The effect of application of soy sauce cake on potato plants cultivated in a sandy dune field.

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Summary

Soy sauce cake, a waste product by a soy sauce production, contains a high concentration of protein, so it is a good material for animal feeds and fertilizers. However, soy sauce cake contains a high concentration of salt (NaCl), so the application of a high amount of soy sauce cake as a fertilizer may induce salt stress of the crops and salt accumulation in the field. In this report, we carried out the field experiment of potato plants with the application of soy sauce cake and desalted cake by washing with water.

One plot was 5.4 m^2 (0.9m × 6m), and 20 potato tubers were planted in one plot. In addition to the basal dressing of P, K, and lime fertilizers, the soil was mixed with 0, 5, 10, 15, or 20 (gN/m^2) of ammonium sulfate, or 10, 20, or 50 (gN/m^2) of soy sauce cake, desalted cake or poultry manure. Ammonium sulfate (10 gN/m^2) was added to the soy sauce cake, desalted cake and poultry manure treatments for supplementing fast-acting N fertilizer. The potato tubers (cv. Danshaku) were planted on 7 May 2001. Plants were harvested at the flowering stage (46 days after planting) and at harvest (96 days after planting). The harvested plants were washed, dried and ground into a powder, and the concentrations of N, P, K, Mg, Ca, Na were analyzed.

The N concentrations of soy sauce cake and desalted cake were about 42 mgN/gDW and equivalent to that in the poultry manure. However, the P, K, Ca, and Mg concentrations in soy sauce cake and the desalted cake was much lower than poultry manure, suggesting that the fertilizer effect of cake and DSC are fundamentally restricted to the N supply.

The different application rates of ammonium sulfate did not affect potato growth and the N, P, K, Mg concentrations, possibly due to the rapid leaching from sandy soil. On the other hand, increasing the application rates of soy sauce cake, desalted cake or poultry manure tended to increase the plant dry weight and tuber yield. However, the highest application rate (50 g/m^2) of soy sauce cake did not increase the dry weight at the flowering stage, possibly due to salt stress. Application of soy sauce cake, desalted cake, and poultry manure increased the N concentration in each part and nitrate concentration in petiole juice, so these organic matters were rapidly decomposed in the soil, and absorbed by the potato roots.

From the results obtained soy sauce cake or desalted cake are as efficient as poultry manure as N fertilizer, although a high dose of soy sauce cake needs caution not to give salt stress for the crops, or salt accumulation in soil.

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Key words : Soy sauce cake, Potato, Ferilizer, Field experiment, Nutrition concentration

Introduction

In the previous paper (Ohyama et al. 2020), we reported the pot experiment of lettuce plants with the application of dry powder of soy sauce cake and desalted soy sauce cake. The chemical composition of soy sauce cake indicated that the cake contains about 4% of N, 2.1% of P_2O_5, and 1.2% of K_2O respectively. By washing the cake, the P, K, and Mg concentrations were significantly decreased in the desalted cake, although N is not washed out. The Na was almost completely removed by washing.

Pot experiments using sandy dune field soil have been done for evaluating the effect of soy sauce cake on the growth of lettuce plants. In the first experiment, lettuce plant was grown with 0, 5, 25, 50, and 100 g of soy sauce cake, with 1-watering or 2-watering per day. The growth of the shoot and roots by 1-watering per day was increased by application of 5 g and 25 g of soy sauce cake but decreased with 50 g and 100 g of cake. The N concentrations and the nitrate concentrations of the shoot increased from 0 to 25 g of cake so the N may be provided by the decomposition of soy sauce cake. However, the concentration of Na was proportionally higher in the shoots to the application rate of soy sauce cake. It was 60 mg /g DW with 100 g cake was added. In the second experiment, a similar pot experiment was conducted to compare the application of 0, 5, 25, 50, and 100 g soy sauce cake or desalted soy sauce cake. We expected that the application of desalted soy sauce cake may be more effective than the original soy sauce cake due to the lack of a high concentration of salt. However, the growth of lettuce was more severely depressed by the addition of a large amount of desalted cake compared with the original cake. As the application rate of soy sauce cake increased, the water content in the surface soil increased. The poor growth of

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lettuce with desalted cake may be due to the excess water stress, which represses respiration and nutrient absorption of the roots.

