The Effect of Excessive Application of K₂O during Root Production on Plant Growth, Mineral Concentration and Yield of Edible Part in Witloof Chicory (*Cichorium intybus* L.)

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(Received October 6, 2016; Accepted July 7, 2017)

Under a high-K stressful condition in a greenhouse pot cultivation, the biomass production and the K absorption capacity of witloof chicory (*Cichorium intybus* L.) were compared with forage chicory. The root biomass of witloof chicory was greater than that of forage chicory among all treatments, indicating that witloof chicory has a certain level of tolerance against high K stressful conditions. As K₂O application increased, the biomass, in top and root, tended to decrease in both types, however, there was not a significant negative impact on the yield or quality of the obtained roots in witloof type at the treatments under 2,000 kg ha⁻¹ level. The K-uptake amount per plant of witloof chicory was 40% to 58% greater comparing forage chicory, at the K₂O treatments from 1,000 to 2,000 kg ha⁻¹. The quality of the etiolated heads, obtained after the forcing culture, could be kept at the same level of the commercially available fresh products when the K₂O application was lower than 2,000 kg ha⁻¹. Through this experiment, witloof chicory showed its potential to be utilized as a remedy for K accumulated soils, concurrently, obtaining an agricultural income from the forcing culture by using roots which absorbed K from soils.

Keywords : chicory, forcing culture, mineral concentration, potassium uptake, witloof

INTRODUCTION

Chicory (*Cichorium intybus* L.) is a common Asteraceae crop, originally developed in Mediterranean regions (Ryder, 1999). The genetic variation of this crop is relatively wider, presenting some unique types that are different from each other in appearance, utilization and chemical components (Lucchin et al., 2008). Examples of this diversity refer to: 1) witloof type; 2) Radicchio Type, forming a cabbage-like head in the open field, some subtypes in this category also need two different cultivation stages; 3) Pain de Sucre type, forming an elongated head resembling the Chinese Cabbage (*Brassica rapa* var. *pekinensis*); 4) Root type, bred for inulin extraction; and 5) Forage type, bred to be used as forage in grasslands (Rumball, 1986; Barry, 1998; Rumball et al., 2003).

The witloof chicory has a unique production cycle, which can be divided into two stages, namely root cultivation and forcing culture. The areas that are well suited for witloof root production are the cold and high-altitude regions where the roots are exposed to cold temperatures for maturation at later stages. Under such environment, photosynthesis products are smoothly transferred to the roots, which in turn will be able to produce new leaves under forcing culture. The chicon, an etiolated heads as an edible part of the witloof chicory, can be obtained from matured roots through the forcing culture. Usually, chicory plants

were grown over 120 d in the open field, from early summer to the beginning of winter. The forcing is normally conducted with a high-density planting of roots in enclosed spaces, under dark conditions with a temperature around 15°C and with high relative humidity (Sasaki, 1990).

Neel et al. (2002) reported that forage type chicory tends to accumulate quite a large amount of potassium to the plant body when grown under mineral-rich conditions. The authors emphasized growers' attention to consider the risks of the negative influence on animal health and performance if the K concentration in the plant body of forage chicory exceeds the maximum tolerable level of ruminants with considerable probability. There is a possibility to use forage chicory as the material for removing the extra K in the soil, not for the feed crops. However, reports on the potassium uptake capacity of witloof chicory is limited and detailed information is necessary for using witloof chicory as a K-scavenger.

The present study describes the efforts to examine the plant growth and K absorption capacity of witloof chicory and the change of soil chemical profiles during growing periods. The witloof type chicory was considered, comparing to forage type chicory, under K₂O rich conditions, growing with a modelled K₂O accumulated soils that were made by excessive application of chemical fertilizers. Experimental forcing cultures were also conducted in order to verify the influence of stress caused by K₂O rich conditions on the yield and quality of the edible part of witloof chicory.

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MATERIALS AND METHODS

Plant materials and seedling establishment

Witloof chicory 'Vintor' (Nunhems B.V., Nunhem, the Netherlands) (CH) and forage chicory 'Puna 2' (PGG Wrightson Seeds Ltd., Christchurch, New Zealand) (P2) were used. The seeds of these two materials were sown in paper pots (FS515; 5 cm diameter, 15 cm height, Nippon Beet Sugar Manufacturing Co., Ltd., Tokyo, Japan), and filled with potting soil mix (Pot Ace; Katakura Chikkarin Co., Ltd., Tokyo, Japan) on July 1, 2012.

