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Influence of Nutrient Loading on Growth, N-, P- and K-Concentrations and Outplanting Performance of *Rosa majalis*

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Summary

Nutrient loading is a fertilization concept with the aim to increase the N-, P- and K-concentration in the plant without changing its size. It can be carried out by a conventional or by an exponential method, which differ in the delivery schedule of nutrients. Nutrient loaded plants are assumed to perform better after outplanting compared to non-loaded ones because the former are capable of remobilizing sufficient nutrient reserves. An experiment was set up with a landscape plant, *Rosa majalis,* to investigate the effect of nutrient loading on growth, N-, P- and K-concentration at the end of the nursery period and on performance one year after outplanting. For conventional loading a slow-release fertilizer was added to the growing medium at potting; exponential loading was carried out with a liquid fertilizer given in exponentially increasing concentration during the vegetation period. In both methods a multinutrient (15 % N, 9 % P_2O_5, 12 % K_2O, 2 % MgO and micronutrients) fertilizer was used. Concerning N, 0.8 g N l^{-1} substrate was added in the non-loading treatment and 2.4 g N l^{-1} in the loading treatments, other nutrients were given according to the composition of the fertilizer. Nutrient loading was achieved for N and P, not for K. Conventionally loaded plants suffered from salt stress due to a high release rate of nutrients from the slow-release fertilizer during a hot period. Plants were outplanted in autumn. One year after outplanting there were no differences in growth between the previously differently fertilized plants.

Key words. fertilization – liquid fertilizer – nutrient dilution – salt stress – steady state nutrition – slow-release fertilizer

Introduction

In the nursery, plants are fertilized to maximize growth in terms of height, stem diameter and number of shoots (i.e. Wilson and Jacobs 2006). This so-called conventional fertilization can lead to nutrient dilution in the plant`s tissues. To overcome this problem a new fertilization technique known as nutrient loading was developed (Salifu and Timmer 2003; Salifu et al. 2009). Nutrient loading aims at increasing nutrient concentrations in the plant without increasing its growth more than for non-loaded plants. Nutrient loading can be carried out in two ways: conventional loading and exponential loading. Conventional loading means to increase the amount of fertilizer compared to the usual practice without changing the delivery schedule. For exponential loading, higher amounts of nutrients are supplied in exponentially increasing doses with increasing growth of the plants during the vegetation period allowing steady state nutrient concentrations (Timmer 1996). However, it is not known if all plants can be loaded.

After outplanting, stored nutrients can be remobilized. Especially for N, reserves resulting from exponential loading are known to be better remobilized than those from conventional loading (Timmer 1996; Salifu and Timmer 2003). For nutrient loaded plants, better survival and growth (height, dry matter accumulation) after outplanting are reported. This is attributed to remobilization of nutrient reserves, followed by increased growth of roots, which enhance water and nutrient uptake and by faster development of new shoots with high photosynthetic area for carbon gain and assimilation (McAlister and Timmer 1998; Xu and Timmer 1998; Salifu and Timmer 2001; Villar-Salvador et al. 2008; Cuesta et al. 2010). Remobilization of nutrients is important, because, immediately after outplanting, nursery grown stock may be not able to absorb enough water and nutrients from the soil due to root system damage (Burdett 1990).

Nutrient loading is mainly described for coniferous plants. The aim of this experiment is to find out if nutrient loading can be achieved with a broad-leaved landscape plant like *Rosa majalis* and if there are benefits for outplanting.

Until now, no information is available on the influence of nutrient loading on stress reactions. The behaviour of conventionally and exponentially loaded plants on frost and drought reactions has to be further investigated.

