,50 mg/kg and 25,52 mg/kg dry weight respectively)

Table 6: Mean SMN content (mg/kg dry weight) in the different treatments in the study orchard Laimburg at the 4 assessments.

Treatment	SMN (mg/kg) - preliminary assessm.		SMN (mg/kg) - ass. after 1. fert.		SMN (mg/kg) - ass. after 3. fert.		SMN (mg/kg) - final assessment	
Untreated control	4,94	ab	5,75	a	4,80	a	4,58	ab
Ammonium sulfate	4,54	ab	73,00	b	8,89	a	4,26	ab
Compost	3,83	a	15,25	a	3,92	a	3,44	a
Compost+Azocor	5,79	b	29,50	ab	6,43	a	6,50	ab
Azocor	4,67	ab	20,75	a	5,93	a	4,74	ab
Compost+Nutristart	4,38	ab	135,50	c	25,52	b	7,09	b
Compost+liquid biogas manure	4,71	ab	30,25	ab	7,45	a	5,24	ab
Agrobiosol	4,50	ab	28,00	ab	9,38	a	6,01	ab

Different letters within the same column indicate statistically significant differences (Tukey’s test: P<0.05).

A similar trend as for SMN content was observed for leaf nitrogen concentration and leaf colour (Table 7). In both study orchards, leaf nitrogen concentration was lowest in the untreated control. In the study orchard Latsch, the highest leaf nitrogen concentration was observed for the conventional reference treatment ammonium sulphate 2,74 % , followed by Agrobiosol 2,69 % and compost+Nutristart 2,61. In the study orchard Laimburg, leaf nitrogen concentration was highest fort he treatment compost+Nutristart. In both study orchards, leaf colour was highest for the treatments ammonium sulfate and compost+Nutristart.

Table 7: Mean leaf nitrogen concentration (%) and leaf colour (nm) in the different treatments in the study orchards Latsch and Laimburg.

	Study orchard Latsch				Study orchard Laimburg			
Treatment	**N (%) in leaves**		**Leaf colour (nm)**		**N (%) in leaves**		**Leaf colour (nm)**	
Untreated control	2,39	a	128,33	a	2,06	a	125,11	a
Ammonium sulfate	2,74	d	128,86	b	2,45	bc	126,82	d
Compost	2,47	ab	128,43	ab	2,16	a	125,56	ab
Compost+Azocor	2,55	abc	128,60	ab	2,42	bc	126,59	cd
Azocor	2,58	bcd	128,74	ab	2,34	b	126,02	bc
Compost+Nutristart	2,67	cd	128,83	b	2,57	c	126,84	d
Compost+liquid biogas manure	2,61	bcd	128,44	ab	2,36	b	126,04	bc
Agrobiosol	2,69	cd	128,79	ab	2,33	b	126,42	cd

Different letters within the same column indicate statistically significant differences (Tukey's test: P<0.05).

In the study orchard Latsch, no significant increase in tree trunk circumference in comparison to the untreated control was recorded during the study period 2009-2013, while a significant increase in total yield was observed for Azocor (47,80 kg/tree) and compost+Nutristart (45,62 kg/tree) in comparison to the untreated control (37,67 kg) (Table 8). In the study orchard Laimburg, instead, significant differences among treatments in the increase in tree trunk circumference emerged, with values being lower for the untreated control and compost+liquid biogas manure than for all the other tested treatments (Table 8).

Table 8: Mean increase in tree trunk circumference (cm) and total yield (kg/tree) in the different treatments in the study orchards Latsch and Laimburg over the entire study period.

	Study orchard Latsch				Study orchard Laimburg	
Treatment	**Tree trunk circumference increase (cm) 2009-13**		**Total yield (kg/tree) 2009-13**		**Tree trunk circumference increase (cm) 2009-12**	
Untreated control	7,58	a	37,67	a	3,71	a
Ammonium sulfate	7,98	a	44,68	ab	5,96	c
Compost	8,21	a	41,84	ab	5,40	bc
Compost+Azocor	7,93	a	39,90	ab	5,82	bc
Azocor	7,62	a	47,80	b	5,55	bc
Compost+Nutristart	7,13	a	45,62	b	5,20	bc
Compost+liquid biogas manure	7,10	a	42,82	ab	4,53	ab
Agrobiosol	7,85	a	40,89	ab	5,53	bc

Different letters within the same column indicate statistically significant differences (Tukey's test: P<0.05).

Group 2: Application timing and rate

In the study orchard Latsch, at the preliminary assessment, the SMN content was significantly higher in plots assigned to the Azocor autumn treatment (18.50 mg/kg dry weight) than in plots of all the other tested treatments (Table 9). At the assessment after the 1st spring application, instead, SMN content was highest for the standard Azocor spring application (52.63 mg/kg dry weight). At the assessment after the 3rd spring application, Azocor 3×50 % (3 times half the recommended field rate) showed the highest SMN content (34.93 mg/kg dry weight). At the final assessment conducted in autumn, differences among treatments failed significance in both study orchards (Table 9 and 10).