Pot culture with extra K₂O concentration

The plant growth tests by pot culture were conducted in a plastic greenhouse at the Experimental Farm, Field Science Center for Northern Biosphere, Hokkaido University, Sapporo, Japan, in 2012. The seedlings were transplanted into plastic pots having 4 small holes in the bottom (30.5 cm height; 30.5 cm diameter, Chubu Nozai Co., Ltd., Aichi, Japan), containing approximately 20 L Andisol soil (chemical analysis results are shown on Table 1), on July 24, 2012. One seedling was transplanted into each pot. Five rates of K₂O chemical fertilizer, 0 mg per 100 g soil (K0, 0 kg ha⁻¹), 8.75 mg per 100 g soil (K200, 200 kg ha⁻¹), 44.1 mg per 100 g soil (K1,000, 1,000 kg ha⁻¹), 88.4 mg per 100 g soil (K2,000, 2,000 kg ha⁻¹) and 220.9 mg per 100 g soil (K5,000, 5,000 kg ha⁻¹) were applied by potassium sulphate (Hokuren Nogyo Kyodo Kumiai, Hokkaido, Japan), respectively. Hayashi et al. (2009) reported that the range of the K₂O concentration in intense cultivated greenhouses in Hokkaido was from 46.1 to 81.7 mg per 100 g soil. In fact, the range of soil K₂O concentrations at the start of cultivation was from 93.1 mg to 210.9 mg per 100 g soil, among K1,000 to K5,000. It is clear that the range of the initial level of K₂O concentration of the soil in this study is covering the range of K₂O concentration level in a practical situation. In every pot, 8.83 mg N per 100 g soil (200 kg N ha⁻¹), given as ammonium sulfate (JFE Chemical Corporation, Tokyo, Japan), and 4.4 mg per 100 g soil (100 kg P₂O₅ ha⁻¹) given as fused magnesium phosphate (Hinode Chemical Industry Co., Ltd., Kyoto, Japan), were added. A total of seven plants were prepared as replications for each treatment. The irrigation was conducted to avoid that drying of the soil surface in the pots, keeping pF between 1.6 to 2.3, measured by pF meter (DIK-8333, Daiki Rika Kogyo Co., Ltd., Saitama, Japan). A manual weed removal was performed to avoid the plant competition for nutritional absorption from the soil. The layout of the pot arrangement in a greenhouse was fully randomized. A temperature and relative humidity data logger (LR5001; Hioki E. E. Corporation, Nagano, Japan) was set in the center of the greenhouse, 1.5 m above the ground,

to record the hourly air temperature and relative humidity.

Throughout the growth period in pot culture, plant samples were collected twice, 9 weeks and 19 weeks after transplanting (WAT). Collected plant samples were separated into two parts, top and root. Plant samples were washed thoroughly with tap water to remove adhering particles from the potting soil mix. The soil in the pot was well-mixed and was sampled at each sampling and at the end of the cultivation, then sieved through a 2.0 mm mesh, and dried 2 weeks at room temperature without exposure to direct sunshine. All samples, both plants and soils, were kept in sealed plastic bags in a refrigerator at 4°C, until analysis. At each sampling timing during pot culture, plant samples were obtained from seven pots which were randomly selected. After measuring fresh weight of the sample plants, top and root separately, plants were dried in an air-circulating oven at 60°C for 2 weeks, and then the dry weight of plants was measured.

Forcing culture in witloof chicory

The roots of CH were harvested around 19 WAT after the pot culture. Collected plant samples were separated into two parts, i.e., top and root, and washed thoroughly with tap water to remove adhering particles from the potting soil mix. After measuring fresh weight (FW), Brix of roots and other growth parameters, roots were sorted and cut into 20 cm lengths (from root shoulder to the bottom end), and stored in a refrigerator, with air temperature from 0.2 to 0.8°C, and a relative humidity of 100%, until the start of the forcing culture. In each experiment, roots were transplanted into plastic containers (57.5 × 41.5 × 19.0 cm), which were filled with a medium normally used for nursery production (Takii Tanemaki Baido, Takii Co., Ltd., Japan). A total seven roots were planted as replications for each treatment and the plant density was 120 plants m⁻². The layout of the roots in each cultivation container was fully randomized. To obtain etiolated heads, roots were grown under dark conditions, with a temperature of 16°C in average, and a relative humidity of 100%, and the irrigation was periodically supplied. The fresh weight (before and after trimming), and the height, diameter and flower stalk length of etiolated heads were measured when those heads were harvested, 21 d after the starting of the forcing culture.

Mineral concentration analysis and potassium update amount per plant

At each sampling, from both pot culture and forcing culture, five dried plants were selected randomly from each treatment, and top and root parts were crashed and ground separately. For analysing the concentration of K, Ca, Mg and P, approximately 100 mg of samples were put into individual metal-free polypropylene tubes. In each tube with ground samples, 1.3 M of HNO₃ (20–50 mL) was added and samples were digested at 60°C for 1 to 2 h. The ob-

Table 1 Chemical profiles of the soil used for the present study.