In this report, we carried out a field experiment using potato cultivation. Potato (*Solanum tuberosum* L.) is a major crop world-wide and the productivity of current cultivars is strongly reduced at high soil salt levels (Jaarsma et al. 2013). Saline soils are abundant in semiarid and arid regions, where the amount of rainfall is insufficient for salt leaching (Marshiner, 2003). Salinity problems occur in nonirrigated lands, but they are critical in irrigated areas. About 33% of the irrigated land worldwide is affected by salinity (Marshiner, 2003). Levy et al. (1988) compare the response of several potato cultivars to salinity levels of up to 51.3 mM NaCl. All cultivar decreased tuber dry matter corresponding to the amount of NaCl applied.

Soils are considered saline when they contain soluble salts to interfere with the growth of most of crop species. According to the definition of the US Salinity Laboratory the saturation extract of a saline soil has an electrical conductivity (EC) grater than 4 dSm^{-1} (equivalent to about 40 mM NaCl) and an exchangeable sodium percentage (ESP) of less than 15. Saline soils with an ESP of greater than 15 are termed saline-alkali soil or saline-sodic soils.

Plant species differ in their growth to salinity. The growth of halophytes is optimum at relatively high levels of salts. However, most are glycophytes (nonhalophytes), which are sensitive to saline stress. The poor growth of plants under saline conditions may arise by three reasons. (1) Water deficit (drought stresss) arising from the low water potential of the rooting medium, (2) ion toxicity of Cl^- and Na^+, especially a high accumulation of Cl^- is more harmful than Na^+, (3) nutrient imbalance and calcium deficiency (Marshner, 2003).

MATERIALS AND METHODS

Chemical analysis of soy sauce cake

The sheet of soy sauce cake was supplied from a soy sauce factory in Niigata. The cake contained 28% of the water in the fresh material. The soy sauce cake was dried in a ventilation oven at 60 C for three days, then ground into fine powder by a vibration mill (Heiko Sample Mill TI-100). The poultry manure was purchased from a market and dried in a ventilation oven at 60 C for three days, then ground as above.

To remove salt from a large amount of soy sauce cake for applying in the field experiment, 40 L of water was added to about 10 kg of soy sauce cake sheet in a bucket, and the water was changed 3 times for 12 h. The desalted cake was dried at 60 C for 6 days, and ground by a vibration mill.

The 50 mg of the powder of soy sauce cake, desalted cake or poultry manure was digested by the Kjeldahl digestion method (Ohyama et al. 1991). The digested solution was filled up to 25 mL by water, then ammonium and phosphate concentrations in the diluted solution were determined colorimetrically by the indophenol method and ammonium molybdate method, respectively.

Table 1. Mineral concentration in soy sauce cake, desalted soy sauce cake and poultry manure.

mg/gDW

	N	P	K	Ca	Mg	Na
Soy sauce cake	41.5	3.3	3.7	4.6	0.9	49.2
Desalted cake	41.7	1.3	0.5	5.4	0.4	7.8
Poultry manure	42.2	60.1	29.1	102.1	10.2	5.2

The 50 mg of the powder of cake, desalinated cake, or poultry manure was digested by 0.5 mL of concentrated nitric acid (HNO_3) and 0.4 mL of perchloric acid ($HClO_3$) (Mizukoshi et al. 1994), and the concentrations of Na, K, Ca, and Mg were determined by an atomic absorption method (Hitachi Z-8200).

