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Influence of a Peat-free Substrate and Kind of Fertilizer on the Nitrogen- and Water Balance and on Plant Growth

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Summary

Prunus laurocerasus 'Otto Luyken' was grown in a peat-free and in a white peat substrate in 5 L containers for 7 months. The peat-free substrate consisted of 40 % substrate compost, 30 % bark compost and 30 % wood fibre. The slow release fertilizer Osmocote (400 mg N L^{-1}) and the organic fertilizer MALTaflor were used. MALTaflor was given in two doses: 400 mg N L^{-1} and 800 mg N L^{-1}. Irrigation was carried out as trickle irrigation when the water tension reached 100 hPa.

Physical properties of both substrates and stability of the N balance of the peat-free substrate were determined. During the experiment, plant growth, N uptake, mineral N content of the substrate and leaching of N, P, and K were measured.

The amount of available water is less in the peat-free than in the white peat substrate. The incubation test showed an N immobilization of 138 mg N L^{-1} for the peat-free substrate.

In both substrates marketable plants were produced. N uptake in the course of time followed the same patterns as fresh matter production. However, fresh matter and N uptake were less in the peat-free than in the white peat substrate. This cannot be attributed to low N content of the substrate, since they were higher in the peat-free than in the white peat substrate during the whole growth period. Higher water tensions in the peat-free substrate are supposed to impair spatial availability of N for the organic fertilizer from which only 25 % was mixed into the substrate at potting and 3 further doses were given as topdressing.

In the first 5 weeks after potting leaching of N was higher for the peat-free than for the white peat substrate. At the end of the growing season the differences between fertilizers were larger than those between the substrates. Leaching for Osmocote was higher than for MALTaflor, even for the high dose of MALTaflor. More K and P were leached from the peat-free substrate than from white peat. From the peat-free substrate more K was leached than was added by the fertilizer.

Key words. N immobilization – N mineralization – N uptake – leaching – water tension – *Prunus laurocerasus* 'Otto Luyken'

Introduction

White peat is known as a favourable growing medium. One reason for this is its homogeneity and almost predictable behaviour. In addition, it has enough available water as well as enough air (Bohne and Wrede 2005). Substitution of white peat by other components changes both physical and chemical properties of the substrate.

Possible substitutes for white peat are bark compost, substrate compost and wood fibre. Quality regulations (RAL GZ 250, 251, 254) for the individual substrate components shall guarantee a balanced N-household. However, in mixtures with these components lower as well as higher N content is found in peat-free substrates compared to white peat (i.e. Bohne and Schacht 2002; Bohne 2007). From this, N immobilization as well as N mineralization is surmised to have taken place during growth. N immobilization can reduce the available N for the plant. If mineralization and fertilization exceed N uptake, leaching of N is to be expected.

Substrate composts are known to contain high amounts of K and to some extend of P (Popp and Fischer 1998). According to Grantzau (1990) only 50 % of total K is water soluble and not immediately available. P is regarded as being less available than K (Grantzau 1996). The question is if this is also true for tree nursery crops with a longer growth period compared to floriculture crops.

Furthermore, the reduction of white peat in a substrate is supposed to reduce the amount of available water. However, there are no recommendations for irrigation supplied by the substrate producer.

The aim of the present study was to investigate the N balance of a peat-free substrate (N content of the substrate, N leaching) containing substrate compost, bark compost, and wood fibre during the vegetation period of *Prunus laurocerasus* 'Otto Luyken'. To find possible explanations concerning the response of the plant to the substrate, the N uptake of the plant was determined as well as possible effects of available water on plant growth. Data on leaching of P and K were gathered to obtain information on the long-run behaviour of these elements.

Materials and Methods

Design of the experiment

Table 1 shows the experimental setup. The treatments were carried out in a partly randomized design. The treatment "substrate" was repeated in three blocks; in each block the treatments "fertilizer" and "time" were randomized. During the growth period there were four (for mineral N) and five (for plant growth and N content of the plant) sampling dates. In all there were 69 plants per block.