Soil Type	pH (H ₂ O)	EC (mS m ⁻¹)	CEC (me/100 g)	Humus (%)	Phosphate Absorption Coefficient	NH ₄ -N NO ₃ -N P ₂ O ₅ K ₂ O MgO CaO					
						(mg 100 g ⁻¹)					
Andisols	6.60	9.00	12.05	3.60	880.0	0.60	0.63	7.64	1.50	5.46	81.03

tained solutions were filtered and diluted with 0.1 M HNO₃, and the mineral element concentrations were analysed by using ICP-AES (ICPE-9000, Shimadzu Corporation, Kyoto, Japan). By using the results of the mineral concentration analysis of plant dry matter, K-uptake amount per plant was calculated separately for both top and root parts. For analysing the concentration of C and N, approximately 10 mg of samples were put into the metal capsules, and the element concentration of plant dry matter was analysed by using NC-coder (Vario EL III, Elementar Analysensysteme GmbH, Hanau, Germany).

Soil chemical profile analysis

Dried soils and distilled water were mixed in a ratio of 1:2.5, and then pH was determined using a pH meter (Portable pH meter D-74, Horiba Co., Ltd., Kyoto, Japan). Dried soils and distilled water were mixed in a ratio of 1:5, and then electrical conductivity (EC) was determined using EC meter (DM-37, Takemura Denki Seisakusho Co., Ltd., Tokyo, Japan). Chemical profiles of soils, collected at each sampling, were analysed by the conventional method, using commercially available integrated colorimeter system for soil analysis (ZA-II, Fujihira Industry Co., Ltd., Tokyo, Japan). The concentration of K₂O in the soil was analysed by the Kalibor (Sodium tetraphenylborate) turbidimetric method.

Statistical analysis

Data obtained from each sampling time were statistically analysed, and significant differences of the mean values were calculated using Tukey-HSD test. For plant growth comparison, under both pot culture and forcing culture, and soil analysis, the values represent the mean of

seven replications. For plant dry matter mineral concentration analysis, the values represent the mean of five replications.

RESULTS

Temperature and relative humidity during pot culture

Recorded temperature and relative humidity were shown in Table 2. The results revealed that plants were exposed to a sub-zero temperature that promotes the translocation of carbohydrate substances from the top to the root after mid-November, a sufficiently low temperature exposure for CH root development even within the greenhouse.

Biomass production during pot culture

The maximum leaf lengths of CH and P2 at 19 WAT were 41.4 cm (K1,000) and 56.7 cm (K0), respectively. The dry weights of top and root tended to decrease corresponding to an increase of K₂O application in CH (Fig. 1). The root dry weights of CH were always heavier than those of P2 in all treatments at each K₂O treatment. At 19 WAT, the root dry weight of CH in K0 was the highest (86.5 g), followed by K200 (84.0 g), K1,000 (83.6 g), K2,000 (72.4 g) and K5,000 (48.2 g), and no significant difference was observed among treatments except K 5,000. However, a significant difference was not observed in the top dry weight of CH 19 WAT (K0; 33.9 g, K200; 28.5 g, K1,000; 31.6 g, K2,000; 25.2 g, and K5,000; 19.6 g). At 19 WAT, the top dry weight of P2 in K200 was the greatest among the treatments, however, there was a no significant difference among the treatments up to K1,000. The peak of the

Table 2 Profiles of temperature and humidity in greenhouse during pot cultivation.

Growing period		Temperature (°C)	Relative Humidity (%)
24 July, 2012–29 November, 2012	Average	18.2°C	83.0%
	Maximum	41.5°C	100.0%
	Minimum	−2.5°C	25.1%

Fig. 1 Effect of K₂O treatment on plant dry matter at 9 weeks and 19 weeks after transplant. Values represent a mean of 7 replications $\pm$ SE. Bars with different letters within the treatments are not same by Tukey's HSD test at $P < 0.05$, ns; not significance, WAT; Weeks after transplant.

root dry weight of P2 was observed in K0 (60.8 g), followed by K200 (56.9 g), K1,000 (37.9 g), K2,000 (31.9 g) and K5,000 (21.7 g), and it decreased linearly as the K₂O application amount was increased.

Mineral concentration on plant dry matter during pot culture

In both CH and P2, the K concentration, both of the top and root parts, increased as the K₂O application increased, and the difference in K concentration between the highest and the lowest in the tops was greater than that of the root part in each of the K₂O treatment at both 9 WAT and 19 WAT (Table 3). In CH, top K concentrations in K5,000 were always the highest at two samplings: 11.7% at 9 WAT and 8.9% at 19 WAT, and those in the root part of CH were also observed in K5,000 (2.6% and 2.0%, respectively). In P2, the highest K concentrations in the top part at 9 WAT and 19 WAT were also observed in K5,000 (13.7%, 8.6%, respectively), and those in the root part of P2 were observed in K1,000 (2.9%) and K5,000 (1.9%), respectively.

The top and root parts' C concentrations in both CH and P2 at 9 WAT tended to decrease when K₂O application increased, however, the disparities of those at 19 WAT was decreased comparing that at 9 WAT. At 19 WAT, there were no significant differences in the N concentrations among the treatments in top and root parts of CH and in top part of P2 except root parts in P2. There were no significant differences among treatments with respect to the P

concentration in top part in CH at 9 WAT; however, significant differences were observed at 19 WAT among treatments, and the same trends were observed in the root part. For both top and root parts of CH, the P concentration tended to slightly decrease as K₂O application increased. There were no significant differences among treatments with respect to the P concentration in top and root part in P2 at each sampling. The concentrations of Ca and Mg in the top and root part of both CH and P2 tended to decrease as K₂O application increased, however: the disparities of root concentrations of Ca and Mg in both CH and P2 among treatments were smaller than those of tops.

