The Potassium Absorption Capacity of Witloof Chicory (Cichorium intybus L.) in Modelled Salt Accumulated Field Made by Excessive Application of Methane Fermentation Digested Slurry

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To evaluate the potential of witloof chicory (Cichorium intybus L.) (VI) as a remedy for K accumulated soils, the K absorption ability of VI under nutrient-rich condition were analysed together with forage type chicory and guinea grass (Panicum maximum Jacq.) (GG) by using modelled salt accumulated soils made by excessive application (733 t ha⁻¹ in 2 years total) of Methane Fermentation Digested Slurry (DS) of cow manure for 2 years. Comparing to the first year, the top biomass of VI in the second year was maintained at the same level and that of root were significantly increased (P<0.05) while the plant total biomass of GG was significantly decreased (P<0.05), and no significant differences were observed in plant total biomass of forage type chicory. The K-uptake amount per plant of VI was 37.6% larger than that of GG, and 73.8% larger than that of forage chicory at 5% level of significance. Through forcing culture experiment, influence of excessive DS application for two years was negligible on production of etiolated heads. In conclusion, the witloof chicory can be utilized for K removal from salt accumulated soils concurrently with deriving income through etiolated head production.

Keywords: chicory, forcing culture, guinea grass, methane fermentation digested slurry, potassium absorption

INTRODUCTION

The Methane Fermentation Digested Slurry (DS) contains sufficient nitrogen and other fertilizer components, thus several studies have been conducted on the development of practical techniques to use DS for horticultural productions (Möller and Müller, 2012; Endo, 2014). In practice, there are several studies for a more efficient use of DS as a fertilizer for realizing a sustainable production of various horticultural crops, such as tomato (Solanum lycopersicum L.), cabbage (Brassica oleracea L.), Komatsuna (Brassica rapa) and cucumber (Cucumis sativus L.) (Endo et al., 2002; Tokuda et al., 2010; Fujikawa and Nakamura, 2010; Yoshino et al., 2012).

On the other hand, it has been recognized that, in Japan, the problem of remanence and accumulation of fertilizer components in the soil is getting conspicuous, not only for indoor fields but also for open field horticultural production, being the cause of this problem an excessive use of fertilizers, both chemical and organic (Tanimoto, 1991). In particular, the organic fertilizers, such as compost and DS derived from livestock wastes, especially for cow manures, contain a high concentration of potassium among the three major plant macronutrients. This specific chemical constitution leads consequently to the potassium accumulation in the soils when we use it based on the required amount of nitrogen (Goto and Eguchi, 1997; Oyanagi et al., 2002). In order to make the best use of organic fertilizers for an efficient production of horticultural crops, it is necessary to develop practical solutions which can avoid potassium accumulation in the soils.

The accumulation of salts, including potassium, tends to break the balance of mineral absorption by crops. This may lead to a yield decreasing, a deterioration in quality and negative impacts to livestock animals such as grass tetany when used as a forage crop; consequently, the importance of effective solutions to evade salt accumulation in the soils has been recognized (Ito et al., 1981; Eguchi, 1993). The major techniques recently used for salt removal from salt accumulated soils are: 1) excessive irrigation or flooding, including dumping the snow into the field (Aragaki et al., 1986); 2) dilution of salts by removing surface soils, soil dressing and plowing to replace surface soil with subsoil; 3) organic matter application which aims to increase chemical, physical and biological soil buffering capacity (Ikeda et al., 1994); and 4) growing a “Cleaning Crop”, which has an excessive salt absorption capacity from the soils, e.g. grass for forage or green manure. The most common method with comparative ease is probably the flooding (excessive irrigation): However, it has been reported that this technique has several problems, such as impacts on the ground water quality by the leaching of nitrate nitrogen or sulphate ion (Yanagase et al., 2005). Furthermore, researches have clarified until now that this technique can lead to the emission of a large amount of ni-
torous oxide, well known as a greenhouse effect gas, as well as leaching nitrate nitrogen. Therefore, to develop effective and environmental-friendly solutions which can be substituted to the flooding is requested (Sadamatsu et al., 2008).