Fifteen additional plants were placed into Mitscherlich containers and positioned at the end of one block per treatment to collect drainage water.

Trickle irrigation was performed and commenced at 100 hPa, measured by tensiometers. The amount of water per irrigation event was not higher than the available water of the two substrates (Table 3) which was determined by the M-ISHS-method with 3 replications. (Wrede and Bohne 2000a).

Substrates, fertilizers, and plant

The white peat substrate consisted of white peat from Lithuania, 50 % of the peat was sod-peat with a particle size of 10–25 mm. The peat-free substrate contained 40 % substrate compost, 30 % bark compost, and 30 % wood fibre (Pietal). The properties of the single substrate components were in accordance with the quality regulations (RAL-GZ 250, 251, 254). pH of the peat-free substrate was 6.2, and 5.8 of the white peat substrate.

The following fertilizers were chosen: Osmocote 6M (16+8+12+2+micronutrients) and MALTaflor universal (minimum 70 % organic matter, 5 % N, 3 % P_2O_5, 5 % K_2O). MALTaflor consists mainly of barley sprouts from the malting process in beer production, sugar beet products and minerals. In this fertilizer micronutrients are considered to be sufficient (product information).

Osmocote was applied in a dose of 400 mg N L^{-1} substrate at potting. For MALTaflor two doses were chosen: 400 and 800 mg N L^{-1}. The higher dose was chosen because not all N from the organic fertilizer was considered to be available in a given time. MALTaflor was applied in four portions of 75 and 175 mg N L^{-1} substrate (mixed into the substrate at potting and as top dressing in weeks 24, 30, and 35). The difference between 400 and 800 mg N L^{-1} was given as NH_4NO_3 $(NH_4)_2SO_4$ at potting.

Prunus laurocerasus 'Otto Luyken' was used as the experimental plant. It was potted into 5 L containers as rooted cuttings in the middle of April.

Measurements and analysis

The Mitscherlich containers were emptied once a week or more often when they were full after a heavy rain. In the drained water NO_3-N and NH_4-N were determined with a rapid flow analyser, P photometrically, K with flame emission spectrometry.

Plant measurements and plant samples were taken in weeks 21, 27, 32, 38, and 44. Except in week 21 mineral N in the substrates was also analysed all theses times.

At each sampling date height and width of all plants were measured. At the sampling dates 1–4 three plants were harvested; at the final sampling date eleven plants were used to get a better base for statistical evaluation. Fresh and dry matter of the plants and % N in dry matter were determined.

For mineral N analysis of the substrate $CaCl_2$ was used as the extracting agent. NO_3-N and NH_4-N were determined with a rapid flow analyser.

Results

Characterization of the substrate with the incubation test, storage test and mineral N content in the substrate during the growth period

The incubation test (two weeks, 25 °C) of the peat-free substrate showed an immobilization of N of 138 mg L^{-1}. At the end of the storage test (28 weeks, 20 °C) 74 mg N L^{-1} was immobilized.

During the whole vegetation period mineral N content was higher in the peat-free substrate than in white peat (Fig. 1). In the white peat substrate mineral N decreased during the vegetation period; in the peat-free substrate N increase and N decrease occurred. The higher dose of MALTaflor resulted in higher mineral N contents compared to the lower dose and to Osmocote.

Table 1. Substrates and fertilizers used in the experiment with *Prunus laurocerasus* 'Otto Luyken'.