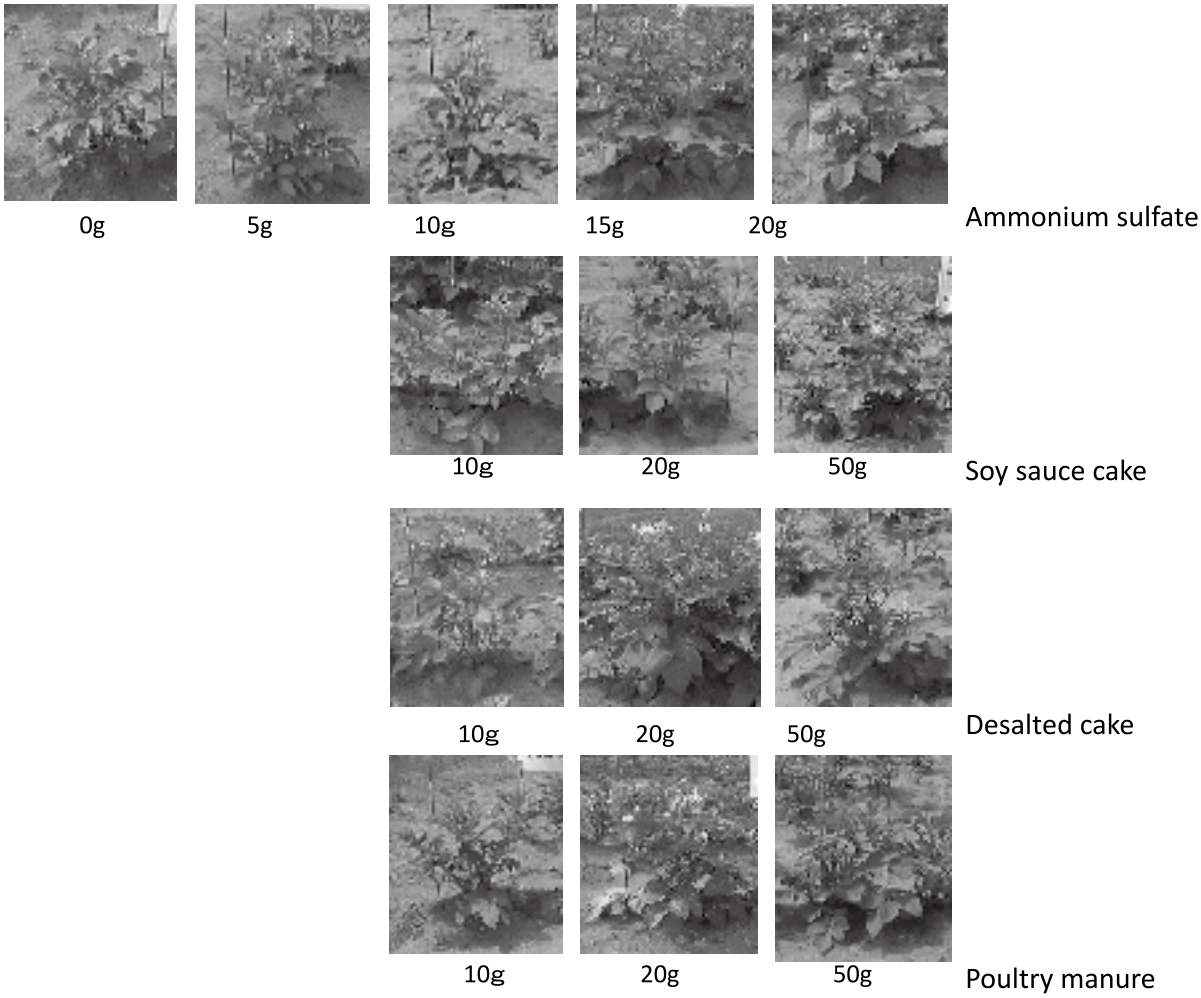
Field experiment for potato plants

The field experiment was conducted in the sandy dune field of the Faculty of Agriculture, Niigata University (37.8701°N/138.9438°E). One plot was 5.4 m^2 (0.9m × 6m) and 20 potato seed tubers with planting space at 30 cm were planted by single stem training. The planting density is 3700 plants/10a. Each treatment was repeated by 3 replications, and the plots were randomly placed. The basal dressing of fertilizers, superphosphate (25 g/m^2) and fused magnesium phosphate (25 g/m^2), potassium sulfate (9.9 g/m^2), and potassium silicate fertilizer (25 g/m^2) and lime (133 g/m^2) were mixed in the field. Mineral compositions in soy sauce cake, desalted cake and poultry manure were analyzed (Table1), and the soil in each plot was mixed with 0, 5, 10, 15, 20, or 25 (gN/m^2) of ammonium sulfate (AS), or 10, 20, or 50 (gN/m^2) of soy sauce cake, desalted cake or poultry manure (Table 2). Ammonium sulfate (10 gN/m^2) was added to the soy sauce cake, desalted cake and poultry manure treatments for supplementing fast-acting N fertilizer. The potato tubers (cv. Danshaku) were planted on 7 May 2001.

