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Time course of N immobilization of wood fibers made Time course of N immobilization of wood fibers produced from different raw materials

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Abstract

Nowadays, wood fiber is the most important peat substitute for growing media, whereby spruce and pine wood are the main raw materials. However, due to climate change and subsequent forest conversion, their available quantity will strongly decrease. Thus, other wood assortments have to be processed in the future. Wood fibers for the present study were made from spruce and pine, deciduous woods (beech, willow), and bark beetle spruce. The wood fibers were mixed at a level of 40 vol.-% with peat. After liming and fertilization, rooted Poinsettia cuttings were potted in the mixtures and cultivated for eight weeks. Three pots per treatment were removed weekly and analyzed for mineral N in the growing medium and N uptake of plants to calculate a weekly and a cumulative N balance. The cumulative N balance for pine and bark beetle spruce was not significant different compared to peat. However, all deciduous woods and spruce showed a significantly higher N immobilization. Thereby, the time course of N immobilization was similar for all wood assortments: most of it took place in the first weeks of cultivation.

1. Introduction

Wood fiber has been used in growing media since the late 1980s (Lemaire et al. 1989) and is nowadays the most important peat substitute (Schmilewski 2017). The main horticultural advantages of wood fibers are the very low nutrient and ballast salt contents. In addition, wood fiber materials are generally free of pollutants, sprouting plant parts or viable seeds, and pathogens. In addition, wood is a regional and renewable resource. However, due to the high amount of easily degradable carbon, wood fibers often show a strong N immobilization (Neumeier and Meinken 2015; Schmilewski 2018). Thereby, both the level and the time course of nitrogen immobilization are difficult to predict and bear a major cropping risk for growers (Gruda 1999; Thomas et al. 1999). As raw material for wood fiber production, mainly spruce and pine wood is currently used (Schmilewski 2018). However, due to climate change and thereby triggered forest conversion, the available quantities of these woods will strongly decrease (Oehmichen et al. 2018). Thus, in future the use of other wood assortments will be inevitable. Two main alternatives could be beech wood – for which an increase in stocks is expected (Polley 2016) – and wood from short-rotation plantations (e.g. willow), whereby competition with thermal utilization has to be considered. Furthermore, by bark beetles infested spruce wood, which is available in larger quantities mainly due to increasing summer drought and more frequent storm damage, could also be an interesting raw material, at least for the next decades (König 2007). However, information about N immobilization of wood fiber made from other raw materials than spruce and pine is rather scare (Schmilewski 2018). A study of Paulus (1998) indicates significant differences between wood types. However, it has to be considered, that processing was done with different defibration techniques, which might influence physico-chemical properties of the wood fibers and thus degradability and consequently N immobilization.

In the current experiment, time course and total height of N immobilization of wood fibers made with the same defibration technique (by refiner) were evaluated in a plant trial with poinsettia (*Euphorbia pulcherrima*). Beside common wood types as spruce (*Picea abies*) and pine (*Pinus sylvestris*), beech (*Fagus sylvatica*) and spruce infested by bark beetle, which are both available in large quantities as well as willow (*Salix alba*), which was provided by Klassmann-Deilmann GmbH from one of their short-rotation plantations, were used. As willow bark may contain phytoactive substances (Wise et al. 2020) the material was used with as well as without bark.

2. Data, Methods and Approach

Wood fibers used

Six wood fibers were produced by the Technical University of Rosenheim using a refiner of pilot scale with the same processing parameters (feed rate, grinding disc spacing and geometry, etc.) and directly after production dried at 40°C and sealed airtight to avoid microbial activity. The N immobilization potential of all wood fibers was tested in two short-time tests (Table 1): The incubation test according to VDLUFA method book I (VDLUFA 2016) and a modified plant response test with Chinese cabbage (*Brassica rapa* subsp. *pekinensis*) (Beuth et al. 2022). Thereby wood fibers are mixed with peat (5050by volume), limed (pH 5.7 to 6.2) and fertilized according to VDLUFA plant response test (VDLUFA 2016). Subsequent 30 seeds of Chinese cabbage are sown and cultivated for four weeks. Finally, a N balance is calculated.