“Cleaning Crop” technique is recognized as one of the efficient solutions to remove salts from the soil without heavy negative environmental impacts to the crops. In other words, this is the method to remove accumulated salts in the soil by the strong absorption capacity of fertilizer components in the forage or green manure grass crops (Kimjo et al., 2007; Kondo et al., 2009; Maeda et al., 2012). Takezawa et al. (1991) reported the difference of nutrient value of grass crops which has potential to be used as the cleaning crop in greenhouse with an excessive application of K₂SO₄, CaCO₃ and MgSO₄, such as Guinea grass (Panicum maximum Jacq.), sorghum (Sorghum bicolor L. Moench), sudangrass (Sorghum × drummondii (Nees ex. Steud.) Millsp. & Chase) and Rhodes grass (Chloris gayana Kunth). However, it is clear that there is little income from the production of cleaning crops because of no cropping for cash crops, especially in greenhouse.

Chicory (Cichorium intybus L.) is a Asteraceae crop, common in wider areas in western, central and southern Europe, north Africa and some parts of Asian countries, originally developed in Mediterranean regions (Ryder, 1988). The genetic variation of this crop is relatively wider, with some unique types that varies in appearance, utilization and inherent chemical components (Lucchin et al., 2008). The witloof type chicory has been developed mainly in France, Belgium and The Netherlands from the 1980’s, and it also started be to introduced as premium European winter vegetable in Japan from the 1990’s (Sasaki, 1990). The forage type has been developed energetically from the 1980’s in New Zealand, and it will expand successfully as a new forage crop that can grow well under warm dry conditions (Rumball, 1986; Barry, 1998; Rumball et al., 2003).

Neel et al. (2002) reported that the forage type chicory clearly has the capacity to accumulate extraordinary high potassium concentrations under mineral-rich conditions, not just potassium. The authors presumed that probably chicory can be used as a remedy for salt accumulated soils, especially for potassium. If chicory could be used as a remedy for the potassium accumulated in soils, it may bring integral benefits to growers by the removal of K from such soils. Concurrently growers may obtain an agricultural income from the forcing culture by using roots that absorbed K from soils in the case the type used is witloof. Furthermore, possibly this technique can be considered as one of the effective solutions for the potassium accumulation problem caused by consecutive application of organic fertilizers such as DS and livestock manure composts.

There were two purposes in the present study. The first purpose was to clarify the potential of witloof chicory to be used as a cleaning crop, which can remediate the K accumulated in soils. The research described here was an effort to examine the growth, K absorption capacity, and the change of soil chemical profiles during growing periods of two types of chicories, witloof and forage, comparing the system to the typical cleaning crop, i.e., Guinea grass, in the modelled salt accumulated field that were made by an excessive application of DS. The second purpose of this study was to check the feasibility of etiolated heads production from the chicory roots obtained from the field with an excess application of DS.

**MATERIALS AND METHODS**

**Experimental fields**

Field experiments were conducted in the Experimental Farm, Field Science Center for Northern Biosphere, Hokkaido University, Sapporo, Japan (E141°20′N43°04′). **Methane Fermentation Digestion Slurry (DS) application**

The DS produced from the biogas plant for the treatment of daily cow waste in Hokkaido University was used, and its chemical profiles are shown in the Table 1. The DS was applied into the experiment field mentioned below once in the first year (the second week of June, 2013) and twice in the second year (the second week of June and the first week of July, 2014). The amount of application in the first year was 200 t ha⁻¹ and that in the second year was 533 t ha⁻¹, for a total applied amount in the two years of 733 t ha⁻¹ (Table 2). An injector of liquid fertilizer was used to prevent the runoff of the DS from the experimental plot (Fig. 1) (Iida et al., 2009). The estimated total applied amount for two years of N, P₂O₅ and K₂O were 2,216 kg ha⁻¹, 657 kg ha⁻¹ and 3,383 kg ha⁻¹, respectively. The av-

| Table 1 | Fertilizer components of digested slurry from the biogas plant in Hokkaido University (3 years average from 2006 until 2008). |
|---------|--------------------------------------------------|
| Fertilizer Components | TN | NH₄-N | P₂O₅ | K₂O | Water Content (%) | pH |
| Amount (mg/kg) | 3,023 | 1,700 | 896 | 4,615 | 94.8 | 7.5 |
| Concentration (%) | 0.30 | 0.17 | 0.09 | 0.46 |

| Table 2 | Estimated application amount by fertilizer component. |
|---------|--------------------------------------------------|
| Application Period | Total Amount (t/ha) | Application Amount (kg/ha) |
| | | TN | NH₄-N | P₂O₅ | K₂O |
| 1st Year | 200 | 605 | 340 | 179 | 923 |
| 2nd Year | 533 | 1,611 | 906 | 478 | 2,460 |
| Total | 733 | 2,216 | 1,246 | 657 | 3,383 |

156 (10) Environ. Control Biol.
average applied amount of total per year was approx. 1.100 kg ha⁻¹, and this was around 10 times higher than the conventional level for root production of witloof type chicory.