Substrate	Treatment	Fertilizers	Fertilization
WP	O400	Osmocote 6M, 400 mg N L^{-1}	at potting
	M400	Maltaflor, 400 mg N L^{-1}	4 doses à 100 mg N L^{-1}
	M800	Maltaflor, 800 mg N L^{-1}	4 doses à 200 mg N L^{-1}
PF	O400	Osmocote 6M, 400 mg N L^{-1}	at potting
	M400	Maltaflor, 400 mg N L^{-1}	4 doses à 75 mg N L^{-1}
	M800	Maltaflor, 800 mg N L^{-1}	4 doses à 175 mg N L^{-1}*

WP: White peat
PF: Peat-free = 40 % (v/v) substrate compost, 30 % (v/v) bark compost, 30 % (v/v) wood fibre
*The difference between 400 resp. 800 mg N L^{-1} was given as $NH_4NO_3(NH_4)_2SO_4$

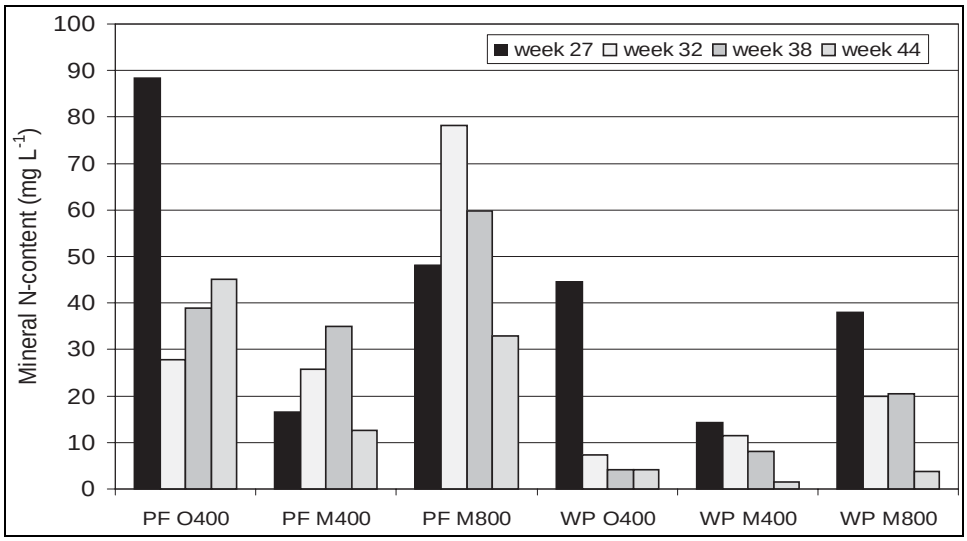


Fig. 1. Mineral-N-content in a peat-free and in a white peat substrate with different fertilizers O400: Osmocote 400 mg N L^{-1}; M400 resp. M800: Maltaflor univ. 400 resp. 800 mg N L^{-1}, Maltaflor was given in 4 doses.