K-absorption amount per plant

There were no significant differences in the top K-absorption amounts between CH and P2 at 19 WAT in all treatments, and the highest K-absorption amount (2.16 g plant⁻¹) was observed at K1,000 in CH, however, the highest K-absorption amount (2.09 g plant⁻¹) was observed at K5,000 in P2 (Table 4). In the root part, the highest K-absorption amount (1.76 g plant⁻¹) at 19 WAT was observed at K0 in CH, however, that was observed at K200 in P2 (0.67 g plant⁻¹). In the root part, CH roots showed larger K-absorption than P2 root in all K₂O treatments and significant differences at the 5% probability level were observed at all treatments.

Plant total amount of K-absorption in CH (19 WAT) were always greater than those of P2, except in K200, and the highest (3.58 g plant⁻¹) was recognized at K1,000, fol-

Table 3 Effect of K₂O treatment on chemical profiles of plant dry matter at 9 weeks and 19 weeks after transplant.

Plant Part	Crop	Sampling Timing	Treatments K ₂ O (kg ha ⁻¹)	Water Content (%)	% / Dry matter									
					K		C		N		P		Ca	
Top	VI	9WAT ^a	0	90.2±0.7	a ^b	6.5±0.4	c	37.1±0.2	a	2.79±0.08	a	0.29±0.03	a	2.24±0.17
			200	90.5±0.8	a	7.8±0.3	c	36.5±0.6	a	2.68±0.12	a	0.29±0.01	a	1.98±0.08
			1,000	93.4±0.9	a	9.3±0.2	b	35.0±0.7	ab	2.75±0.15	a	0.29±0.02	a	1.55±0.05
			2,000	91.6±1.2	a	9.9±0.4	b	35.1±0.3	ab	2.61±0.11	a	0.25±0.03	a	1.40±0.03
			5,000	92.1±1.2	a	11.7±0.2	a	33.5±0.6	b	2.67±0.11	a	0.21±0.02	a	1.21±0.11
		19WAT	0	82.4±1.2	a	4.4±0.6	c	41.2±0.1	a	0.74±0.06	a	0.18±0.01	a	2.23±0.29
			200	80.6±0.4	a	4.6±0.3	c	41.2±0.3	a	0.78±0.07	a	0.08±0.00	b	1.95±0.12
			1,000	83.3±0.4	a	6.8±0.3	b	40.1±0.3	b	1.00±0.05	a	0.14±0.02	a	1.40±0.06
			2,000	81.2±0.7	a	7.5±0.1	ab	40.8±0.2	ab	0.81±0.03	a	0.09±0.00	b	1.45±0.05
			5,000	82.2±0.8	a	8.9±0.5	a	40.4±0.3	ab	0.88±0.10	a	0.09±0.01	b	1.11±0.06
	P2	9WAT	0	91.7±0.6	b	6.4±0.2	c	41.7±0.3	a	0.96±0.10	a	0.29±0.04	a	1.97±0.06
			200	92.5±0.7	ab	8.0±0.6	c	39.9±0.7	ab	1.07±0.09	a	0.22±0.02	a	1.96±0.17
			1,000	92.9±0.3	ab	10.9±0.6	b	38.7±0.9	b	1.14±0.10	a	0.26±0.02	a	1.29±0.06
			2,000	93.0±0.4	ab	11.8±0.3	ab	38.1±0.4	b	1.33±0.10	a	0.20±0.02	a	1.33±0.05
			5,000	94.6±0.8	a	13.7±0.8	a	38.5±0.7	b	1.15±0.07	a	0.22±0.02	a	0.99±0.04
		19WAT	0	75.3±1.4	a	2.4±0.3	b	41.7±0.1	a	0.66±0.11	a	0.07±0.01	a	1.31±0.22
			200	74.8±0.8	a	3.9±0.5	b	41.7±0.1	a	0.69±0.10	a	0.10±0.02	a	1.72±0.23
			1,000	78.3±1.6	a	6.7±0.5	a	41.7±0.1	a	0.61±0.04	a	0.09±0.01	a	1.27±0.04
			2,000	79.0±1.0	a	8.3±0.4	a	41.4±0.1	a	0.73±0.06	a	0.11±0.02	a	1.21±0.06
			5,000	77.6±1.4	a	8.6±0.9	a	41.0±0.5	a	0.78±0.11	a	0.10±0.01	a	0.90±0.08
Root	VI	9WAT	0	78.2±0.8	a	1.9±0.2	b	37.0±0.3	a	3.48±0.21	a	0.18±0.02	a	0.24±0.01
			200	75.6±1.7	a	2.1±0.1	b	36.9±0.3	a	3.13±0.12	ab	0.16±0.01	a	0.24±0.01
			1,000	67.8±3.4	ab	2.2±0.1	ab	35.9±0.3	ab	3.20±0.09	ab	0.16±0.02	a	0.21±0.01
			2,000	70.3±1.4	ab	2.6±0.1	a	36.2±0.4	ab	2.89±0.24	ab	0.16±0.02	a	0.20±0.02
			5,000	56.6±6.2	b	2.6±0.1	a	35.2±0.2	b	2.56±0.12	b	0.12±0.01	a	0.17±0.01
		19WAT	0	73.4±0.6	a	1.8±0.1	a	40.6±0.1	a	0.78±0.06	a	0.19±0.02	a	0.19±0.01
			200	71.0±0.4	b	1.3±0.0	b	40.7±0.1	a	0.71±0.04	a	0.08±0.01	b	0.17±0.01
			1,000	73.2±0.4	a	1.7±0.1	ab	40.5±0.1	a	0.78±0.06	a	0.13±0.03	ab	0.16±0.01
			2,000	72.1±0.3	ab	1.9±0.1	a	40.6±0.1	a	0.73±0.09	a	0.09±0.01	b	0.15±0.01
			5,000	71.8±0.5	ab	2.0±0.1	a	40.7±0.1	a	0.73±0.04	a	0.09±0.01	b	0.13±0.00
	P2	9WAT	0	80.1±2.9	a	1.3±0.1	d	39.6±0.3	a	1.95±0.14	a	0.14±0.02	a	0.24±0.02
			200	77.2±2.9	a	1.7±0.2	cd	39.6±0.2	a	1.25±0.08	c	0.15±0.02	a	0.25±0.01
			1,000	79.6±1.4	a	2.9±0.2	a	38.9±0.2	ab	1.69±0.11	ab	0.18±0.05	a	0.32±0.02
			2,000	78.2±1.6	a	2.1±0.2	bc	38.7±0.2	ab	1.30±0.08	bc	0.14±0.01	a	0.22±0.01
			5,000	84.0±2.3	a	2.5±0.2	ab	37.8±0.3	b	1.17±0.03	c	0.11±0.01	a	0.20±0.01
		19WAT	0	62.6±6.3	a	1.0±0.1	b	41.5±0.1	a	0.97±0.10	a	0.09±0.02	a	0.17±0.01
			200	69.5±1.6	a	1.2±0.1	ab	41.8±0.1	a	0.55±0.05	b	0.11±0.02	a	0.18±0.01
			1,000	69.9±0.4	a	1.3±0.1	ab	40.4±0.9	a	0.64±0.14	ab	0.07±0.01	a	0.15±0.01
			2,000	71.4±0.7	a	1.6±0.1	ab	40.8±0.8	a	0.55±0.04	b	0.10±0.01	a	0.15±0.01
			5,000	72.6±0.6	a	1.9±0.4	a	41.1±0.5	a	0.51±0.06	b	0.09±0.02	a	0.15±0.02

