Growth, yield, and mineral content of butterhead lettuce (Lactuca sativa var. capitata) grown in NFT

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Growth, Yield, and Mineral Content of Butterhead Lettuce (*Lactuca sativa* var. *capitata*) Grown in NFT

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Abstract

To improve greenhouse lettuce yield and quality and avoid enviromental pollution it is necessary to optimize plant nutrition. Plants uptake nutrients at different ratios during the growing period. Therefore, total N, K^+, Mg^{2+}, and Ca^{2+} accumulation and NO_3^-, NH_4^+ K^+, Mg^{2+}, and Ca^{2+} uptake were evaluated during greenhouse growth of two cultivars of butterhead lettuce ('Mindoro' and 'Tibet') in a discontinous closed loop NFT sstem. Growth rate and water consumption were also measured.

In the last 20 days of the growing cycle, lettuce plants produced 70% of the shoot dry weight and 60% of the leaf area obtained in the enitre growing period. From 30 DAT to harvest, the shoot dry matter content decreased from 7.0 to 5.1 g·100 g^{-1} fw in 'Mindoro', and from 7.0 to 6.0 g·100 g^{-1} fw in 'Tibet'. From 30 to 50 DAT, both cultivars had increasing content of leaf total N up to 4.3 and 4.6 g·100 g^{-1} dw in 'Mindoro' and 'Tibet', respectively, when RGR was still high. Thereafter, and up to harvest the total N concentration decreased more markedly in 'Mindoro' (14%) than in 'Tibet' (6%) while simultaneous dry biomass production was peaking. Similar variations with time were found for K^+, Ca^{2+}, and Mg^{2+} leaf contents. 'Mindoro' had higher N use efficiency (NUE) than 'Tibet'. Leaf NO_3 content was moderate (1,622 mg·kg^{-1} fw) and 80% of total N was in reduced form. During the whole growing cycle, 5.5 L/plant of water was used with a water use efficiency (WUE) of 12.4 dw g·L^{-1}.

INTRODUCTION

To optimize plant nutrition in greenhouse soilless growing systems, it is necessary to synchronize water and salt availability to plant demand in a short-time period. The application of high greenhouse technology allows monitoring and controlling of plant nutrition and environmental conditions. However, to decrease production costs and to avoid environmental pollution, optimal management of water and nutrient supply is essential.

Several studies focus on plant water (Jones and Tardieu, 1998) and nutrient uptake (Mankin and Fynn, 1996; Gary et al. 1998; Le Bot et al., 1998; Mathieu et al., 1999). Under not-limiting conditions, as in the NFT, nutrient uptake depends only on plant demand determined by the environmental conditions. Hence, mineral uptake by roots is driven by plant growth requirements (Mankin and Fynn, 1996). Nevertheless, nutrient solution is often managed irrespective of actual demand of plant. Moreover, N nutrition of lettuce requires particular attention because of the high capability to accumulate nitrate.

The objective of this research was to characterize growth, nutrient content and uptake of greenhouse butterhead lettuce grown in NFT in a spring cycle, in Southern Italy.

MATERIALS AND METHODS

Two cultivars of butterhead lettuce (*Lactuca sativa* var. *capitata*, 'Mindoro' and 'Tibet') were grown in NFT (Nutrient Film Technique) in a discontinuous closed loop system.

The trial was conducted during Jenuary-March in the polimetacrylate greenhouse of the experimental farm 'La Noria' of the Institute of Sciences of Food Production of NRC in Mola di Bari, Southern Italy (41°N, 17°E). Plants, at the 6^{th} true leaf stage, were placed on six gullies (600x20x8 cm), and spaced at 25 cm on the row, 30 cm between rows, and 85 cm between double-rows obtaining the density of 6.9 plants/m^2. Each gully (containing 20 plants) was arranged in a completely randomized block design with three replications.

The nutrient solution (NS) was prepared with rainwater and $Ca(NO_3)_2$, KNO_3, NH_4NO_3, $MgSO_4$ $7H_2O$, KH_2PO_4 obtaining 143, 16, 46, 180, 108, 30, 39 mg•L^{-1} of NO_3-N, NH_4^--N, P, K^+, Ca^{2+}, Mg^{2+}, and S, respectively, and an electric conductivity (EC) of 1.1 dS·m^{-1}.