Four plants per a plot were sampled at flowering on 22th June (46 days after planting), and dried in a ventilation oven, and the dry weight of the shoot, roots and young tubers were measured and ground into a fine powder using a vibration mill (Heiko, Sample Mill TI-100). The fresh petioles were cut into pieces and juice was obtained by squeezing with a garlic press. The juice was diluted to 1/10 or 1/100 and the nitrate concentration was measured by RQ flex (Merck). The potato was harvested on 1st August (96 days after planting), and the potato tubers were dried in a ventilation oven. The dried plant powder was digested by the Kjeldahl digestion or HNO_3-$HClO_3$ digestion as mentioned before, and the concentrations of N, P, K, Ca, Mg, Na, and were determined.

Table 2. Fertilizer treatment design.

Treatment	Ammonium sulfate (gN/m^2)	Soy sauce cake (gN/m^2)	Desalted cake (gN/m^2)	Poultry manure (gN/m^2)
AS 0g	0	0	0	0
AS 5g	5	0	0	0
AS 10g	10	0	0	0
AS 15g	15	0	0	0
AS 20g	20	0	0	0
Cake 10g	10	10	0	0
Cake 20g	10	20	0	0
Cake 50g	10	50	0	0
DSC 10g	10	0	10	0
DSC 20g	10	0	20	0
DSC 50g	10	0	50	0
PM 10g	10	0	0	10
PM 20g	10	0	0	20
PM 50g	10	0	0	50



Photograph 1. Photographs of potato plants in the field with various fertilizer treatments at flowering stage.