^a WAT; Weeks after transplant

^b Values represent a mean of 5 replications ± SE. Values within a column with different letters are not same by Tukey's HSD test at $P < 0.05$.

Table 4 Effect of K₂O treatment on K absorption in chicory.

K ₂ O Application (kg/ha) ^z	Plant	K absorption amount ^y (g plant ⁻¹)		
		Top	Root	Plant Total
0	CH	1.49	1.76	3.24
	P2	0.94	0.61	1.55
	<i>t</i> test	ns	**	**
200	CH	1.32	1.08	2.41
	P2	1.81	0.67	2.47
	<i>t</i> test	ns	**	ns
1,000	CH	2.16	1.42	3.58
	P2	1.77	0.49	2.26
	<i>t</i> test	ns	**	*
2,000	CH	1.89	1.35	3.24
	P2	1.81	0.50	2.31
	<i>t</i> test	ns	**	ns
5,000	CH	1.74	0.95	2.69
	P2	2.09	0.41	2.50
	<i>t</i> test	ns	**	ns

^z Pots of 0, 200, 1,000, 2,000 and 5,000 were fertilized with 0, 200, 1,000, 2,000 and 5,000 kg K₂O ha⁻¹, respectively.

^y K Absorption amount=(K concentration on dry weight) × Dry weight.

^x **, * and ns; significance at *P*=0.01, 0.05 and non-significance by *t* test (*n*=7).

WAT; Weeks after transplant

lowed by K0 and K2,000, K5,000 and K200 (3.24 g plant⁻¹, 2.69 g plant⁻¹ and 2.41 g plant⁻¹, respectively). The plant total K-absorption of CH at 19 WAT in K1,000 and K2,000 (3.56 g plant⁻¹ and 3.24 g plant⁻¹, respectively) was about 58% and 40% greater than that of P2 (2.26 g plant⁻¹ and 2.31 g plant⁻¹, respectively).