Tab. 1: N immobilization of the six wood fibers from different raw materials in the incubation test according to VDLUFA and a modified plant response test with Chinese cabbage

Raw material	N-Balance (mg L^{-1} wood fiber) in short time experiment	
	VDLUFA incubation test	Plant response test
Spruce	-226	-309
Pine	-9	-232
Bark beetle spruce	-86	-152
Beech	-160	-475
Willow, debarked	-297	-348
Willow, with bark	-152	-365

Experimental setup and procedure

The wood fibers were mixed with bog peat (degree of degradation according van Post's scale between H3 and H5) in a ratio of 40 to 60% by volume. The pH of the mixtures was adjusted to 6.0 (± 0.2) using dolomitic limestone (Otterbein Naturkalk, 85% $CaCO_3$). For nutrient supply, ammonium nitrate (35% N) and a water soluble fertilizer 14% P_2O_5 + 38% K_2O + trace elements; both provided by Planta, Regenstauf) were added resulting in N and

K_2O levels of 250 mg L^{-1}. As control, the pure bog peat was treated in the same way. Subsequently, 24 pots per treatment were filled with 500 ml of growing medium by weight according to VDLUFA bulk density (VDLUFA 2016) and a rooted poinsettia cutting was put in each pot. Pots were placed in saucers to avoid nitrogen losses by leaching and arranged randomly in a glass-sheltered greenhouse (heating set point day/night of 20/20 °C; ventilation set point 3 degrees above heating; supplement light with HPS lamps for 14 h per day if irridation was below 10 klx). Plants were irrigated with deionized water on demand from above. Fertilization was adjusted based on weekly analysis of growing media, whereby nitrogen was applied in doses of 50 mg N per pot.

Data collection and statistical analysis

At the beginning of the experiment, the amount of total N in the cutting (N_{cut}) itself and mineral N in the propagation plug (N_{plug}) as well as mineral N in the freshly prepared growing media (peat-wood fiber mixtures or peat, respectively) were analyzed ($N_{GM(f)}$). During the eight-week trial period, three plants per treatment were taken out weekly. Poinsettia plants were cut off directly at the growing medium surface, dried at 60 °C until constant weight and analyzed for total N. N uptake of plants (N_{up}) was calculated by multiplying dry weight and N concentration in plant tissue. Afterwards, pots were weighted and the stock of mineral N in the growing medium ($N_{GM(u)}$) was measured. From these data and the N amount given as top dressing (N_{top}) since the beginning of the experiment, the weekly N balance was calculated as follows:

1. N amount at the beginning of the experiment: $N_0 = N_{cut} + N_{plug} + N_{GM(f)}$
2. N amount at evaluation date x: $N_{Dx} = N_{up} + N_{GM(u)} - N_{top}$
3. N balance at evaluation date x: $\Delta N_{Dx} = N_{Dx} - N_0$
4. Weekly N balance: $\Delta N_{Wx} = \Delta N_{Dx} - \Delta N_{D(x-1)}$

Additionally to the weekly N balance, the cumulative N balance after eight weeks of cultivation was calculated. For each of the eight weekly N balances as well as for the cumulative one, a one-way ANOVA was computed. If the ANOVA indicated significant differences ($p < 0.05$), the N balance of each of the six wood fibers was checked for significant differences to the corresponding peat control (Dunnett test, $p < 0.05$). Subsequently, the suitability of short-term experiments (incubation test according to VDLUFA and plant response test according to Beuth et al. 2022, respectively) to predict N immobilization of wood fiber under practical conditions was evaluated by correlation analyses. To make also the absolute values more comparable, the cumulative N balance was converted from mg N per pot in mg N per liter of wood fiber. In the first step, the cumulative N balance was adjusted for the presumed contribution of peat by subtracting 60% of the cumulative N balance of the peat control. In the second step the adjusted N balance was multiplied with five as each pot contains 200 ml of wood fiber (total volume of pots = 500 ml, percentage of wood fiber 40% by volume) For data pre-processing and visualization Microsoft Excel (2016) was used. Calculation of ANOVA and post-hoc Dunnett's test was done with the statistic software package Minitab (V 18).