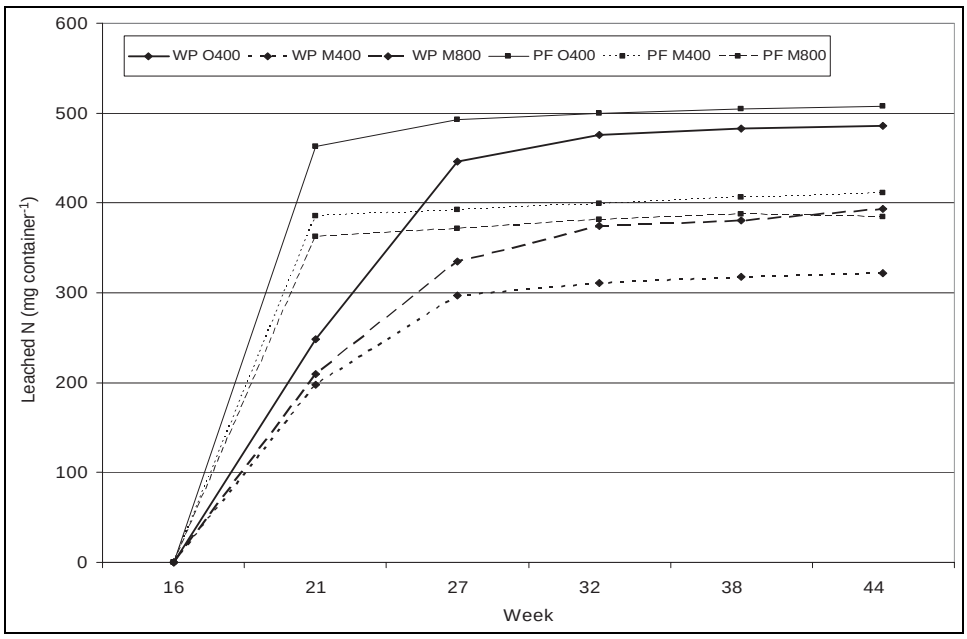


Fig. 2. Cumulative leaching of N during growth of *Prunus laurocerasus* 'Otto Luyken' with different substrates and fertilizers. O400: Osmocote 400 mg N L^{-1}; M400 resp. 800: Maltaflor univ. 400 resp. 800 mg N L^{-1}, Maltaflor was given in 4 doses.

Leaching of N, P, and K

Most leaching of N occurred in the first 5 weeks after potting. In the beginning of the growth period more N was leached from the peat-free substrate compared to white peat (Fig. 2). At the end of the growth period there was no difference between white peat and the peat-free substrate when Osmocote was used as fertilizer. About 25 % of the N fertilizer was leached with Osmocote. Using the organic fertilizer MALTaflor reduced leaching compared to Osmocote (Fig. 2). The percentage leached was even lower (about 10 %) for the higher dose of MALTaflor compared to the lower dose (16–21 %).

More K and P were leached from the peat-free substrate compared to white peat and for both from the treatments with MALTaflor compared to those with Osmocote (Table 2). From the peat-free substrate more K was leached than was added. This was not the case for P. The percentage of leached K in the white peat substrate was about 50 % of the amount added either by Osmocote or the low dose of MALTaflor and 37 % of K added with the high dose of MALTaflor. The percentage of leached P was between 0.5–2 % for all treatments, the lowest value again for the high dose of MALTaflor.

Characterization of the water and airbalances of the substrates

The peat-free substrate had a lower container capacity (water volume at 10 hPa), less available water and a higher air capacity compared to white peat (Table 3). This is in accordance with Wrede and Bohne (2000b).

Water tension in another woody crop in the same substrate and directly neighboured to *Prunus laurocerasus* most of the time was higher in the peat-free substrate than in white peat. The aim not to exceed 100 hPa was

Table 2. Leaching of K and P during the growth of *Prunus laurocerasus* 'Otto Luyken' with different substrates and fertilizers.

White peat			Peat-free		
O400	M400	M800	O400	M400	M800
mg K container^{-1}					
780	1260	1780	2250	2270	2650
mg P container^{-1}					
5	6	6	8	10	14

not always reached in the peat-free substrate (Bohne 2007).

Plant growth and N uptake

During the first five weeks after potting (week 16 to week 21) there was no fresh matter production. From week 21 to 27 fresh matter production was similar in the white peat and in the peat-free substrate, from week 27 differences between the substrates appeared. At the end the plants in the white peat substrate produced more fresh matter than those in the peat-free substrate (Fig. 3).

N uptake in the course of time followed fresh matter production (Fig. 4).

In all treatments marketable plants were produced. For each fertilizer treatment height and width of plants were better in the white peat than in the peat-free substrate (not shown). Only in regard to the plant widths there were interactions between substrate and fertilizer. Table 4 shows the results of the Tukey test for the combinations of fertilizer and substrate for all plant parameters except plant width. The differences in fresh matter, plant height, N content of the plants were significant for the substrates (white peat/peat-free) and for the fertilizers (O400/M400, O400/M800, M400/M800), but not for all combinations of substrate and fertilizer. Fresh matter was not significant different when applying the high dose of organic fertilizer in the peat-free substrate compared to Osmocote in the white peat substrate (white peat O400/peat-free M800). The same is true for the comparison between the substrates and the low and high doses of organic fertilizer (white peat M400/peat-free M800). Non significant differences in fresh matter corresponded to non significant differences in the N content of the plants.