Table 9: Mean SMN content (mg/kg dry weight) in the different treatments in the study orchard Latsch at the 4 assessments.

Treatment	SMN (mg/kg) - preliminary		SMN (mg/kg) - ass. after 1. fert.		SMN (mg/kg) - ass. after 3. fert.		SMN (mg/kg) - final assessm.	
Untreated control	4,92	a	14,00	a	8,39	a	10,48	a
Azocor	8,42	a	52,63	b	15,62	ab	13,63	a
Azocor (autumn)	18,50	b	38,17	ab	16,66	ab	16,85	a
Azocor 2x50%	6,38	a	22,83	ab	13,84	ab	11,05	a
Azocor 3x33%	8,38	a	43,08	ab	21,38	ab	19,63	a
Azocor 3x+50%	11,21	a	38,13	ab	34,93	b	13,74	a

Different letters within the same column indicate statistically significant differences (Tukey's test: P<0.05).

In the study orchard Laimburg, SMN content was highest for the treatment Azocor (autumn) at both the preliminary assessment and the assessment in spring after the 1st spring fertilization. At the after the 3rd spring fertilization, instead, SMN content was highest for Azocor 3×50 % (Table 10).

Table 10: Mean SMN content (mg/kg dry weight) in the different treatments in the study orchard Laimburg at the 4 assessments.

Treatment	SMN (mg/kg) - preliminary		SMN (mg/kg) - ass. after 1. fert.		SMN (mg/kg) - ass. after 3. fert.		SMN (mg/kg) - final assessm.	
Untreated control	4,94	a	6,61	a	6,47	a	4,54	a
Azocor	4,63	a	27,28	bc	18,51	abc	4,74	a
Azocor (autumn)	54,75	b	36,92	c	26,13	bc	5,62	a
Azocor 2x50%	6,29	a	15,17	ab	15,13	ab	6,29	a
Azocor 3x33%	5,50	a	11,75	a	20,21	abc	7,00	a
Azocor 3x+50%	4,88	a	13,22	a	37,24	c	5,75	a

Different letters within the same column indicate statistically significant differences (Tukey's test: P<0.05).

Leaf nitrogen concentration was highest for Azocor 3×50% (2,68% and 2,51%) in both study orchards (Table 11). In the study orchard Latsch, no significant differences among treatments in leaf colour emerged, while in the study orchard Laimburg leaf colour was highest for Azocor 3×33% (Table 11).

Table 11: Mean leaf nitrogen concentration (%) and leaf colour (nm) in the different treatments in the study orchards Latsch and Laimburg.

	Study orchard Latsch				Study orchard Laimburg			
Treatment	N (%) in leaves		Leaf colour (nm)		N (%) in leaves		Leaf colour (nm)	
Untreated control	2,39	a	128,33	a	2,06	a	125,11	a
Azocor	2,58	ab	128,74	a	2,34	bc	126,02	ab
Azocor (autumn)	2,53	ab	128,53	a	2,43	bc	126,49	ab
Azocor 2x50%	2,57	ab	128,52	a	2,28	b	126,05	ab
Azocor 3x33%	2,60	ab	128,65	a	2,47	bc	127,10	b
Azocor 3x50%	2,68	b	128,59	a	2,51	c	126,83	ab

Different letters within the same column indicate statistically significant differences (Tukey's test: P<0.05).

No significant differences in increase in tree trunk circumference were recorded in the study orchard Latsch (Table 12). Total yield, instead, was highest for the single spring application of Azocor (47.80 kg/tree) at the recommended field rate. In the study orchard Laimburg the increase in tree trunk circumference was highest for the single autumn application of Azocor (6.52 cm) and for Azocor 3×50 % (Table 12).

Table 12: Mean increase in tree trunk circumference (cm) and total yield (kg/tree) in the different treatments in the study orchards Latsch and Laimburg over the entire study period

	Study orchard Latsch				Study orchard Laimburg	
Treatment	**Tree trunk circumference increase (cm) 2009-13**		**Total yield (kg/tree) 2009-13**		**Tree trunk circumference increase (cm) 2009-12**	
Untreated control	7,58	a	37,67	a	3,71	a
Azocor	7,62	a	47,80	b	5,55	bc
Azocor (autumn)	7,50	a	43,81	ab	6,18	c
Azocor 2x50%	7,81	a	45,58	ab	4,67	ab
Azocor 3x33%	7,53	a	45,97	ab	5,14	abc
Azocor 3x50%	7,72	a	42,77	ab	6,52	c

Different letters within the same column indicate statistically significant differences (Tukey's test: $P<0.05$).