Materials and Methods

Nursery phase

One year old seedlings of *Rosa majalis* were potted into 3 L containers using white peat as the growing medium, fertilized with a multinutrient fertilizer under three fertilization regimes with regard to nitrogen: 0.8 g N l^{-1} (conventional fertilization = K8), 2.4 g N l^{-1}, (conventional loading = K24) and 2.4 g N l^{-1} (exponential loading = E24). The experiment was laid out in a complete randomized block design with 27 plants per treatment. Conventional fertilization was carried out using a slow-release fertilizer (5–6 M; 15 % N, 9 % P_2O_5, 12 % K_2O, 2 % MgO, micronutrients), which was added to the growing medium at potting. A liquid fertilizer (15 % N, 10 % P_2O_5, 15 % K_2O, 2 % MgO, micronutrients) was used for exponential loading. For the exponential fertilization an exponentially increasing amount of fertilizer was given with an interval of three weeks (in totally eight times during the vegetation period of 154 days), starting at potting in April. The amount needed for each application based on N was calculated from an equation given by Ingestad and Lund (1979) in Xu and Timmer (1998): $N_T = N_S(e^{rt}-1)$ where r being the relative addition rate needed to increase N_S, the initial level of the nutrient in the plant, to the intended final level N_T+N_S, with N_T being the amount of N given with t fertilizer applications and assuming no leaching. The r parameter is determined from the number of fertilizer applications which is t = 8 in this experiment. In this experiment N_T+N_S is 2.4 g N per plant in the non-loaded treatment (K8) derived from experience of previous experiments and an intended threefold increase to 7.20 g N per plant in the conventionally and exponentially loaded treatments (K24, E24). In an ideal manner, N_S would have been determined by chemical analysis short before starting the fertilization. Due to lack of time this was not possible and N_S was assumed to be 80 mg N $plant^{-1}$ using data from other tree nursery crops. Later on it turned out that the supposed N-amount per plant was too low which lead to a slight overestimation of the calculated amount of fertilizer in the first application and a final application of 7.22 g N per plant. The amount of fertilizer for each single application at the time t (N_t) is derived from the following equation: $N_t = N_S\ (e^{rt}-1)\ -N_{t-1}$, where N_{t-1} is the amount of fertilizer summed up from the single applications (here from t = 1 to t = 8) including the previous one (t–1). To avoid loss of nutrients with the application of liquid fertilizer in the exponential loading treatment, the 3 L containers were inserted into 5 L containers covered with plastic film at their bottom and border. Leachates were collected and re-added to the respective plants. Irrigation was carried out as drip irrigation starting at −100 hPa and monitored with tensiometers.

Sampling for dry matter and N-, P- and K-analysis took place at three times during the vegetation period with 8 (E24) resp. 6 (K24, K8) plants per sampling date. From all plants, non-destructive growth parameters like shoot length and number of shoots were taken at the sampling times as well. Nitrogen was determined by controlled burning at 900 °C using Vario MAX CN analyzer. For the determination of P and K, samples were ashed overnight at 480 °C, dissolved in 0.5 M HCl. The solutions were filtered. P was determined by a photometer at 470 nm, K using atomic absorption spectrometry.

Outplanting phase

At the end of the nursery phase, plants were outplanted on a sandy soil with approximately 4 % organic matter in a complete randomized design. Compared to recommendations for tree nurseries (Alt 1990) it has to be classified as rich in P and poor in K, mineral N is low (10–26 kg ha^{-1} in 0–60 cm, data not published). Mean annual rainfall is 633 mm and the mean temperature during the growing season (April–October) is 15.5 °C. After outplanting, plants were irrigated by drip irrigation but there was no fertilization. In the beginning, mid, and at the end of the growing season, the height of the longest shoot and number of shoots were determined on seven randomly chosen plants per treatment. Also at the end of the growing season dry matter was taken, and N-, P-, and K-concentrations were determined in new shoots, old shoots and roots with the methods described above.

Statistical analyses

Statistical analyses were done with R (R Development core Team 2011). For the results from the nursery phase a linear mixed model according to Bates et al. (2011) was adjusted to calculate means per treatment, sampling date and plant part. Means were separated for $P \leq 0.05$ using adjusted p-values for all-pair comparisons according to Hothorn et al. (2008). Because of clarity, in the results presented here, significances were indicated for comparisons of sampling time within a treatment and of treatments for a certain sampling time. For the results from the outplanting phase an ANOVA was carried out followed by the Tukey test to separate means at $P \leq 0.05$.