Changes in soil chemical profile during pot cultivation

The EC decreased sharply in both CH and P2 after root production, mainly for the soils exposed to high K₂O treatments; the decreased ratio of P2 during 9 weeks cultivation was larger than that of CH at K5,000 (Fig. 2a). The trends of changes in pH were basically same between CH and P2, namely they tended to decrease at 9 WAT, and recovered to the level at the starting of the experiment or slightly decreased at 19 WAT (Fig. 2b).

K₂O concentrations in soils decreased after cultivation, especially in the high K₂O application, both in CH and P2 (Fig. 2c). At 9 WAT, in K5,000 (210.9 mg 100 g⁻¹ at transplant), the soil K₂O concentrations decreased to 94.7 mg 100 g⁻¹ in P2, lower than in CH (109.6 mg 100 g⁻¹). However, in K2,000 (131.4 mg 100 g⁻¹ at transplant), soil K₂O content in CH was lower (37.4 mg 100 g⁻¹) than that in P2 (83.1 mg 100 g⁻¹), and same trend was shown in K1,000 (93.9 mg 100 g⁻¹ at transplant) application. At 19 WAT, the soil K₂O concentration in CH pots decreased further. After cultivation, the soil K₂O concentration of all plants decreased to the level of the original soil, around 0.9 mg 100 g⁻¹, in K200. Even in K2,000 and K5,000, the K₂O concentration in the soil decreased at 28.7 mg 100 g⁻¹ (CH) and 59.5 mg 100 g⁻¹, respectively, in CH plant.

Forcing culture of witloof chicory

The root FW of plants grown from K0 to K2,000 were 253–295 g per plants; no significant difference was observed among treatments from K0 to K2,000, and these were larger than that in K5,000 (Table 5). The average FW of trimmed etiolated heads obtained after the forcing culture always exceeded 150 g, except for K5,000. The size of the etiolated heads obtained in all the treatments except K5,000 was at the same level of the commercial standard. No significant differences were observed among treatments in the average ratio of flower stalk (flower stalk length / height of etiolated head).

Mineral concentration in etiolated head

The K concentration in the dry matter of etiolated heads was observed in the range between 4.4–5.1% in the present study. There were no significant differences among treatments with the K concentration of etiolated heads based on dry matter (Table 6). The dry matter concentration of N, P, Ca and Mg in etiolated heads tended to decrease as the K₂O application amount increased, and K5,000 was always the lowest among the treatments. There were no significant differences among treatments with the C concentration of the dry matter of etiolated heads.

Fig. 2 Changes in chemical profiles of soils contained with 5 levels of potassium treatments. Values represent a mean of 7 replications $\pm$ SE. TP; Transplant. WAT; Weeks after transplant.

Table 5 Effect of K₂O treatment during root cultivation on growth parameters of roots and etiolated heads after forcing culture, in witloof chicory cv. Vintor. Roots were trimmed by cutting into 20 cm length.

Treatments K ₂ O (kg ha ⁻¹)		Roots (19 Weeks after transplant)						Etiolated heads											
								Before Trimming		After Trimming ^a									
		Fresh Weight (g plant ⁻¹)	Diameter (cm)	Brix.	Fresh Weight (g plant ⁻¹)	Fresh Weight (g plant ⁻¹)	Height (cm) (B)	Diameter (cm)	Flower Stalk Length (cm) (A)	Ratio: (A)/(B)									
K 0	0	290.7±31.6	a ^b	5.9±0.3	a	17.9±0.2	a	231.0±25.2	a	205.6±20.1	a	14.4±1.2	ab	6.9±0.3	a	4.7±0.2	a	0.35±0.06	a
K 200	200	255.9±39.7	a	5.4±0.3	a	19.6±0.3	b	190.9±33.2	ab	165.9±25.1	a	14.7±0.7	a	6.3±0.4	a	4.1±0.1	a	0.28±0.01	a
K 1,000	1,000	253.4±12.9	a	5.5±0.1	a	19.5±0.4	b	170.0±7.6	ab	154.9±6.3	a	14.8±0.4	a	6.4±0.2	a	4.0±0.3	a	0.27±0.02	a
K 2,000	2,000	295.4±39.7	a	5.8±0.2	a	19.7±0.4	b	198.3±42.0	ab	163.9±36.0	a	13.4±1.3	ab	6.6±1.1	a	3.9±0.3	a	0.30±0.02	a
K 5,000	5,000	120.3±7.7	b	4.2±0.2	b	19.8±0.5	b	96.0±8.6	b	86.9±8.1	b	11.0±0.4	b	4.8±0.2	a	2.7±0.2	b	0.25±0.01	a

^a Trimming: Removing outer leaves for marketing of etiolated heads.^b Values represent a mean of 7 replications ± SE. Values within a column with different letters are not same by Tukey's HSD test at $P < 0.05$.**Table 6** Effect of K₂O treatment on chemical profiles of etiolated head dry matter after forcing culture in witloof chicory cv. Vintor, at nine weeks after transplanting.