Minimum and ventilation temperature were set at 7/10°C (night/day) and 15°C, respectively. The average mean and maximum temperatures recorded during the trial were 13°C and 20°C, respectively. The greenhouse mean solar radiation increased gradually from 5 to 10.5 MJ·m^{-2} ·d^{-1} during the cycle (Fig. 1). Nutrient solution was renewed weekly and samples of fresh and residual NS were taken to assess uptake of NO_3^-, NH_4^+, K^+, Mg^{2+}, and Ca^{2+}. Water consumptions were calculated weighting the NS.

Leaf number and area, fresh and dry weight of two plants per experimental unit were measured at five sampling dates: 22, 29, 43 (for 'Mindoro' only), 50 (for 'Tibet' only), 57, and 64 DAT. At harvest (65 DAT), fresh and dry weight of whole and marketable heads were measured. Plant material was dried to a constant weight in a forced-draft oven at 65°C for the determination of head dry weight.

Dried samples, finely ground, were used for quantitative chemical analysis of K^+, Mg^{2+}, Ca^{2+}, NO_3^-, and total N. Inorganic anion and cation concentrations in plant material and in NS were determined according the procedure reported by Santamaria and Elia (1997). Total N was determined with Kjeldahl method (2300 Kjeltec Auto Analyser) with addition of salicylic acid for the recovery of NO_3-N. Relative growth rate (RGR) was calculated for each period between two sampling dates using dry mass (W) relative to times t_1 and t_2 according the formula: $(W_2-W_1)/[W_1\cdot(t_2-t_1)]$.

Data were subjected to SAS's (Cary, NC, USA) general linear model procedure (Sas Institute Inc., 1999). For growth analysis quadratic functions were fitted to the data.

RESULTS AND DISCUSSION

Plant Growth and Nutrient Content

During growth leaf area, leaf number, and dry weight increased quadratically in both cultivars (Fig. 2). In the last 20 days, plants produced 70% of total dry biomass and 60% of total leaf area, mainly due to leaf blade expansion more than leaf number increase (Fig. 2a and 2b). Lettuce is characterized by a fast growth in the last two-three weeks (Serio et al., 2001), especially under conditions of high irradiance and nutrient availability. In another study growth achieved 10 g fw per day under irradiance of 25 MJ·m^{-2}·d^{-1}, compared to 3 g fw per day under irradiance of 5 MJ·m^{-2}·d^{-1} (Gent, 2003). In our research, irradiance increased up to 10 MJ·m^{-2}·d^{-1}, on average, in the 20 days before harvest (Fig. 1). Dry matter content decreased for both cultivars during the crop (29 DAT 7.0 g·100 g^{-1} fw, on average). In 'Tibet' dry matter content declined lineary until to the harvest (5.1 g•100 g^{-1} f.w.), while in 'Mindoro' it decreased until 50 DAT and thereafter had a light increase (6.0 g•100 g^{-1} f.w.) (Fig. 2d).

The total N content increased up to 50 DAT for both cultivars (4.3 and 4.6 g•100 g^{-1} dw in 'Mindoro' and 'Tibet', respectively); thereafter it decreased in Mindoro (-14%) more markedly than in 'Tibet' (-6%) (Fig. 3a). 'Tibet' accumulated 16% more N than 'Mindoro' (Table. 1).

A similar variation of N concentration for lettuce grown with costant N level in the medium have been reported (Huett e Rose, 1989; Hett e Whyte, 1992; Burns *et al.,* 1997; Broadley *et al.*, 2000). The increase of N content, as well as of P, K, Ca, and Mg at the early phase of growth was associated to high relative growth rate (RGR) of shoot and young roots and to the high uptake efficiency of roots (Sorensen, 2000). According to the compartimentation theory, there are two distinct metabolic pools into the plant. The first one is rich of N and it is the site of the photosynthetic activity and physiologically active for growth; the second one is a structural pool rich of C derivates (structural and reserve compounds). During growth, the structural pool should become more consistent, therefore even if the dry biomass production rises, the N concentration decreases (Caloin e Yu, 1984; Adamowicz and Le Bot, 1999). Consequently, a positive and strong relation exists between N content and RGR during the late vegetative phase (Dapoigny et al., 1996; Broadley et al., 2000). In this study, RGR was high (more in 'Tibet' than in 'Mindoro') in the early phase when N content was increasing; thereafter RGR declined faster in 'Tibet' than in 'Mindoro' (Fig.4). Similarly the N content decreased (Fig. 3a).

Under the described environmental conditions, we can define a different N content associated to optimal growth of the two cultivars, even if they had a similar morphological and yield behavior (Table 1).