Discussion

Leaching of N and N content in the substrate

Most leaching occurred within the first five weeks after potting. In this period N leaching was higher in the peat-free substrate than in white peat. In the peat-free treatments, 91–94 % of the total leached N was lost in this time while this loss was 51–61 % when using white peat. At the end of the growth period the influence of the fertilizer was greater than the influence of the substrate. More N was leached when using Osmocote compared to MALTaflor, even for the higher dose of MALTaflor (M800).

The peat-free substrate had a smaller container capacity (Table 3, water volume at 10 hPa). In spring, shortly after potting, the substrates are not well rooted and the water demand of the plant is not high. Only a smaller portion of rain can be stored in the peat-free substrate due to its lower container capacity. Hence, drainage and leaching of N is higher than in the white peat-substrate in this period. During the first 5 weeks after potting there was drainage of 2.96 L of water per container averaged over the peat-free treatments, while there were only 1.53 L per container drained averaged over the white peat treatments. Since there was no irrigation in this time, this drainage was due to the natural precipitation. However, leaching decreased earlier in the peat-free substrate resulting in similar amounts of total leached N for the same fertilizer in both substrates (except white peat M400). This might be the result of the more densely rooted peat-free substrate which was observed when sampling the plants for fresh matter and N content.

Leaching was higher for Osmocote than for MALTaflor since the total amount of N applied via MALTaflor was divided into 4 doses and had to be mineralized before becoming soluble. The percentage of leaching was lowest for the high dose of MALTaflor (M800). In this treatment fresh matter production and N uptake were higher than for the low dose of MALTaflor (M400).

Cabrera (2003) found that N leaching for *Ilex opaca* 'Hedgeholly' increased with increasing fertilization and reached 45 % of the added amount when 300 mg N L^{-1} was applied. Increasing fertilization also increased leaching in experiments by Andersen and Hansen (2000). For *Campanula carpatica* 39 % of the N fertilized was leached, for *Weigela* 'Bristol Ruby'10 %, both at a fertilization rate of 220 mg N L^{-1}. In the trials with *Prunus laurocerasus* reported here the maximum percentage of leaching was 25 % of the added N, the minimum 10 %. In these trials fertilization was carried out with slow release

Table 3. Water and air characteristics of a white peat and a peat-free (40% substrate compost, 30% bark compost, 30% wood fibre) substrate.

Substrate	Total porespace	Air volume at 10 hPa	Water volume at 10 hPa	Available water 10–100 hPa
	(%, v/v)			
White peat	94.5 (0.5)	21.0 (5.1)	73.5 (4.7)	34.1 (0.8)
Peat-free	88.3 (1.0)	36.1 (0.5)	52.2 (0.7)	15.6 (2.6)