**Plant materials**

Witloof chicory ‘Vintor’ (Nunhems B.V., Nunhem, The Netherlands) (VI), forage chicory ‘Puna2’ (PGG Wrightson Seeds Ltd., Christchurch, New Zealand) (P2) and Guinea grass ‘Soil Clean’ (Snow Brand Seed Co., Ltd., Sapporo, Japan) (GG) were used. The seeds of these three species were sown directly by hand in the modelled K-accumulated soil by excessive application of DS, two weeks after the DS application. Manual thinning of extra seedlings was conducted three weeks after sowing. The plant density of these three crops was set at the same level (0.1 m × 0.45 m, 222,222 plants ha⁻¹) after the thinning. The field experiment was conducted for two cropping seasons: i) June 2013 to November 2013 and ii) June 2014 to November 2014. Four plots per each plant material, VI, P2, GG and no cropping (NC), with a plot without growing any plant were prepared, with a plot size of 5.0 m² (2.0 m × 2.5 m). The examinations were arranged with four replications.

**Experiment 1: K absorption from excessive DS applied field**

**Sample collection during the open field experiment**

Plant samples of each crop were collected three times, at 6, 12 and 18 weeks after sowing (WAS). Collected plant samples were separated into two parts, top and root shares, and each samples were washed thoroughly with tap water to remove adhering particles from the field. At each sampling, fresh weights of the top and root parts were measured separately by using 10 plant samples randomly selected from each plot. Samples were dried in an air-circulating oven at 60°C for 2 d, and then the dry weights were measured. The soil samples were collected from three different depths, 0.15 m, 0.3 m and 0.8 m from the surface, at the same time of plant sampling. An iron pipe, 50 mm in diameter, was inserted into soil for collecting soil samples from 0.3 m and 0.8 m depth, and all holes where the samples were collected were plugged carefully. Soil samples were collected from 5 different places in each plot and those were mixed to make one representative sample of each plot. The collected sample soils were sieved through a 2.0 mm mesh, and then dried 2 weeks at room temperature without exposure to direct sunshine. All samples, both plants and soils, were kept in sealed plastic bags within in refrigerator at 4°C, until analysis.

**Experiment 2: Yield and quality of etiolated leaves from the root grown at excessive DS applied field**

**Forcing culture in witloof chicory**

A forcing culture experiment was conducted to clarify the effect of excessive DS application during root production on the yield and quality of etiolated heads by comparing the roots that were grown under conventional condition (with a treatment of normal chemical fertilizer application, no excessive DS application). VI roots for Control were grown with conventional applications of chemical fertilizers (N−P₂O₅−K₂O=100 kg ha⁻¹−100 kg ha⁻¹−100 kg ha⁻¹). The cultivation period was similar to that in the plants produced in the field with an excess application of DS (Treatment (DS)). The plot size was 1.35 m², and the matured roots of both Control and Treatment (DS) were collected 140 d after sowing in the second season. Collected plant samples were separated into two parts, top and root shares, and washed thoroughly with tap water to remove adhering particles from the field. After the roots were sorted and cut into 0.2 m lengths (from root shoulder to the bottom end), the fresh weight (FW) and other growth parameters of both top and root parts were measured and stored in refrigerator, with air temperature of 0.2 to 0.8°C and a relative humidity of 100%, for 83 d until the start of the forcing culture. The experiment was conducted with four replications.