Genetic differences between the two cultivars regarding N metabolism may exist. Probably an early synthesis of structural and reserve compounds was activated in 'Mindoro' in competition with the metabolic pool. This hypothesis can be supported by the rapid leaf N diluition, the higher N use efficiency (NUE) (28.4 $g \cdot g^{-1}$ *vs* 25.4 $g \cdot g^{-1}$ in 'Tibet') (Fig. 5) and by the increase of dry matter concentration a week before harvest (Fig. 2d).

Similar variations with time were recorded for K^+, Ca^{2+}, and Mg^{2+} leaf content (Fig. 3). Especially 15 ('Tibet') and 22 days ('Mindoro') before harvest plants accumulated 8.0 and 6.8 $g \cdot 100\ g^{-1}$ d.w. of K^+, respectively. Then, K^+ content decreased by 15% in both cultivars (Fig. 3b).

'Tibet' had greater requirements for N and K than 'Mindoro' (Fig. 3). Potassium was twice than N content. Calcium and Mg content in marketable heads were not different between the cultivars (on average 0.7 and 0.2 $g \cdot 100\ g^{-1}$ dw) (Fig. 3).

Head mean nitrate content was rather low (1,622 $mg \cdot kg^{-1}$ fw) and the reduced N was 81% of total N (Table 1), though plants were grown at high and quite constant N level in NS (159 $mg \cdot L^{-1}$), with EC of 1.7 $dS \cdot m^{-1}$. Probably it was due to the high light availability. Lettuce nitrate content was moderate at high light intensity irrespective to the NS nitrate level. With the NS EC and ratio between and other mineral nutrients (Gent, 2003). At low light intensity, only plants grown at high NS EC (2 $dS \cdot m^{-1}$) had high nitrate level. However, nitrate:other nutrient ratio did not affect nitrate level in plants. These results confirmed the hypothesis, largely supported in literature, according to which nitrate ion works as an osmotic compound (Blom-Zandstra and Lampe, 1985) accumulating in vacuoles to keep water potential at more negative levels than the growing medium (Gent, 2003). At high light availability other osmotica replace nitrate (Steingröwer et al., 1986a,b).

Nutrient and Water Uptake

From 32 to 46 DAT, N and K uptake were quadruplicated up to 2.6 and 1.8 meq/plant, respectively. Subsequently, 'Mindoro' requirements were decreased by 20 (N) and 17% (K) (Fig. 6a), while daily uptake of the two elements in 'Tibet' were unchanged until harvest (Fig. 6b) confirming the results concerning the N and K^+ leaf content. A positive correlation between N and K uptake occurred (R^2=0.95 y=0.7161x+0.0712 for 'Tibet', and R^2=0.97 y=0.7x-0.0147 for 'Mindoro'). In terms of milligrams per plant, K^+ uptake was twice than N during the crop cycle (data not shown). The daily Ca^{2+} and Mg^{2+} uptake was on average 0.22 and 0.06 meq/plant. The ratio $K^+/(Ca^{2+}+Mg^{2+})$ increased exponentially until harvest from 1.5 to 8.2, on average in the two cultivars (data not shown).

Daily water consumption was similar for both cultivars. One month before harvest it almost triplicated compared to the previous period (from 76 to 214 mL/plant) (Fig. 7), due to the radiation and leaf area increase (Fig. 1 and 2b).

At the end of the experiment, total water consumption was 5.5 L/·plant, while WUE was 12.4 dw $g \cdot L^{-1}$ as average of the two cultivars. According to the water and nutrient removal patterns and the $K^+/(Ca^{2+}+Mg^{2+})$ ratio, it appears that during a specific phenological phase, plant nutrient uptake is mainly controlled by plant requirement and is not influenced exclusively by the plant transpiration flux.

CONCLUSIONS

To correctly schedule and manage fertigation in soilless cultivation, knowledge of actual plant demand is required. The phase of higher plant demand for both butterhead lettuce cultivars grown in greenhouse during spring time, started near 30 DAT and reached the maximum two weeks later.

Potassium is the main mineral element of lettuce. It accumulated two folds than N even if their uptake was strictly correlated. However, the concentration of these two elements decreased in both cultivars with the plant age.

Plants did not accumulated nutrients in excess. This is proved by the increase of the dry weight until the harvest together with a low nitrate content of heads.

To produce the same fresh and dry biomass, the cultivar Tibet removed and accumulated more N and K than ‘Mindoro’, especially during the last weeks of the crop cycle.