In brackets: standard deviation, n=3

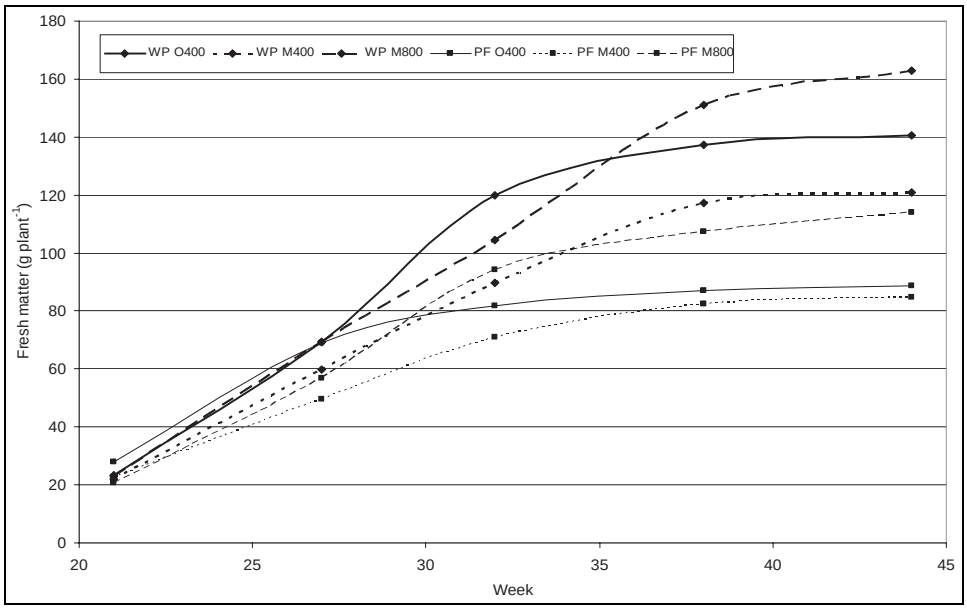


Fig. 3. Fresh matter production of *Prunus laurocerasus* 'Otto Luyken' with different substrates and fertilizers. O400: Osmocote 400 mg N L^{-1}; M400 resp. 800: Maltaflor univ. 400 resp. 800 mg N L^{-1}, Maltaflor was given in 4 doses.

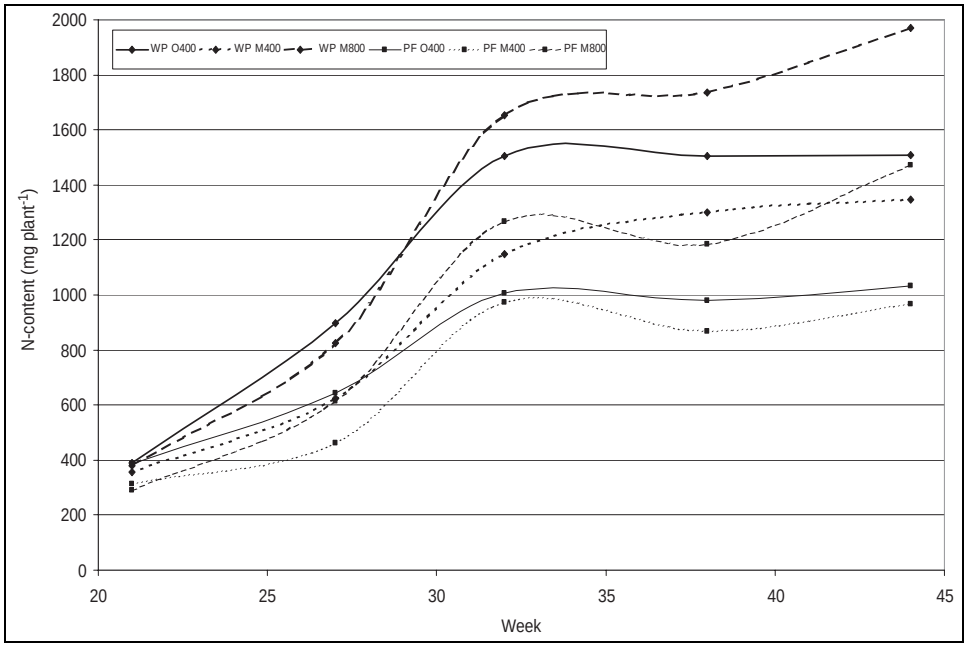


Fig. 4. N-content of *Prunus laurocerasus* 'Otto Luyken' with different substrates and fertilizers. O400: Osmocote 400 mg N L^{-1}; M400 resp. 800: Maltaflor univ. 400 resp. 800 mg N L^{-1}, Maltaflor was given in 4 doses.

or organic fertilizers, while N was applied via fertigation in the experiments by ANDERSEN and HANSEN (2000) and CABRERA (2003). This might have increased leaching.

Higher N contents were measured in the peat-free substrate compared to white peat during the entire vegetation period. This can be attributed to lower N uptake by the plants grown in the peat-free substrates (Fig. 4). In the peat-free substrate fertilized with Osmocote the mineral N content decreased from week 27 to week 32 and then increased. Refertilization with MALTaflor increased mineral N until week 32 and week 38, followed by a decrease. Increase in mineral N means that more N is supplied than taken up by the plant. Increase in mineral N also means that N immobilization – if it occurs at all – is very small. N immobilization is often stated as a reason for less plant growth in peat-free substrates without knowing the mineral N content during growth (i.e. POPP and FISCHER 1998). The results presented here do not support this.