Group 3: soil management techniques

In the study orchard Latsch, no significant differences among soil management techniques emerged at the preliminary and at the final assessment (Table 13). At the assessment after the 1st. fertilisation SMN content was highest for Azocor Ploughing-brushing (8,42 mg/kg dry weight)., while at the assessment in after the 3rd. fertilisation SMN content was highest for Azocor Soil incorporation (24,54 mg/kg dry weight) (Table 13).

Table 13: mean SMN content (mg/kg dry weight) in the different treatments in the study orchard Latsch at the 4 assessments.

Treatment	SMN (mg/kg) - preliminary assessm.		SMN (mg/kg) - ass. after 1. fert.		SMN (mg/kg) - ass. after 3. fert.		SMN (mg/kg) - final assessm.	
Untreated control	4,92	a	14,00	a	8,39	a	10,48	a
Azocor Ploughing-brushing	8,42	a	52,63	b	15,62	ab	13,63	a
Azocor Soil incorporation	7,75	a	49,42	ab	24,54	b	16,21	a
Azocor Mulching	6,58	a	38,58	ab	11,93	ab	13,11	a
Azocor Crumbling	5,21	a	40,79	ab	14,00	ab	16,11	a

Different letters within the same column indicate statistically significant differences (Tukey's test: $P<0.05$).

In the study orchard Laimburg, the highest SMN content was recorded for Azocor Crumbling at the preliminary assessment (7.00 +), for Azocor Soil incorporation at the assessment after 1st fertilization (52.25 mg/kg dry weight). and for Azocor Ploughing-brushing at the assessment after 3rd fertilisation (18,51 mg/kg dry weight) (Table 14). At the final assessment, instead, differences among treatments failed significance (Table 14).

Table 14: mean SMN content (mg/kg dry weight) in the different treatments in the study orchard Laimburg at the 4 assessments.

Treatment	SMN (mg/kg) - preliminary assessm.		SMN (mg/kg) - ass. after 1. fert.		SMN (mg/kg) - ass. after 3. fert.		SMN (mg/kg) - final assessm.	
Untreated control	4,94	ab	6,75	a	4,80	a	4,60	a
Azocor Ploughing-brushing	4,63	a	27,28	a	18,51	c	4,74	a
Azocor Soil incorporation	6,42	ab	58,25	b	8,70	ab	6,01	a
Azocor Mulching	5,96	ab	12,25	a	6,18	ab	5,25	a
Azocor Crumbling	7,00	b	31,50	a	12,73	bc	6,22	a

Different letters within the same column indicate statistically significant differences (Tukey's test: $P<0.05$).

Leaf nitrogen concentration was highest for Azocor Soil incorporation in the study orchard Latsch (2.65 %), and for Azocor crumbling in the study orchard Laimburg (2,53) (Table 15). No significant differences among treatments in leaf colour were observed in the study orchard Latsch, while in the study orchard Laimburg also leaf colour was highest for Azocor crumbling (Table 15).

Table 15: Mean leaf nitrogen concentration (%) and leaf colour (nm) in the different treatments in the study orchards Latsch and Laimburg.

	Study orchard Latsch				Study orchard Laimburg			
Treatment	N (%) in leaves		Leaf colour (nm)		N (%) in leaves		Leaf colour (nm)	
Untreated control	2,39	a	128,32	a	2,06	a	125,11	a
Azocor Ploughing-brushing	2,58	ab	128,74	a	2,34	bc	126,02	b
Azocor Soil incorporation	2,65	b	128,65	a	2,46	cd	126,14	bc
Azocor Mulching	2,46	ab	128,51	a	2,25	ab	126,34	bc
Azocor Crumbling	2,58	ab	128,66	a	2,53	d	126,78	c

Different letters within the same column indicate statistically significant differences (Tukey's test: P<0.05).

In the study orchard Latsch, highest total yield was recorded for Azocor Ploughing-brushing (47.80 kg/tree) (Table 16). A significant increase in tree trunk circumference in comparison to the untreated control was observed only for Azocor Mulching.

In the study orchard Laimburg all tested treatments resulted in a significantly increase in tree trunk circumference in comparison to the untreated control (Table 16).

Table 16: Mean increase in tree trunk circumference (cm) and total yield (kg/tree) in the different treatments in the study orchards Latsch and Laimburg over the entire study period.

	Study orchard Latsch				Study orchard Laimburg	
Treatment	Tree trunk circumference increase (cm) 2009-13		Total yield (kg/tree) 2009-13		Tree trunk circumference increase (cm) 2009-12	
Untreated control	7,58	ab	37,67	a	3,71	a
Azocor Ploughing-brushing	7,62	ab	47,80	b	5,55	b
Azocor Soil incorporation	6,95	a	42,43	ab	5,29	b
Azocor Mulching	8,18	b	41,30	ab	5,82	b
Azocor Crumbling	7,43	ab	39,15	a	6,42	b

Different letters within the same column indicate statistically significant differences (Tukey's test: P<0.05).