Results

Nursery phase

At the end of the nursery phase, loading of N in K24 and E24 treatments was evident for new shoots, old shoots and roots having plants with higher N-concentration but not higher dry matter (Fig. 1 and 2) compared to the non-loaded plants (K8). In contrast to the loaded plants, in the non-loaded ones there was a gradual decrease in the N-concentration in new shoots, old shoots and roots during the vegetation period (Fig. 2). In E24 treated plants, N-concentration of new shoots was characterized by a steady-state, while N-concentration of old shoots and roots was gradually increased, until the end of the vegetation period (Fig. 2). Despite the same fertilizer amount, new shoots of conventionally loaded plants had higher N-concentrations than exponentially loaded ones (Fig. 2). This is due to the very low dry matter in conventionally loaded plants especially for new shoots and roots (Fig. 1). The low dry matter of these plants appeared already in the first half of the growing season and was also to be seen in number and length of shoots (data not shown). Concerning P, both new and old shoots of the K24 and E24 plants were loaded while the new shoots of the K24 plants showed higher P-concentrations compared to those of the E24 plants. In the roots no loading took place. For K, however, loading was not successful. In the new shoots the non-loaded plants had the highest K-concentration while in old shoots and roots different treatments had no influence (Fig. 3).

Exponential loading did not reduce root growth compared to the non-loading treatment, while this occurred for the conventionally loaded plants (Fig. 1).

Outplanting phase

At the end of winter, all plants from the treatments K8 and E24 and 96 % of the K24 plants survived (data not shown). In the beginning of the growing season, previously conventionally loaded plants, which suffered from salt stress in the nursery phase, had fewer shoots than the plants from the other fertilization treatments, which, in turn, did not differ between them. However, already in July, growth had been completely restored for conventionally loaded plants, which did not differ from plants of the other two treatments. Also at the end of the growing season, plants did not differ much in their appearance having similar number of shoots. Concerning height of shoots, E24 plants were smaller than K8 plants (Table 1). However, this is not reflected in the dry matter of new shoots, which did not differ between the fertilization treatments. This is also true for the roots. For old shoots, however, dry matter of plants which had been treated with conventional loading (K24) was much smaller than that of plants with exponential loading and non-loading (Table 2). The biomass of old shoots still reflected the salt stress that occurred during the previous year. One year after outplanting, apart from N in old shoots, N-, P- and K-concentrations in new shoots, old shoots and roots did not differ between the fertilization treatments (data not shown).

Discussion

Nursery phase

Nutrient loading and especially exponential nutrient loading has been examined mainly with forest trees, many of them being coniferous ones (i.e. Qu et al. 2003; Salifu and Timmer 2003; Dumrose et al. 2005). Apart from *Potentilla fruticosa* (Dumrose 2003), no landscape shrubs had been investigated so far. According to Larimer and Struve (2002), not all species can be loaded. For *Rosa majalis*, tested in this experiment, loading was achieved. Conventional fertilization, which does not result in loading, resulted in decreasing N-concentration

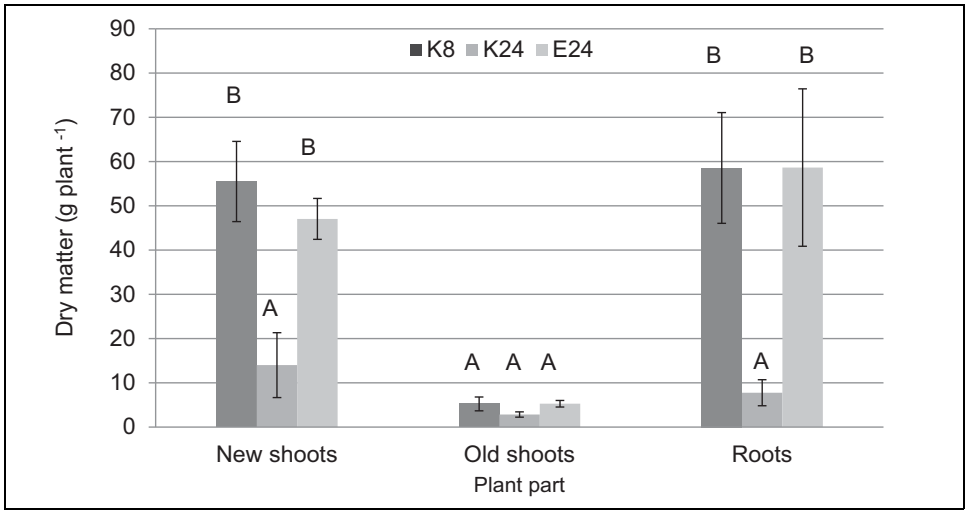


Fig. 1. Dry matter of new shoots, old shoots and roots of differently fertilized *Rosa majalis* at the end of the nursery period. K8: conventional fertilization, K24: conventional loading, E24: exponential loading. Means ± standard deviation, n = 8 (E24), n = 6 (K24, K8). Different letters show significant differences between treatments at $P \leq 0.05$.