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Tables

Table 1. Cultivar, yield, nitrate, and nitrogen content of lettuce heads.

Cultivar	Fresh weigth	NO_3^-	Total N	Reduced N
	(g)	(mg/kg fw)	(g/100 g dw)	%
Mindoro	325	1.580	3,7	82
Tibet	354	1.664	4,3	80
Significance[1]	ns	ns	**	ns

[(1)] ns, ** Not significant and significant at P<0.01, respectivly.

Figures

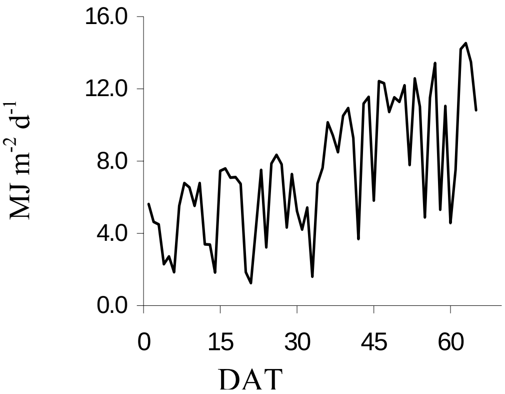

Fig. 1. Mean values of radiation in the greenhouse during the experiment.

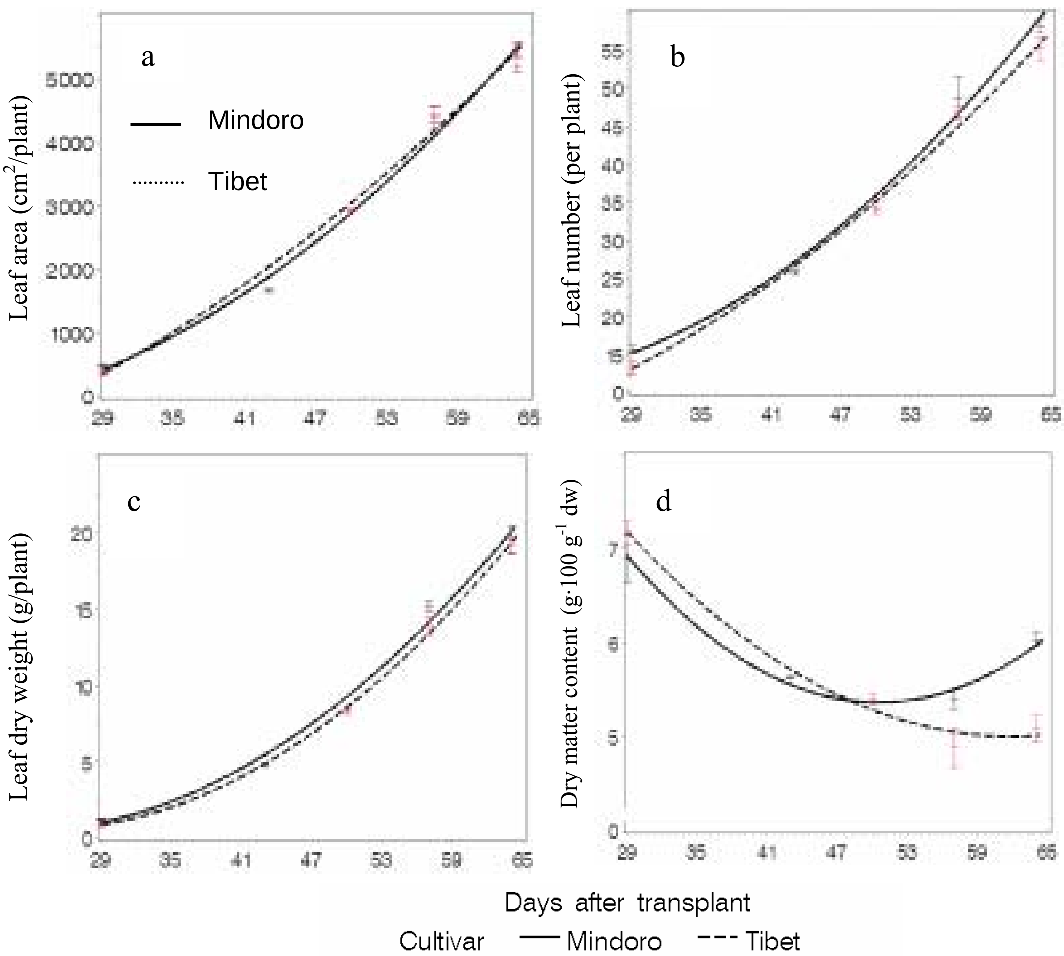

Fig. 2. Leaf area (a), leaf number (b), leaf dry weight (c), and leaf dry matter percentage (d) patterns during the experiment. Vertical lines indicate ±SE of mean (n=3).