Likewise the results of the incubation test were not confirmed by the mineral N contents of the substrates. The incubation test showed an N immobilization of 138 mg L^{-1} during the longer lasting storage test an N immobilization of 74 mg L^{-1} was found. Although lower than in the incubation test, obviously neither test adequately describes the behaviour of the substrate under the conditions of woody plant cultivation. In experiments of HARTZ et al. (2000) most plant residue composts showed initial N-immobilization and slow net mineralization thereafter when incubated for 12 or 24 weeks. From

Table 4. Statistical evaluation of fresh matter, plant height, and N content of the plant at the end of the vegetation period (week 44), Tukey-test with adjusted p-values.

	Fresh matter	Plant height	N content
WP O400/PF O400	<0.0001	0.0004	<0.0001
WP O400/PF M400	<0.0001	<0.0001	<0.0001
WP O400/PF M800	0.0998	0.0207	0.9964
WP M400/PF O400	<0.0001	0.2236	0.0022
WP M400/PF M400	<0.0001	0.0228	<0.0001
WP M400/PF M800	0.9997	0.8789	0.5984
WP M800/PF O400	<0.0001	<0.0001	<0.0001
WP M800/PF M400	<0.0001	<0.0001	<0.0001
WP M800/PF M800	<0.0001	0.0002	<0.0001
WP/PF	<0.0001	<0.0001	<0.0001
O400/M400	0.0380	0.0897	0.1012
O400/M800	<0.0001	0.1908	<0.0001
M400/M800	<0.0001	0.0005	<0.0001

WP: White peat
PF: Peat-free = 40 % (v/v) substrate compost, 30 % (v/v) bark compost, 30 % (v/v)wood fibre

this an incubation of 2 weeks as in the standard incubation test (VDLUFA 2002) is too short to predict the behaviour concerning N mineralization and immobilization. In addition, mineralization is affected by temperature. Effects of temperature differed over time of incubation, as shown by KRAUS et al. (2000). While there was no temperature effect during the first five weeks of incubation, from week 6 to 16 influence of temperature, kind of compost and temperature x compost interactions were found. The percentage of organic N mineralized from a composted turkey litter was greater at temperatures changing between 25 and 45 °C and constant 45 °C than at constant 25 °C. Temperature of container substrates can reach 40 °C and changes in temperature are normal.

The peat-free substrate consisted of 30 % composted bark, 30 % wood fibre and 40 % substrate compost. Concerning compost WILSON et al. (2003) found higher N contents in a medium with 50 % compost compared to the peat-based medium. Concerning wood fibre, GRUDA and SCHNITZLER (1997) showed that an impregnation with slow release fertilizer provides enough N for an initial microbial N fixation.

Leaching of P and K

Leaching of P and K in the course of time followed the same patterns as for N (results not shown) the highest portion being leached in the first 5 weeks. In the end more K was leached from the peat-free substrate than was added by fertilizer. K from the substrate compost must have become soluble earlier and in the long run to extent higher than hypothesized by GRANTZAU (1990). In respect to P, on average 1.5 % of the added P from fertilizers was leached from the peat-free substrate, with 0.7 % being leached in white peat. Thus also in the long run little P from the substrate compost is lost by leaching. This is in accordance with GRANTZAU (1996) who stated that P in substrate composts is less soluble than K.

Comparing the uptake of P and K by the shoots of *Corylus avellana* 'Contorta' and *Ribes sanguineum* and the content in the substrate (probably white peat) at the end of the growing season with the supply, ALT et al. (1995) found considerable "unknown residuals" of 40 and 70 % of the P supply and 70 % of the K supply. From the results reported here for P only a small part of this "unknown residual" can be attributed to leaching, while for K leaching reached 50 % of the supply.