Roots were transplanted into plastic containers (575 × 415 × 190 mm) which were filled with a medium used for the nursery production (Takii Tanemaki Baido, Takii Co., Ltd., Kyoto, Japan). All collected roots from all replications were planted into the plastic containers with plant density of 84.0 plants per m². To obtain etiolated heads, roots were grown under dark conditions (15.9°C in average, 100% of relative humidity), with period irrigations. After the forcing culture, the etiolated heads were cut from the roots, and the outer leaves removed to obtain trimmed heads. The fresh weight (before and after trimming), height, diameter and flower stalk length of etiolated heads were measured at 22 d after starting the forcing culture.

**Mineral concentration analysis and potassium uptake amount per plant**

At each sampling in both field experiment and forcing culture, the obtained dried plant samples, top and root parts, were crashed and ground separately. For each experiment, samples of 10 plants that were collected from the same plot were mixed into one sample for mineral analysis. For analysing the concentration of K, Ca, Mg and P,
approximately 100 mg of samples were inserted into individual metal-free polypropylene tubes. 1.3 M HNO₃ (20–50 mL) was added to each tube, and tissues were digested at 60°C for 1 to 2 h. Obtained 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). Using the results of mineral concentration analysis of the plant dry matter, the K absorption amount per plant was calculated separately for both top and root parts.

Soil chemical profile analysis

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 major fertilizer components of soils that were 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 exchangeable K₂O of soils were analysed by the Sodium tetraphenylborate turbidimetric method.

Statistical analysis

Data obtained from each sampling were statistically analysed, and significant differences of the mean values were calculated using Tukey-HSD test and Welch’s t test. For the plant growth comparison, under both pot culture and forcing culture, and the soil analysis, the values represented the mean of seven replications. For the plant dry matter mineral concentration analysis, the values represented the mean of five replications.

RESULTS

Climate condition during field experiment

The summary of climate conditions (10 d average air temperature and 10 d total precipitations) during each experiment period are shown in Fig. 2: 3rd July, 2013 to 9th November, 2013, 13th June, 2014 to 8th November, 2014, including Long Term Average (LTA) (30 years; from 1984 to 2014) was shown in Fig. 2. The precipitation in the experiment periods, especially in August and September was considerably larger than the LTA.

Experiment 1; K absorption from excessive DS applied field

Biomass production during field experiments

The top dry matter of GG at the end of the field experiments (18 WAS), in both years was always greater than in the two types of chicories (Fig. 3). The top dry matter of GG at 18 WAS in the second year decreased approx. 50% comparing to that in the first year. However, no significant difference was found on root dry matter of GG at 18 WAS between the first year and the second year. In contrast, the root dry matter of VI at 18 WAS in the second year (28.3 g) was significantly larger than that in the first year (20.0 g) (P < 0.01). There were no significant differences in top dry matters at 12 WAS and 18 WAS in VI between the years of experiments. At each sampling and among the years of experiments, there were no significant differences on dry matter of top and root parts of P2 plant.

Mineral concentration on plant dry matter during field experiment

The results clearly showed that the K concentration of the two types of chicories in both top and root parts is sig-
CHICORY’S CAPACITY AS K-SCAVENGER

nificantly greater than that of GG at all samplings time throughout the experimental periods ($P < 0.05$) in the second year (Fig. 4 (a)). Similar tendency was obtained in the K concentration of the first year’s examination. At 18 WAS in the second year, the top dry matter K concentration in VI was the greatest (8.92%), 2.4 times higher than that of GG’s (3.74%) and 1.2 times higher than that of P2’s (7.27%). The root dry matter K content of GG was significantly smaller than that of the two types of chicories ($P < 0.05$), and this trend was also observed in the first year.

The top Ca concentrations of P2 tended to be the greatest at every sampling, except 12 WAS of the second year, and that of GG were always significantly smaller than that of two types of chicories ($P < 0.05$) (Fig. 4 (b)). The root dry matter Ca concentration of VI was significantly smaller than GG at 18 WAS in the second year ($P < 0.05$). The dry matter Mg concentration in both top and root parts of GG was significantly larger than that of VI and P2.
throughout the growing period in the second year \( (P < 0.05) \) (Fig. 4(c)). No significant differences on the top dry matter P concentrations were observed among plants at 18 WAS in the second year; in addition, there was no significant difference between VI and GG in the root dry matter P concentration at 18 WAS in the second year (Fig. 4(d)).