In both study orchards and in all 3 treatment groups, leaf analyses showed that the phosphor, potassium, boron, iron and copper content, and in part also the zinc content was higher in leaves of untreated control plots than in those of treated plots (data not reported). It is assumed, that this is due to the reduced growth of control plants and thus due to a dilution effect in more vigorously growing treated plants.

Summary and discussion

The trials had been conducted over 5 years in two different study orchards, which are representative for apple cultivation in South Tyrol. One study orchard (Laimburg) was a lowland orchard, located at 200 m above sea level and cultivated with the apple cv. Braeburn. The other study orchard (Latsch), instead, was located at 600 m above sea level and cultivated with the apple cv. Golden Delicious. For a better interpretation of the effect of the 14 different treatments on nitrogen mineralization and plant nitrogen uptake and development, the treatments were divided into 3 groups: fertilizers and soil conditioners, application timing and rate, and soil management techniques.

In general it can be said that the soil content of mineral nitrogen in spring before fertilization was low. This applies both to the unfertilized controls and to the fertilized treatments except for autumn fertilization. Converted to kg/ha it was less than 40 kg per ha in the first 30 cm of soil, which is the recommended value by the advisory centre in the region. The same is for the leaf content in June. The reference value in the area for Golden Delicious (location Laces) is 2.45 %. For Braeburn (location Laimburg) the reference value is 2.65 %. In both cases in the unfertilized controls the values were lower in comparison to the values which are recommended by the advisory centro in the region (Drahorad 2004)

Fertilizers and soil conditioners: At the preliminary (before fertilizer application) and final (in autumn) assessment, no considerable differences among treatments in SMN content and leaf nitrogen concentration, which would be relevant from an practical point of view, were observed.

The most striking differences in SMN content were recorded 4 weeks after the 1st spring application of the fertilizers at this assessment, the combined application of compost and vinasse (Nutristart) showed SMN content values, which were comparable to those of the conventional reference fertilizer ammonium sulfate. At this assessment, also the most evident correlation between SMN content and leaf nitrogen concentration was observed.

Differences among treatments in increase in tree trunk circumference over the entire study period (2009-2013) were minor, even though sometimes significant differences among treatments emerged.

Total yield is the parameter, which is of highest interest to the grower, but assessments on total yield over the entire study period could be conducted only in the study orchard Latsch and not in the study orchard Laimburg for reasons explained above. In the study orchard Latsch, highest mean total yield values were recorded for the organic fertilizer Azocor 105 (47.8 kg/tree), followed by the conventional standard ammonium sulfate (44.68 kg/tree) and compost+Nutristart (45.62 kg/tree). Even though the tested in this study used by it did not supply any mineral nitrogen, mean yield per tree was increased by 4 kg in comparison to the untreated control (37.67 kg/tree).

Application timing and rate: At the assessment 4 weeks after the 1st spring application, statistically significant differences among spring and autumn applications emerged, as expected, in both study orchards. The 1st spring applications resulted in increased SMN content, and the higher the applied rate, the higher was the observed increase. However, also the autumn application positively affected SMN content. Applying the organic fertlizer several times over the season at a reduced rate instead of once at the recommended field rate, seemed to result in an increased SMN content at the assessment conducted in 4 weeks after the 3rd spring application, but not at the final assessment carried out in autumn.

No differences among treatments in increase in tree trunk circumference emerged in the study orchard Latsch, while signficant differences among treatments were observed in the study orchard Laimburg. One single application of Azocor 105 in early spring at the recommended field rate proved to be most effective in increasing total yield in comparison to the untreated control (mean total yield: 47.80 vs. 37.67 kg/tree). Intermediate values, not differing significantly neither from the untreated control nor from the most effective treatment, were recorded for the autumn application and for 2-3 spring applications of Azocor 105 at reduced rates.

Soil management techniques: Also for this group of treatments, no significant differences among treatments in SMN content emerged at the preliminary assessment and at the final assessment. The fertilizer application in spring obviously resulted in an increase in the SMN content in treated plots. The effect of the different soil management techniques on SMN content varied between the two study orchards. The differences between Mulching and Crumbling were not always significant, but Crumbling seemed to be more effective than Mulching.

In the study orchard Laimburg, the increase in tree trunk circumference was significantly higher in treated than in untreated control plots, but this difference is due to the fertilizer application rather than due to the soil management technique used. In the study orchard Latsch, total yield (47.80 kg/tree) was highest in the treatment, which provided for fertilizer application in combination with ploughing and brushing

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