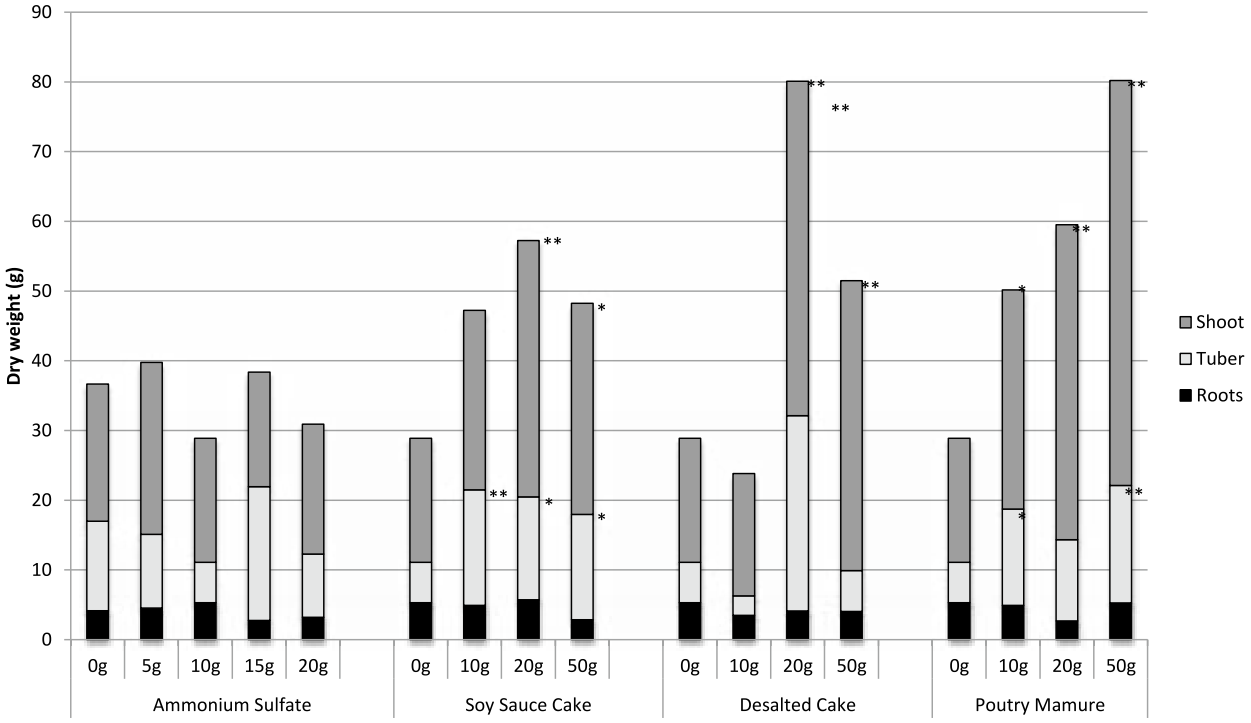


Figure 1. Dry weight of shoot, tubers, and roots of the potato plants at flowering stage supplied with various materials.
* (P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

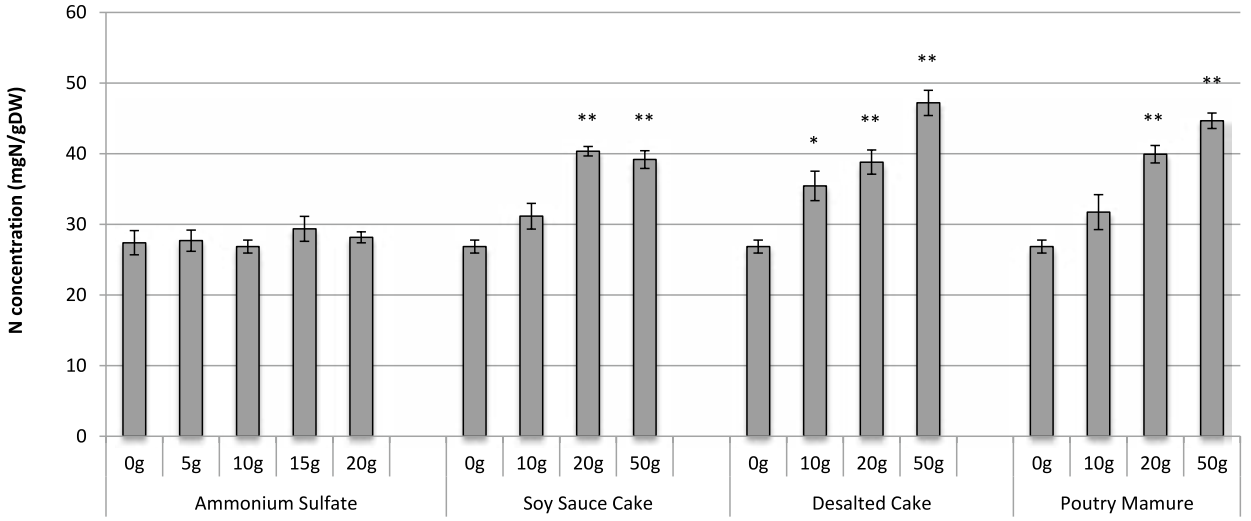


Figure 2. N concentration in shoot of potato plants at flowering stage.
* (P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