**K absorption amount per plant**

The estimation of the plant total K absorption amount of GG (3.96 g) in the first year was significantly greater than that of the two types of chicories (VI; 2.22 g, P2; 1.63 g) \( (P < 0.05) \). However, that of VI in the second year (2.87 g) was significantly greater than that of P2 (1.60 g) and GG (2.02 g) (Table 3). In the second year, the top K absorption amount of P2 (1.41 g) was significantly smaller than that of VI (2.20 g) and of GG (1.95 g) \( (P < 0.05) \). However, VI (0.58 g) had the greatest in root K absorption amount, and significant differences were observed comparing P2 (0.19 g) and GG (0.07 g) \( (P < 0.05) \).

**Soil chemical profile**

The chemical profile analysis results at the starting of the first year of experiment is shown in Table 4. With regard to the EC level during the field experiment, at the end of the first year, NC (26.4 mS m\(^{-1}\)) was significantly greater than VI (16.0 mS m\(^{-1}\)) and GG (16.4 mS m\(^{-1}\)) at 0.8 m depth. At the end of the second year, at 0.3 m depth and 0.8 m depth, the EC in NC were greater than the other treatments, although no significant differences were observed among them at 0.15 m depth (Fig. 5(a)).

The K-O concentrations of VI at the end of the first year of the experiment were significantly smaller than that of the NC in all layers (0.15 m, 0.3 m and 0.8 m) \( (P < 0.05) \), and only in VI (107.0 mg per 100 g soil) they were significantly smaller than in the NC at 0.15 m depth (83.7 mg per 100 g soil) \( (P < 0.05) \). However, at the end of the second year, no significant differences in all layers and, among treatments were found (Fig. 5(b)).

**Experiment 2: Yield and quality of etiolated leaves from the root grown at excessive DS applied field**

The number of leaves in Treatment (DS) was significantly larger than Control \( (P < 0.05) \) (Table 5). However, there was no significant difference in the top FW and root FW before starting the forcing culture between Treatment (DS) and Control. There was no significant difference in etiolated head FW before trimming between Control and Treatment (DS) (Table 6). However, the FW of trimmed etiolated heads in Control was significantly greater than that of Treatment (DS) \( (P < 0.05) \) and consequently the ratio of etiolated head FW after/before trimming in Control was significantly larger than that of Treatment (DS) \( (P < 0.01) \). Table 6 also reveals that there were no significant differences in size of etiolated heads, height and diameter, and core length among treatments.

**DISCUSSION**

**Effect of excessive application of DS on plant growth of witloof chicory**

No significant decreases in the plant total biomass comparing the end of the first year and the end of the second year was found between two types chicories. In addition, the root biomass of witloof type increased approx. 41.5% from the first year to the second year (1st year (18WAS): 20.0 g per plant; 2nd year (18 WAS): 28.3 g per plant) (Fig. 3). Such results are highly suggestive of hitherto the tolerance of two types of chicory, both witloof and forage types, against nutrient-rich conditions made by the excessive application of DS to the soils, more than 10 times higher than the normal application. Those facts can be interpreted as there is a fair chance for witloof chicory to obtain matured roots that can be utilized for forcing culture in nutrient-rich conditions which are made by an excessive continuous application of organic fertilizers.

Sergio et al. (2012) investigated the salinity tolerance of chicory. They found that chicory is able to germinate and grow further in saline conditions, and they suggested that this unique characteristic maybe highly relate to its antioxidative responses. Arshi et al. (2006) reported that a

### Table 3 K accumulation per plant in chicory and guinea grass.

| Year     | Crops | K Accumulation Amount* (g plant \(^{-1}\)) |
|----------|-------|------------------------------------------|
|          |       | Top | Root | Plant Total |
| First Year | VI     | 1.08 b | 0.42 a | 2.22 b |
|           | P2     | 1.46 b | 0.18 b | 1.63 b |
|           | GG     | 3.85 a | 0.11 b | 3.96 a |
| Second Year | VI     | 2.20 a | 0.58 a | 2.78 a |
|           | P2     | 1.41 b | 0.19 b | 1.60 b |
|           | GG     | 1.95 a | 0.07 c | 2.02 b |

* K accumulation amount = K concentration (%) \( \times \) Dry matter weight.  

† Different letters indicate significant differences among treatments by Tukey’s test \( (n=4) \) at 5% level.