Treatments K ₂ O (kg ha ⁻¹)	Water Content (%)	%Dry matter												
		K		C		N		P		Ca		Mg		
0	94.5±0.2	a ^c	4.6±0.4	a	40.1±0.2	a	4.13±0.13	a	0.55±0.04	a	0.60±0.02	a	0.44±0.01	a
200	93.9±0.4	ab	4.6±0.3	a	40.5±0.2	a	4.09±0.12	a	0.50±0.05	a	0.57±0.04	ab	0.45±0.03	a
1,000	94.1±0.3	a	4.5±0.2	a	40.6±0.1	a	3.95±0.08	a	0.44±0.02	a	0.45±0.04	bc	0.38±0.03	a
2,000	94.2±0.5	a	5.2±0.3	a	40.5±0.2	a	3.94±0.13	a	0.49±0.04	ab	0.40±0.05	c	0.36±0.02	ab
5,000	92.5±0.5	b	4.4±0.2	a	40.4±0.2	a	3.19±0.15	b	0.34±0.01	b	0.21±0.02	d	0.27±0.01	b

^a Values represent a mean of 5 replications ± SE. Values within a column with different letters are not same by Tukey's HSD test at $P < 0.05$.

DISCUSSION

Effect of K₂O application on plant growth during pot cultivation

At 9 WAT, the top and root dry weights of CH decreased with the increase of K₂O application, but no significant differences were observed in top growth even with a greater K₂O application at 19 WAT (Fig. 1). The root dry weights of CH were kept at the same level from K0 to K2,000. Those result indicates that CH has the potential for growth under high-K₂O stressful conditions. In contrast, in P2, the top dry weights at 19 WAT were decreased significantly when the K₂O application amount exceed 1,000 kg ha⁻¹, and the root dry weight also decreased linearly according to the increase of K₂O application.

Through the present study, it must be recognized that there were large differences in the biomass production under high K stressful conditions, especially in the root part, between two different types of chicory crop, namely in the witloof type and the forage type (Fig. 1). Such results mentioned above are of great interest, because they indicate that the morphological differences, in the root structure, is one of the main reasons for the differences. In fact, witloof chicory forms a vertically long and straight taproot, while the forage chicory has a strongly branched, horizontally wider root. Theoretically, the surface area of the branched root system can be wider than that of the tap root system with a smooth straight shape. Cassan et al. (2008) suggested that the nitrogen use efficiency of witloof chicory during the root production could be genotype dependent. The authors also pointed out that further breeding effort may enlarge the genetic variability of the species for the nitrogen metabolism and it can expand the geographical adaptability of this crop. It remains a challenge for future research to investigate the relationship between morphological differences in root system and macronutrient

efficiencies in witloof chicory.

Effect of K₂O application on mineral concentration in plant dry matter

The K concentration in the dry matter was enormously higher than that of Ca and Mg in CH and P2 (Table 3). Inthichack et al. (2012) reported that Ca and Mg concentrations in plant dry matter of lettuce, celery and cabbage decreased as K concentration increased in plant body, by the application of several types of potassium sources. In the present study, it was observed that concentrations of Ca and Mg in the top dry matter of CH and P2 decreased significantly, both in 9 WAT and 19 WAT, when the K concentration in plant dry matter increased with the increase of K₂O application (Table 3). In roots of all plants used, Ca concentrations in plant dry matter decreased in almost all of the cases, as with the increase of K₂O application; however, the differences in Ca concentrations among treatments were smaller than those occurring in the top parts. From these facts, there is considerable support for the existence of validity a trade-off relationship among the accumulation of K, Ca and Mg in the top part of CH under high K stressful conditions as reported by Inthichack et al. (2012).

Effect of K₂O application on K-uptake of witloof chicory

In the present study, the K concentration in the dry matter of CH increased as K₂O application increased, especially for top parts, and a wide variation was recognized in top-K concentration among the treatments, ranging from 4.4% in K0 to 8.9% in K5,000.

It is well known that various kinds of plants consume large amounts of K under high K available environments, and K easily increases its concentration in the plant body to a luxurious level (Zörb et al., 2014). In this regard, CH (witloof chicory) is superior to P2 (forage chicory), especially for its top. The total amount of K-uptake per CH plant was the highest at K1,000, 3.58 g plant⁻¹, approx. 58.4% greater than that of P2 in the same treatment. In

other treatments, such ratios of total amount of K uptake in CH to GG were 40.2% in K2,000, 7.6% in K5,000 (Table 4).

Rengel and Damon (2008) suggested that increasing the surface area of contact between roots and soil is the key to improve K absorption capacity. K-efficient genotypes could have a relatively larger proportion of thin roots in the whole root system compared with K-inefficient genotypes. Lastly, the authors also suggested the importance of the quantity and of the structure of root hairs in contributing to the K uptake capacity, by the enlargement of root surface area.