3. Results and Discussion

As shown in Figure 1, there were remarkable differences in the cumulative N balances for the six wood fibers compared to peat. Thereby, a clustering of wood types was observed. Whereas N immobilization of wood fibers made of deciduous woods (beech, willow) was two to three fold higher than for peat, only smaller differences – which only were significant for spruce – existed for wood fibers made of coniferous woods. Regardless of the mentioned shortcomings caused by the different processing techniques, the results of Paulus (1998) indicated the same trend: wood fibers made of deciduous woods cause a higher N immobilization than those made of coniferous woods. This might be due to a higher percentage of easily decomposable carbon sources (mainly cellulose and hemicellulose) in deciduous woods than in coniferous woods, which tend to contain a higher proportion of less degradable lignin (Schütt et al. 1992). Furthermore, also resins present in conifers might delay the microbial degradation (Paulus 1998). It is well known, that lipophilic resinous constituents on the wood surface of felled conifers form a protective layer against wood destroying fungi (Black et al. 2000). Additionally to wood chemistry, deciduous and coniferous woods differ in their anatomical organization. In general, structure of deciduous woods is more complex (e.g. higher number of cell types), but coniferous woods cotain a higher percentage (up to 95%) of fibers compared to around 50% in deciduous woods (Daniel 2009).

Besides differences between wood types, infestation with bark beetle seems to reduce N immobilization. Whereas the N immobilization of the growing medium with healthy spruce was significantly higher than for the peat control, this was not true for the growing medium containing bark beetle spruce. However, the absolute difference in N immobilization between the two treatments was only 19 mg per pot and thus of minor practical relevance. Reasonable for the slight decrease might be less the feeding activity of bark beetles and their larvae, but a fungal infestations following quite often after bark beetle attack (Hýsek et al. 2021). This fungal infestation can lead to structural changes in the wood affecting physico-chemical properties of the wood fiber and thus their degradability. For example, Ludwig (2007) reported an increased buffer capacity in wood fibers made from spruce infected with red rot (*Heterobasidion annosum*) compared to those from healthy spruce. However, thereby interactions between wood type, microbiome, environmental conditions and wood degration process need to be considered (Herrmann and Bauhus 2013; Hoppe et al. 2014; Kahl et al. 2017). From a practical point of view partial wood degredation either by targeted pretreatment with wood-decomposing fungi, elongated storage, composting or fermentation, might be an interesting approach to improve N stability of wood fibers. However, costs for the pretreatment as well as volume loss during degradation probably make this approach uneconomical.

Time course of N immobilization was similar for all four wood fibers showing a significant cumulative N immobilization (spruce, beech, willow with and without bark): significant differences in the weekly N balance compared to peat (indicated by dark colored columns in Figure 1) occurred only within the first three weeks of cultivation. This corresponds to experiences of growers with substrates containing wood fiber (Fritzsche et al. 2023).