‡ Sampling date: 9 Nov., 2013, 8 Nov., 2014

### Table 4 The soil chemical profiles before the starting of field experiments (25th May, 2013).

| Soil Type | Depth (m) | pH (H2O) | EC (mS m\(^{-1}\)) | Cation Exchange Capacity (me/100 g) | Humus (%) | Phosphate Absorption Coefficient | T-N (%) | T-C (%) | NH4-N (mg 100 g\(^{-1}\)) | NO3-N (mg 100 g\(^{-1}\)) | P2O5 (mg 100 g\(^{-1}\)) | K2O (mg 100 g\(^{-1}\)) | MgO (mg 100 g\(^{-1}\)) | CaO (mg 100 g\(^{-1}\)) |
|-----------|-----------|----------|-------------------|------------------------------------|-----------|--------------------------------|----------|---------|---------------------|---------------------|----------------|----------------|----------------|----------------|
| Andisols  | 0.15      | 5.72     | 10.6              | 22.7                               | 7.19      | 1004.8                         | 0.208    | 3.28    | 0.43                  | 1.26                | 130.5          | 76.6           | 36.2           | 302            |
|           | 0.3       | 5.76     | 8.6               | 24.8                               | 8.74      | 1087.0                         | 0.197    | 3.02    | 0.91                  | 0.83                | 123.0          | 63.9           | 38.8           | 363            |
|           | 0.8       | 6.10     | 5.8               | 16.4                               | 3.67      | 877.2                          | 0.073    | 0.44    | 0.25                  | 0.38                | 13.7           | 54.3           | 46.6           | 209            |
The transition of soil chemical profiles. The marks represent a mean of 4 replications ± SE. The symbol marks with different letters are not same by Tukey-HSD test at 5% level (ns; not significant). NC; Without growing any plants.

Table 5  Effect of excessive application of methane fermentation digested slurry on growth parameters of chicory roots (second year).

| Treatment       | Number of Leaves | Leaf Length (cm) | Top FW (g) | Diameter (cm) | FW (g) |
|-----------------|------------------|------------------|------------|---------------|--------|
| Control (Conventional) | 9.4 ± 0.4 *     | 55.3 ± 3.7       | 110.4 ± 21.1| 3.5 ± 0.1     | 128.1 ± 6.4 |
| Treatment (DS)     | 10.9 ± 0.3       | 60.4 ± 1.5       | 144.9 ± 8.7| 3.5 ± 0.1     | 111.2 ± 11.8|

* = indicate significant at P < 0.05, ns = not significant

Table 6  Effect of excessive application of methane fermentation digested slurry on yield and quality of etiolated heads.

| Treatment       | Before Trimming | After Trimming | Etiolated Head Quality Index |
|-----------------|-----------------|----------------|----------------------------|
|                 | Fresh Weight (g plant⁻¹) | Fresh Weight (g plant⁻¹) | Height (cm) | Diameter (cm) | Core Length (cm) | FW Ratio (After/Before Trimming) | Core Ratio (Length/Heighbt) (%) |
| Control (Conventional) | 211.5 ± 8.9 * | 193.6 ± 4.6 | 18.6 ± 0.5 | 6.5 ± 0.3 | 1.1 ± 0.2 | 0.88 ± 0.03 | 6.0 ± 1.0 |
| Treatment (DS)     | 176.8 ± 13.5    | 129.8 ± 21.2   | 18.7 ± 0.4  | 6.2 ± 0.3  | 1.1 ± 0.0  | 0.70 ± 0.07 | 5.7 ± 0.1  |

* = indicate significant at P < 0.01 and P < 0.05, respectively

Forcing period; 21 Feb., 2015–15 Mar., 2015 (22 d)
CaCl₂ application is probably able to reduce the negative effects of a NaCl application on plant growth of chicory. In the future, the mechanism of chicory’s tolerance against salinity or nutrient-rich conditions also needs to be discussed in more details.

**K absorption capacity of witloof chicory**

Throughout the present study, the total K absorption amount by VI plant under nutrient-rich condition was larger than that by GG, which is widely known as a practical solution for removing salts from salt accumulated soils (Table 3). At the end of the second season, the plant total K absorption amount of VI was approx. 37.6% larger than that of GG, and 73.8% larger than that of forage type chicory (P2). The estimated absorbed K amount of VI per ha in the second year (from 13th June to 8th November, 2014) was 617.8 t ha⁻¹ in the case of same planting density in VI and GG, and this was 37.6% larger than that of GG. Such results reveal that witloof chicory is a good candidate to absorb excessive K from K accumulated soils.