Wang and Wu (2015) reported that i) the K utilization efficiency (KUE) of plants is highly dependent on the potassium acquisition capacity of the roots, ii) the KUE of the plants is dependent on the K transport and translocation capacity in plant tissues and organs. The authors emphasized the importance of optimizing the plant root architecture for improving KUE. They also pointed out that the larger root volume increases the root surface area, which may significantly enhance the nutrient absorption, and the keys for improvements of KUE are increasing the length and the density of lateral roots and root hairs.

Further research on broadening the morphological variations in root part of witloof chicory would be helpful to understand the reason for the differences in the K absorption capacity among two types, witloof and forage.

Effect of K₂O application on quality and mineral concentration of etiolated head of witloof chicory

The negative influence of an excessive application of potassium less than 2,000 kg ha⁻¹ (131.4 mg 100 g⁻¹ soil at transplant) during chicory root production on the FW of trimmed etiolated heads after forcing culture was not observed until the potassium application amount did not exceed. Also, no significant difference in flower stalk ratio (flower stalk length/ height of etiolated head) was observed among the treatments, even in the excessive potassium application, such as 2,000 kg ha⁻¹ application. From those facts, it was recognized that the marketable etiolated heads could be obtained from the roots grown in the field with a high potassium concentration, such as 2,000 kg-K ha⁻¹ application (131.4 mg 100 g⁻¹ soil), as the level of in the present study.

No significant difference in the K concentration in the etiolated head dry matter was observed among the treatments. Also, no significant differences in etiolated head dry matter concentration of N, C, P and Mg were observed among the treatments under K2,000. Although a significant difference in Ca concentration in etiolated head dry matter was observed among the treatments, the differences were not large, ranging, from 0.40% at K0 to 0.60% at K2,000. It is reasonable to suppose that a high K condition during root production does not have a strong negative influence on the mineral concentration in the etiolated heads obtained the forcing culture.

Ameziane et al. (1997) investigated the effect of the nitrate and phosphate nutrition on chicory tap root development and quality of etiolated heads. Based on the results of their experiments, they suggested the following points: i)

root production stage: the regulation of nitrogen during root production may have a large negative impacts on root growth, and the impacts of the phosphate regulation on root growth is very limited; ii) forcing stage: the negative effect of larger amount of both nitrogen and phosphate applications during root production on etiolated head yield and quality is large; however, the lack of phosphate during the root growth has strong positive effects on yield and quality of etiolated heads. The authors also emphasized that the outer leaves of etiolated heads tended to be open and twisted when the nutrition balance during the root production was broken.

In the present study, the author investigated the effects of excessive application of K₂O on both the root growth and quality and yield of the etiolated heads, however, the effects of combined excessive applications of several major fertilizer components on vegetative growth and edible parts' quality is still open discussion, and this remains as a matter to be discussed further for improvement of income level of witloof chicory cultivation which is aiming to reclaim the balance of mineral concentration in the soils.

The potential of witloof chicory as a cleaning crop

Thorup-Kristensen et al. (2003) mentioned that the effect of a catch crop can depend strongly on the species chosen. They also suggested some points to be considered when a species should be chosen as a catch crop, namely; i) the speed of the establishment and growth rate; ii) the rooting depth; iii) the kill date (incorporation date); iv) the fixing capacity of nutritional components; and v) the chemical component of the plant material (e.g. C/N ratio, lignin contents and contents of water-soluble compounds).

Through the experiments in the present study, it became clear that witloof chicory can be grown without any problems with sowing in spring, growing under a subarctic wet climate condition (Sapporo, Hokkaido, Japan). The K fixing capacity (=absorption capacity) in witloof chicory per plant was also conducted at the practical level in the experiments. However, the results of the detailed analysis related to the plant dry matter concentrations of major elements at the end of the pot experiments with an excessive K application clearly indicated that it is not preferable to use the plant dry matter, which can be obtained after cropping for K-removal from soils, as green manure because of the risks of health problems of livestock due to the high concentration of K these crops can then contain (Table 3). Despite this, still witloof chicory has numerous advantages as a winter cash crop in cold regions; it can also be used as a remedy for K accumulated soils.

CONCLUSION

A witloof chicory variety cv. Vintor, has the potential to be used as a remedy for K accumulated in soils, and its K-uptake capacity can be estimated 40% to 58% greater than that of forage type chicory that has large capacity to absorb extraordinary amount of K. The results from the present study proves clearly that marketable etiolated heads can also be obtained even when the witloof chicory (root production) is used as a remedy of potassium accumulated

in soils. More detailed research focusing on the performance of witloof chicory as a 'Cleaning Crop', in natural conditions such as a modelled salt-accumulated field in outdoor, is needed to develop an effective remedy for salt-accumulated agriculture fields.

ACKNOWLEDGEMENTS

We wish to thank Prof. S. Nicola, the University of Turin, Department of Agriculture, Forest and Food Science, Mr. T. Kawai and Mr. H. Nakano, technicians of the Field Science Center for Northern Biosphere, Hokkaido University, Mr. T. Yokota, Yokota Setsubi Co., Ltd., for their advices and generous technical assistance in crop cultivation and installation of the forcing culture system.

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