RESULTS AND DISCUSSION

Composition of soy sauce cake, desalted cake and poultry manure

Table 1 shows the concentrations of N, P, K, Ca, Mg and Na in soy sauce cake and desalted cake, and poultry manure used for the field experiment. The concentration of N in soy sauce cake was about 41.5 mg/gDW and almost the same in the desalted cake (41.7 mg/gDW). The N concentration in poultry manure is almost similar (42.2 mg/gDW) to those of Cake and DSC. The concentration of P, K, and Mg was decreased by washing in DSC compared with Case as same as previous analysis (Ohyama et al. 2020). The concentrations of P, K, Ca, Mg were much higher in poultry manure than in the soy sauce cake and desalted cake. The Na concentration was high (49.2 mg/gDW) in soy sauce cake. By washing soy sauce cake, the Na concentration decreased to 7.8 mg/gDW. In this case the Na concentration was higher than the

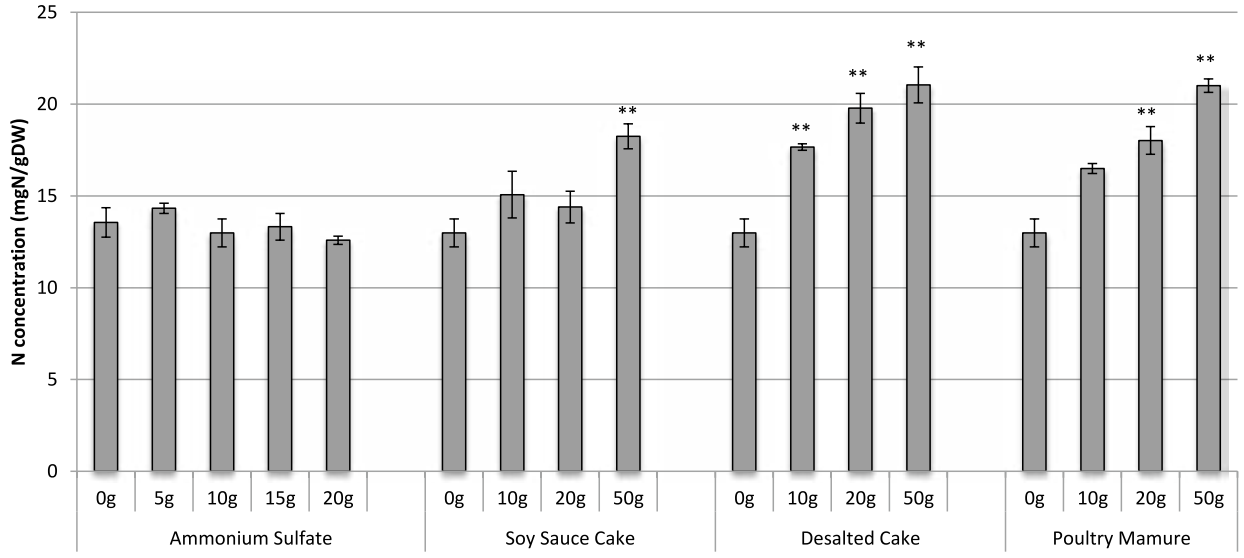


Figure 3. N concentration in roots of potato plants at flowering stage.
* (P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