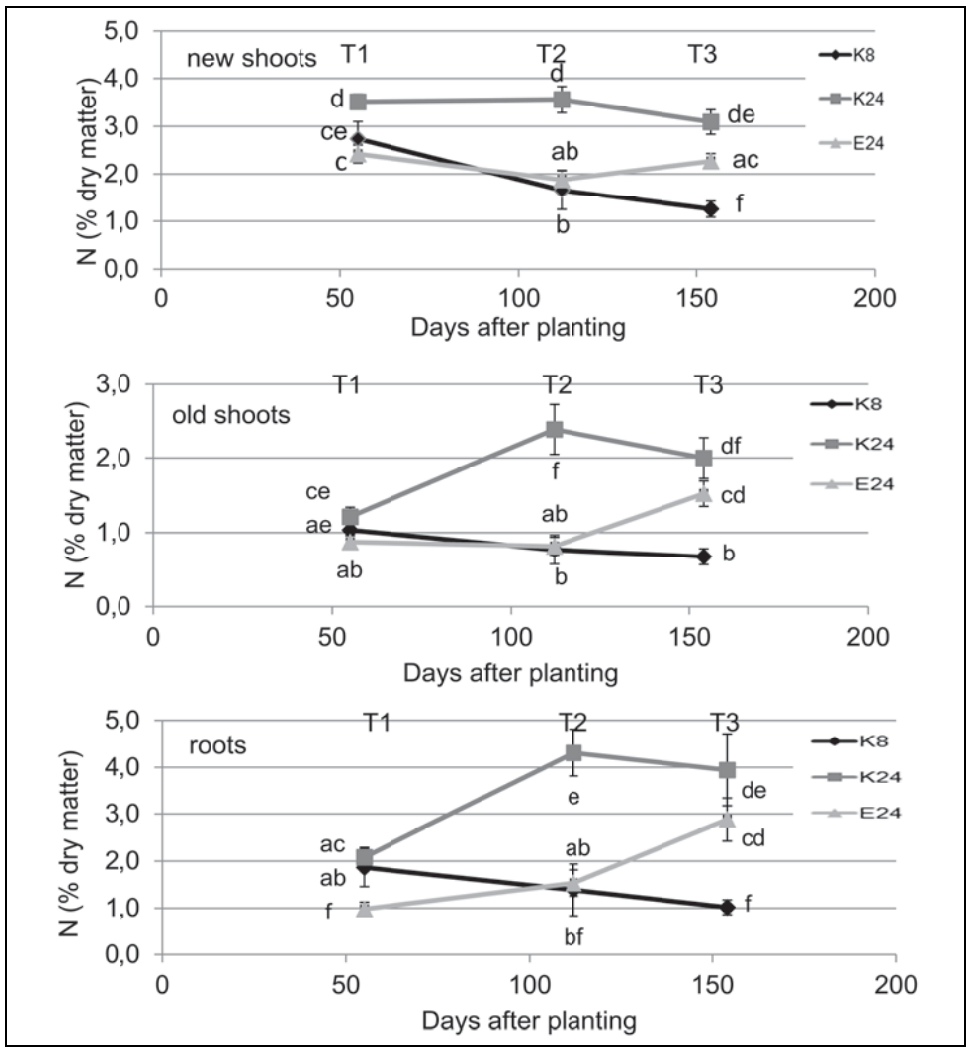


Fig. 2. Nitrogen (% in dry matter) in new shoots, old shoots and roots of differently fertilized *Rosa majalis* during the nursery period. K8: conventional fertilization, K24: conventional loading, E24: exponential loading. T1, T2, T3: sampling time. Means ± standard deviation, n = 8 (E24), n = 6 (K24, K8). Different letters show significant differences between treatments and between sampling times at $P \leq 0.05$.