Growth and N-uptake of plants

The plants in the white peat substrate produced more fresh matter than those in the peat-free substrate. The higher dose of the organic fertilizer MALTaflor (M800) yielded more fresh matter than the lower dose (M400) or the same low dose of Osmocote (O400). Since N in organic fertilizers is only partly mineralized during the growth period, higher doses are necessary compared to a mineral slow release fertilizer. The higher dose of the organic fertilizer in the peat-free substrate could also compensate for some of this substrate's disadvantages since there were no significant differences in fresh matter and plant height for the treatments "white peat O400/peat-free M800" and "white peat M400/peat-free M800".

Significant effects on fresh matter in most cases were associated with the same effects on N uptake. This is comprehensible since N uptake in the course of time followed fresh matter production (Fig. 3, 4). This was also found by BOHNE and SCHACHT (2002) and CRAIG et al. (2003).

SCHÜTT et al. (2004) stated that optimum growth can be expected when the N concentration in the substrate is not below 30 mg L^{-1}, provided that there is further N supply from either slow release fertilizer or N mineralization from organic fertilizers or refertilization. This is supported by Röber and Rohde for *Forsythia* x *intermedia* (1982), for *Lonicera xylosteum* (1983), and for *Philadelphus inodorus* (1984). Mineral N content was lower than 30 mg L^{-1} in the white peat substrate most of the time and reached or exceeded this value in the peat-free substrate. From this the mineral N content of the substrate cannot be the reason for less growth and N uptake of the plants in the peat-free substrate.

For *Prunus laurocerasus* water tension was not measured continuously. However, in previous and in a directly neighboured experiment with *Weigela* 'Bristol Ruby' water tension was often higher in the peat-free substrate than in the white peat substrate (BOHNE 2007). Although the irrigation was monitored by tensiometers, especially during hot summer days the irrigation schedule obviously could not compensate for the lower amount of available water in the peat-free substrate (Table 3). Higher water tension in the peat-free substrate means that water uptake for the plants is more difficult than for those in the white peat substrates. ZUBILLAGA and LAVADO (2001) found for *Petunia hybrida* and *Vinca* sp. that differences in plant parameters for treatments including 25–100 % biosolid compost were related to water availability and also to substrate salt content (*Petunia*) and to pH (*Vinca*). WILSON et al. (2003) attribute reduced plant growth of *Salvia*

'Van Houttei' to the lower moisture content of a compost amended medium (50 % compost).

Higher water tension also influences the uptake of nutrients especially when they are unevenly distributed in the container. This was the case for the organic fertilizers which were reapplied as topdressing. This effect is more pronounced for the lower dose than for the higher dose of the organic fertilizer. *Prunus laurocerasus* showed the lowest N uptake in the peat-free substrate and the low dose of organic fertilizer (M400, Fig. 4), although mineral N-contents in the substrate were higher than for white peat fertilized with the low dose of MALTaflor or with Osmocote. For container grown plants the fine root-mass, which is responsible for nutrient uptake, is concentrated at the bottom and periphery of the root ball (BEESON 1993). Less uniform distribution of a fertilizer as in top dressing will reduce nutrient availability. This effect can be increased at high water tensions. Mean mineral N determined for thoroughly mixed samples will lead to misleading interpretations when the fertilizers are not evenly distributed.

Conclusions

Growth of *Prunus laurocerasus* 'Otto Luyken' in a peat-free substrate yielded marketable plants. However, growth and N uptake were reduced compared to a white peat substrate. The reason for this is not the mineral N content in the peat-reduced substrate. It is hypothesized that higher water tension in this substrate impairs water uptake and reduces the spatial availability of N when it is applied as topdressing. From this the significance of irrigation increases.

Leaching of nutrients from the peat-free substrate occurs mainly in the spring shortly after potting due to the lower container capacity of the substrate. In addition, nutrient uptake is minor in the spring. From this uptake-dependent release of nutrients from fertilizers is an instrument to reduce leaching. In respect to K, the main source for leaching is the substrate compost.

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