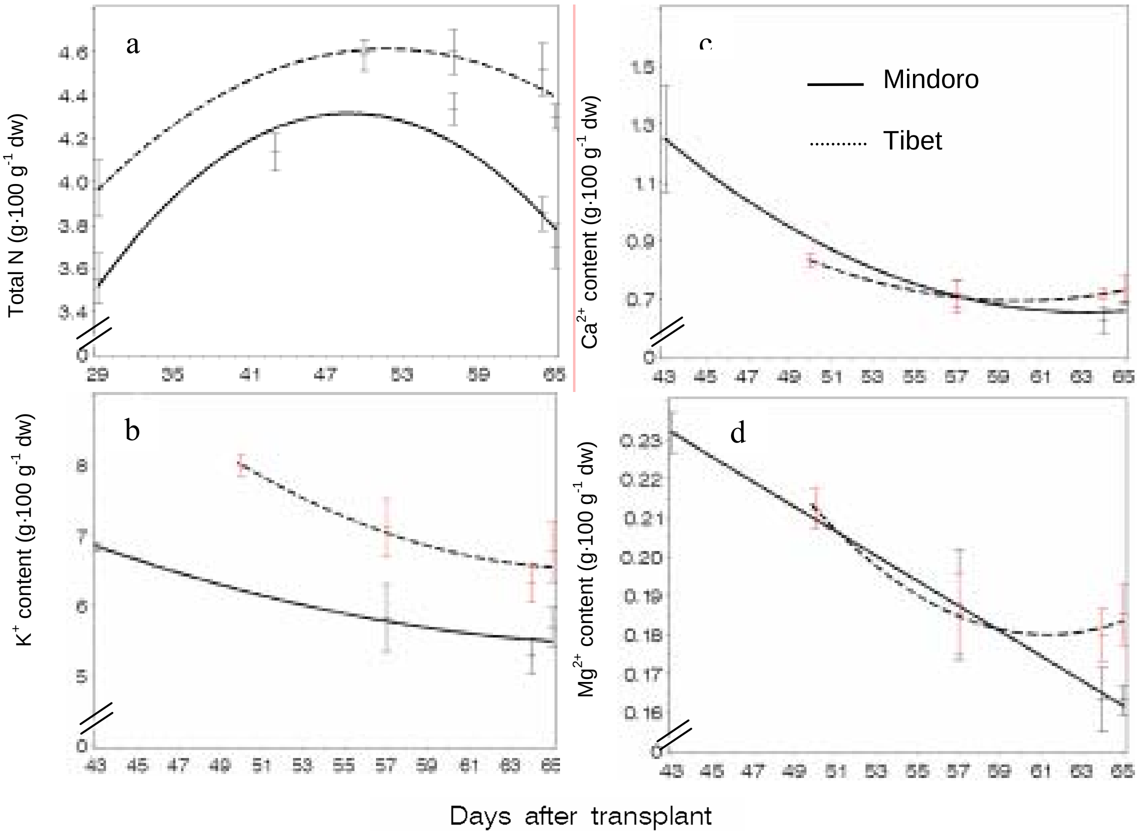

Fig. 3. Pattern of N (a), K^+ (b), Ca^{2+} (c), and Mg^{2+} (d) leaf content during the experiment. Vertical lines indicate ±SE of mean (n=3).

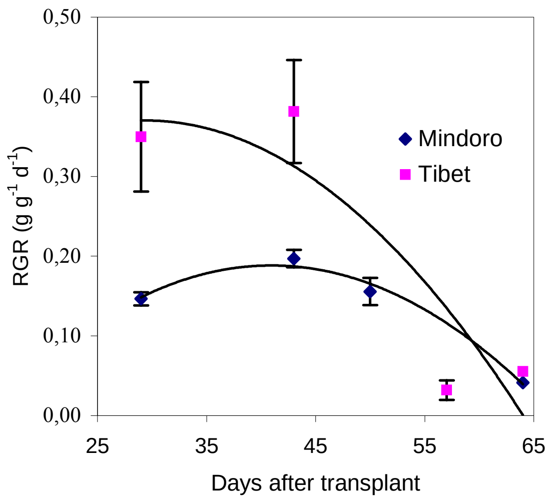

Fig. 4. Pattern of RGR during hte experiment. Vertical lines indicate ±SE of mean (n=3).