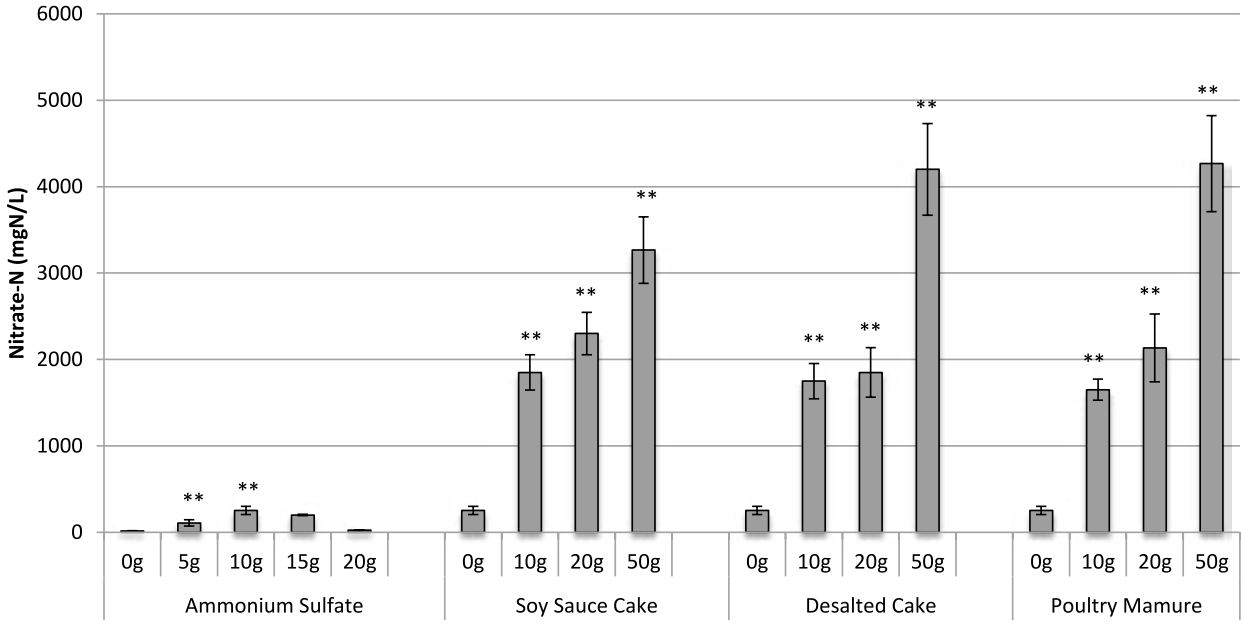


Figure 4. Nitrate concentration in juice from pressed petiole at flowering stage.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

previous desalted cake (0.6 mg/gDW) (Ohyama et al. 2020). This is incomplete washing for treating a large amount of cake that is washed for the field experiment. However, the Na concentration in desalted cake was almost the same as poultry manure (5.2 mg/gDW), and much reduced by washing compared with the original soy sauce cake.

The growth of potato plants

Photo 1 shows photographs of a potato plant in each treatment. The growth of plants with ammonium sulfate treatment from 0 to 20 g/m^2 appeared to be similar irrespective of the amount of N fertilizer applied. The application of 50 g or 20 g of soy sauce cake, desalted cake and poultry manure increased potato growth at flowering.

Figure 1 shows the dry weight of the shoot, roots and tubers of potato plants at flowering stage with various fertilizer treatments. The application of ammonium sulfate a fast-acting fertilizer did not promoted the plant growth for shoot, tubers, and roots. The experiment was done in the sandy dune field, so most fertilizer might be leached out before absorbed by potato roots. The application of 20 gN soy sauce cake + 10 gN ammonium sulfate resulted in higher DW