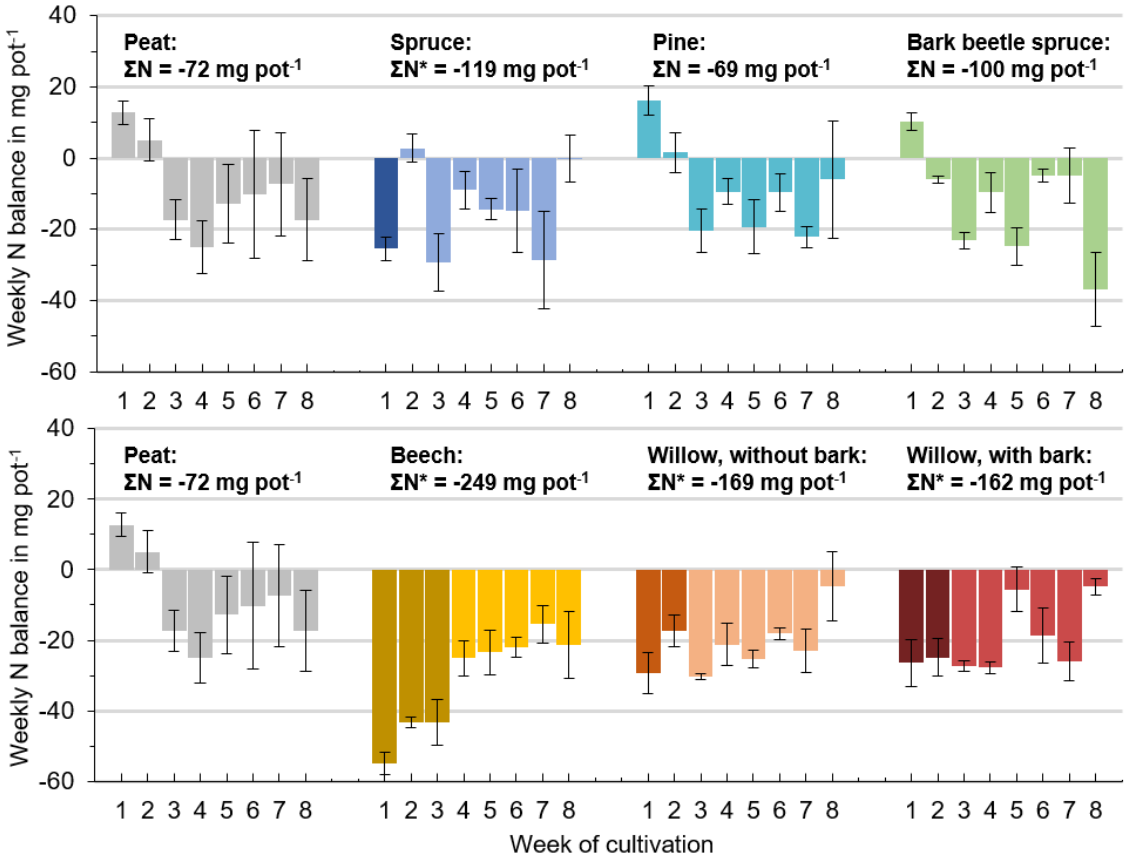

Figure 1: Weekly and cumulative N balance for the three coniferous (upper graph) and the three deciduous woods (lower graph) compared to the peat control (dark colored columns indicate a significant difference for weekly and underlined values for cumulative N balance compared to the peat control (Dunnett test, $p \leq 0.05$ in both cases; error bars indicate the 95% confidence interval for weekly N balance; n = 3).

Although most of the N immobilization in the poinsettia trial takes place in the first three weeks and thus within the duration of the incubation test according to VDLUFA (Table 1), correlation between cumulative N balance (adjusted for peat and converted to mg L^{-1}) and the N immobilization found in the incubation test is rather poor (Figure 2). Whereas for beech and willow with bark the same N immobilization was found in the incubation test, cumulative N balance in the poinsettia trial differs by about 50%. On the other hand, cumulative N balance for willow with and without bark is nearly the same, but in the incubation test the N immobilization of willow without bark was -297 mg L^{-1} wood fiber and only -152 mg L^{-1} for the one with bark. In contrast, the N immobilization predicted by the modified plant response test with Chinese cabbage according to Beuth et al. (2022) fits quite well (r = 0.84, p = 0.03) to the results of the poinsettia trial. Only for bark beetle spruce , a higher discrepancy exists. Notwithstanding the close relationship, the absolute values differ by a factor of about two. The poor correlation between the VDLUFA incubation test and the N balance of the poinsettia trial for the six tested wood fibers (r = 0.50, n.s.) fits to prior results for 57 different wood fibers (Beuth et al. 2022) and confirmed that the results of the VDLUFA incubation test is not well suited to predict the N immobilization of wood fiber under practical conditions. Indeed, the modfied plant response test is more reliable, but is unsuitable for routine testing. Thus, further research should focus on the development of new test procedures.