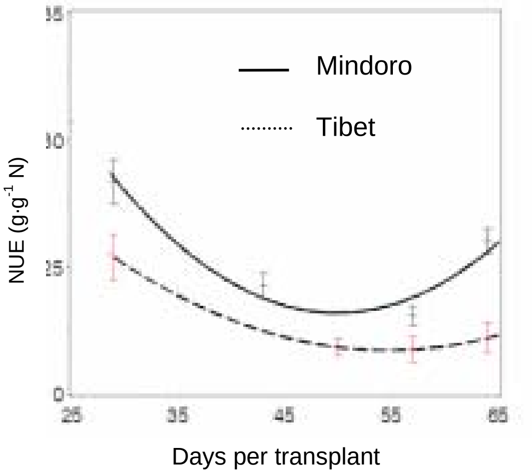

Fig. 5. Pattern of nitrogen use efficiency during the experiment. Vertical lines indicate ±SE of mean (n+3).

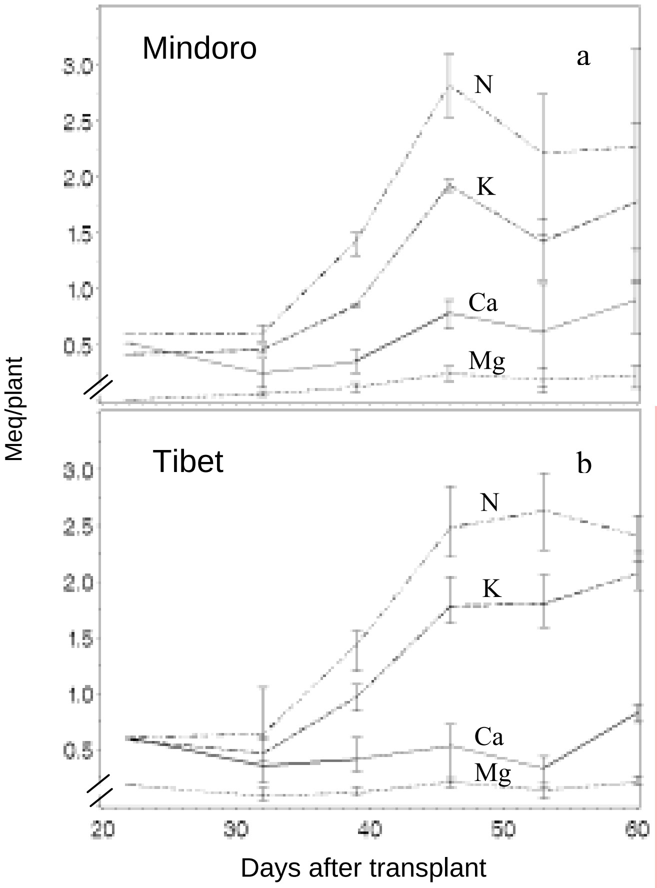

Fig. 6. Pattern of N, K^{+}, Ca^{2+}, and Mg^{2+} uptake during the experiment. Vertical lines indicate ±SE of mean (n=3).

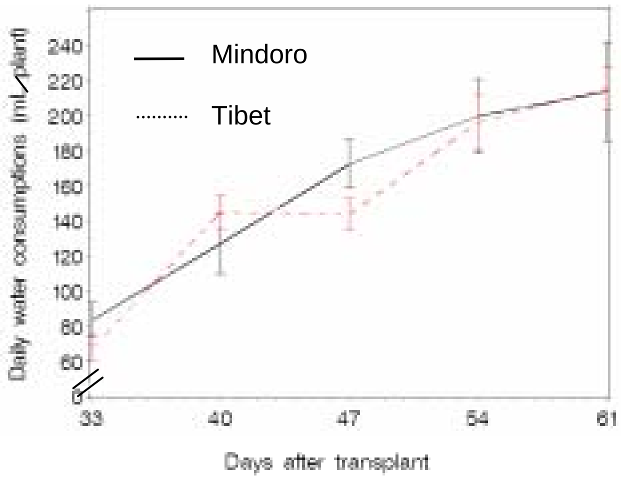

Fig. 7. Pattern of water consumption during the experiment. Vertical lines indicate ±SE of mean (n=3).