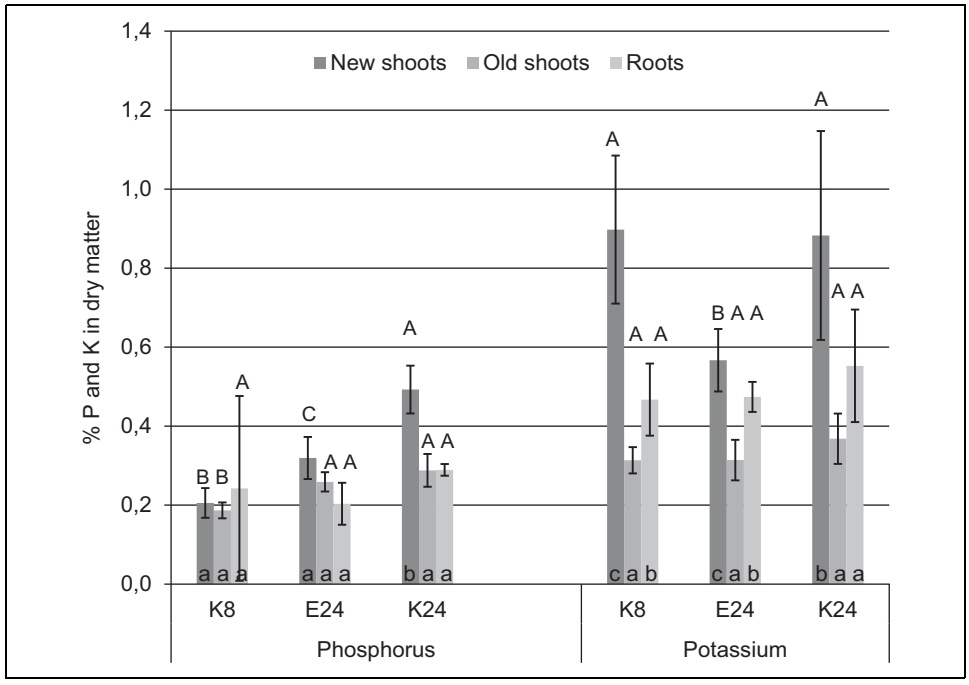


Fig. 3. Phosphorous and potassium (% in dry matter) in new shoots, old shoots and roots of differently fertilized *Rosa majalis* at the end of the nursery period. K8: conventional fertilization, K24: conventional loading, E24: exponential loading. Means ± standard deviation, n = 8 (E24), n = 6 (K24, K8). Different letters show significant differences, capitals between treatments, lower case between plant parts at $p \leq 0.05$.

Table 1. Number of shoots and height of the longest shoot of *Rosa majalis* with different fertilization in the nursery during the first year after outplanting. K8: conventional fertilization, K24: conventional loading, E24: exponential loading. Means ± standard deviation, n = 7. Different letters show significant differences, capitals between treatments, lower case between dates within a treatment at $P \leq 0.05$.

Date	April 2011		July 2011		October 2011	
Treatment	Number of shoots	Height (cm)	Number of shoots	Height (cm)	Number of shoots	Height (cm)
K8	12 ± 5 AB a	31 ± 6 A a	21 ± 9 A a	111 ± 21 B b	21 ± 9 A a	112 ± 22 B b
K24	7 ± 6 A a	33 ± 4 A a	21 ± 4 A b	95 ± 12 AB b	21 ± 4 A b	96 ± 13 AB b
E24	14 ± 5 B a	31 ± 4 A a	22 ± 5 A b	87 ± 12 A b	23 ± 5 A b	87 ± 12 A b

Table 2. Dry matter of new shoots, old shoots and roots of *Rosa majalis* with different fertilization in the nursery one year after outplanting. K8: conventional fertilization, K24: conventional loading, E24: exponential loading. Means ± standard deviation, n = 7. Different letters show significant differences between treatments at $P \leq 0.05$.

Treatment	New shoots (g plant part^{-1})	Old shoots	Roots
K8	104.1 ± 32.2 A	24.7 ± 7.0 B	325.4 ± 32.5 A
K24	112.0 ± 28.8 A	6.7 ± 4.1 A	297.9 ± 19.9 A
E24	105.9 ± 19.8 A	21.4 ± 4.5 B	291.0 ± 15.1 A