Neel et al. (2002) investigated the salinity stress tolerance of chicory, and reported that an increase of K:Ca ratio in the nutrient supply during root production may cause physiological disorders such as brown pith, hole pith and tip burn. Zamaniyan et al. (2012) reported that the relationship might be influenced by the morphological differences in the root system. Applying their approach in future studies would give better insights into the difference in the K absorption capacity among the two types of chıcories.

**The change of soil chemical profiles during the field experiment**

As it can be seen from Fig. 5(b), the soil K₂O concentration at the end of the first year in VI was the lowest among the treatment, and VI was also the only treatment that had significant differences from the NC both at 0.15 m and 0.3 m depths. Based on the fact that the K absorption amount per plant in VI was significantly greatest (P<0.05), it may be presumed that the soil K₂O concentration of VI at the end of the second year was also the lowest, even though significant differences in the soil K₂O concentration among treatments at the end of the second year was not observed. The seasonal total precipitation (from the first week of July to the first week of November) in the first year was 594.0 mm and that in the second year was 581.5 mm. These values are greater (28.4% and 25.6%, respectively) than those of the long term average (same period, 30 years; from 1984 to 2014) (Fig. 2). It is probably reasonable to suppose that the soil K₂O in the experiment field has been reduced by leaching caused by a relatively large precipitation during the experimental period.

**The effect of excessive DS application during root production on the yield and quality of etiolated head**

There were no significant differences in the top FW and root FW between Control and Treatment (DS) before the forcing culture (Table 5). Furthermore, there were no significant differences in the FW of etiolated heads, with the outer leaves, which were obtained after the forcing culture as shown in Table 6. However, the FW of trimmed etiolated heads, without outer leaves, differed significantly among treatments (P<0.05); FW in Control was approx. 41% greater than that in Treatment (DS) (Control; 183.6 g per plant, Treatment (DS); 129.8 g per plant).

The fresh weight of marketable etiolated heads is usually more than 120 g; the FW obtained in etiolated heads from the roots grown in the field with excessive DS application was recognized as marketable. However, an excessive application of DS in the root production stage (366.5 t ha⁻¹ in yearly average) has a significant effect on the quality of the etiolated head. After the forcing culture, the outer leaves of the etiolated head in Treatment (DS) were relatively opened and twisted, and sometimes they developed an internal tip burn (Fig. 6). Zamaniyan et al. (2012) reported that an increase of K:Ca ratio in the nutrient supply during root production may cause physiological disorders of the etiolated heads such as brown pith, hole pith and tip burn. In present study, in the VI plot, the K₂O concentra-

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Fig. 6  Forcing chamber with heat insulators and heat exchangers (Left), the Roots with etiolated heads at the end of forcing experiment (22 d after starting) (Center) and the etiolated heads after trimming, C; Control, T; Treatment (DS) (Right).
tions in the shallow layers of soils increased before the second season, however, that of CaO decreased 9.5–13.0% in 0.15 m and 0.3 m depth soil (Data not shown). Zamabiyam et al. (2012) also reported that there is a possibility to change the K:Ca ratio into unsuitable conditions. It is likely to say that the main reasons for the low marketable ratio and the low quality of etiolated head in Treatment (DS) are probably the increase of K:Ca ratio in the soils during the root production by an excessive DS application.

CONCLUSION

A major goal of this research has been to investigate the potential of witloof chicory to be used as a cleaning crop which can remediate the K accumulated in soils and concurrently to obtain agricultural incomes. The results from the present study demonstrated that: i) the witloof chicory has enough tolerance against nutrient-rich conditions, especially those of high K2O accumulations, caused by an excessive application of DS (733 t ha\(^{-1}\) in 2 years total); ii) the potential of witloof chicory in the K absorption from the K accumulated in soils is relatively high, and its K absorption capacity is approx. 37.6% larger than the existing cleaning crop Guinea grass; and iii) the negative impacts of nutrient-rich conditions during root production on the yield and quality of edible part (etiolated heads) were limited.

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