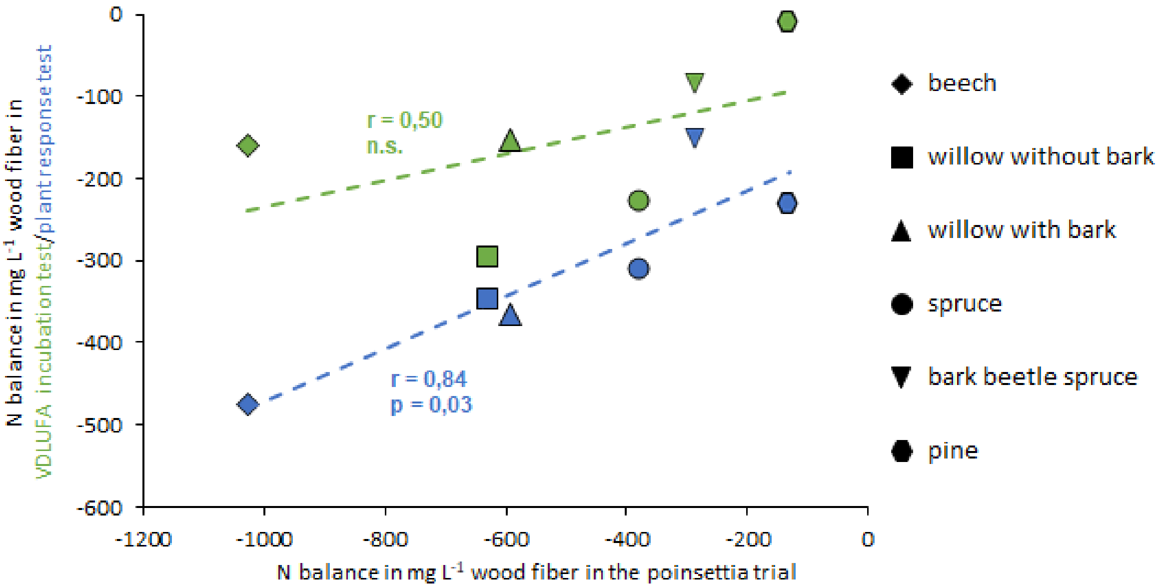

Figure 2: N balance in the poinsettia trial (adjusted for contribution of peat and converted to mg L^{-1}) compared to the N immobilization found in the VDLUFA incubation test (green) and in a modified plant response test with Chinese cabbage (blue) for the six wood fibers (symbols indicate raw materials).

4. Conclusions

If more deciduous woods are used in future for the production of wood fiber, problems with N immobilization might increase and consequently the proportion of wood fiber in growing media needs to be reduced. In contrast, the use of bark beetle spruce even seems to be advantageous. This suggests, that partial degradation of the wood structure, e.g. by adding special wood-degrading fungi, possibly in combination with prolonged storage, might be an interesting approach to increasing N stability of wood fibers. This should be investigated in detail in subsequent research projects. Furthermore, the results revealed that N immobilization mainly takes place in the first weeks of culture. From this fact, the recommendation for growers can be derived that analysis of mineral N in the growing medium might be necessary already within 14 days after potting. Finally, the results emphasize the need for new test procedures to measure the N stability of wood fibers.

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