in the whole plant. This is due to dilution because of increasing biomass, and is also shown by other authors (i.e. McAlister and Timmer 1998; Xu and Timmer 1998). When compared to data from Rohde and Röber (1983) for new shoots of *Lonicera xylosteum* and from Röber and Rohde (1984) for new and old shoots of *Philadelphus inodorus* L. var. *grandiflorus*, no N-deficiency developed in *Rosa majalis*. On the contrary, both loading techniques prevented dilution of nitrogen during growth. This is also shown by Xu and Timmer (1998) and Salifu and Timmer (2003). However, in this experiment, concerning the conventionally loaded plants, the above is the result of decreased biomass of K24 plants probably because of salt stress, which occurred in the hot period during summer. Conventional loading was carried out with a slow release fertilizer, which, however, showed an increased nutrient release rate with increasing temperature. This did not happen for exponentially loaded plants, where a liquid fertilizer was applied in three weeks intervals. Hence, depending on climatic conditions, loading using slow release fertilizers bears the risk of salt damage. Similar biomass but higher N-concentration of the exponentially loaded plants compared to the non-loaded ones resulted – though not statistically different – in a higher N-content at the end of the nursery period. Imo and Timmer (2001) and Salifu et al. (2009) achieved an increase in the N-content of nutrient loaded plants up to 150 % compared to non-loaded ones. This increased N-content represents a reserve, which can be used by remobilization in the following spring. Since the remobilization of N is source-driven (Millard and Grelet 2010), this reserve can improve establishment after transplanting when N-uptake is impaired. Especially N that has been taken up late in the vegetation period – as it was the case for exponentially loaded plants – is known to be better remobilized than N taken up earlier (Timmer 1996).

In the shoots, P was also loaded. Similarly to N, there was no deficiency in the conventional fertilization (Rohde and Röber 1983; Röber and Rohde 1984). From the literature it is known that loading of P can be achieved (Malik and Timmer 1995), despite that there are reports for the opposite (Hawkins et al. 2005; Salifu et al. 2009).

There was no loading of K. At the end of the nursery phase, new shoots of conventionally fertilized plants even had a higher K-concentration compared to those, which received more fertilizer. In all fertilization treatments, the K-concentration decreased during the vegetation period (data not shown), indicating dilution and/or reduced uptake compared to the other nutrients. Thresholds indicating a sufficient K-concentration in new and old shoots differ between species. While 0.7 % in dry matter of new shoots indicates a high K-level for *Philadelphus inodorus* (Röber and Rohde 1984), 1.1 % is classified as low for *Lonicera xylosteum* (Rohde and Röber 1983). K-concentrations in *Rosa majalis* ranged from 0.6 % (exponential loading) to 0.9 % (conventional fertilization and conventional loading) and suggest a low level, however without deficiency symptoms. Similarly to P, there are reports for

K-loading (Malik and Timmer 1995), and reports for the opposite (Salifu et al. 2009). For both P and K, this is explained by competition in uptake with N, either with nitrate in the case of P or with ammonium in the case of K.

Exponential loading did not diminish root growth. From the literature it is known that high N-fertilization often results in reduced root growth (i.e. Larimer and Struve 2002; Williams et al. 2004; Schoene and Yeager 2006). Obviously, the application of a slowly increasing amount of N did not have this effect. Plants with conventional loading fertilization had a very low root dry matter, which was probably due to salt damage (see above).

Outplanting phase

The soil in this experiment was a sandy soil with organic matter content of about 4 %. Growth of plants after outplanting, especially on nutrient poor soils, mainly depends on stored nutrient reserves. Obviously, at least in the first year after outplanting, all fertilization treatments in the nursery were able to maintain growth. From previous reports, it is known that the influence of fertilization during the nursery phase on outplanting performance is not consistent (Oliet et al. 2005; Lloyd et al. 2006). Both, species (Cuesta et al. 2010) and site conditions (Bayley and Kietzka 1996) seem to influence outplanting performance. In this experiment, the site properties may not have been limiting enough to establish an effect of the fertilization during the nursery phase. Furthermore, only the first year after outplanting was considered. Since site properties play an important role concerning the effect of fertilization in the nursery on outplanting performance, a drought experiment was carried out with the differently fertilized plants. The results will be given in another paper.

Conclusion

In *Rosa majalis*, an important landscaping plant, nutrient loading was successfully achieved for N and P, but not for K. In contrast to exponential loading, conventional loading bears the risk of salt stress, when too many nutrients are released from the slow release fertilizer in a period with high temperatures. One year after outplanting, nutrient loading did not affect outplanting performance with regard to dry matter, but exponentially loaded plants had shorter shoots than the non-loaded ones.

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