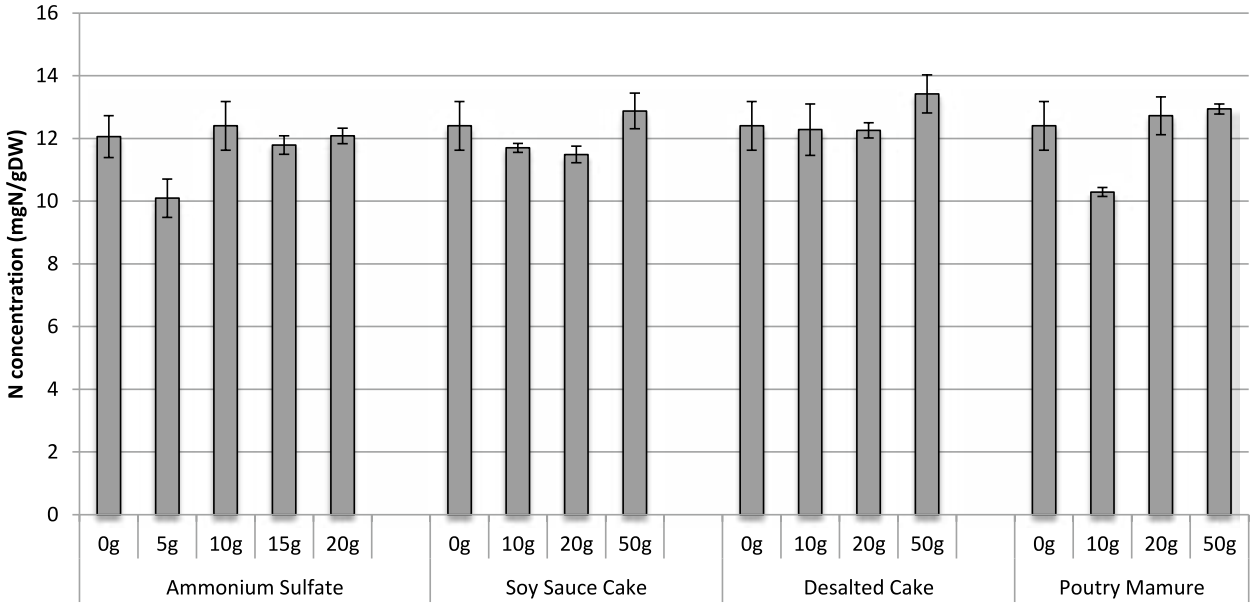


Figure 5. N concentration in tubers of potato plants at flowering stage.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

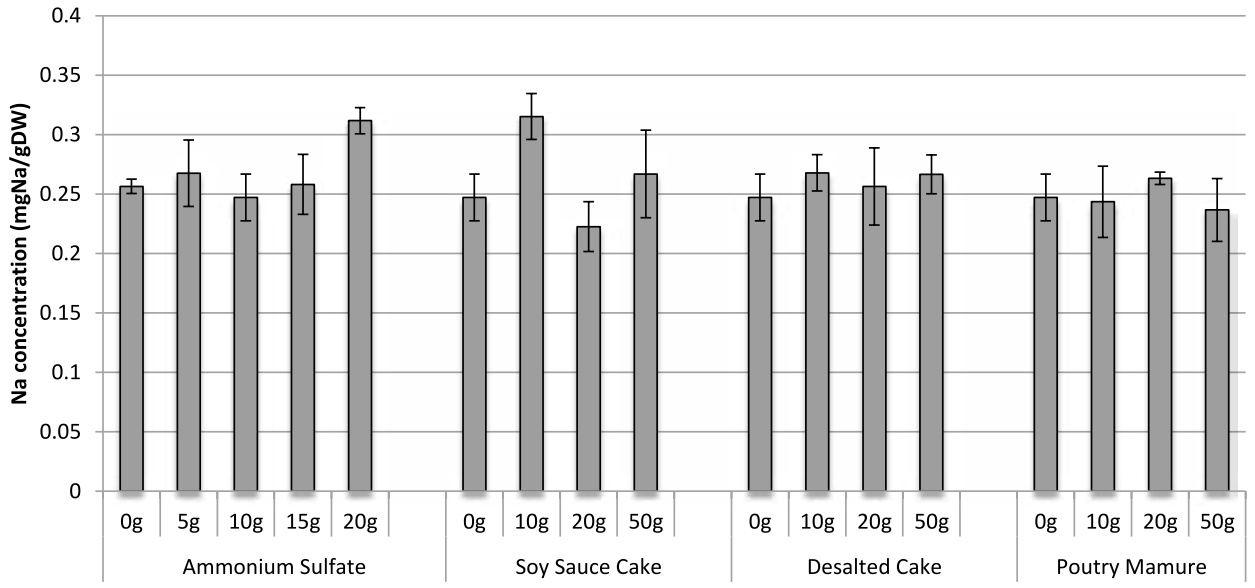


Figure 6. Na concentration in potato shoot at flowering stage.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

(58 g/plant) compared with 0 gN soy sauce cake (29 g/plant). The application of 20 gN of desalted cake gave much higher DW (80 g/plant). However, the application of 50 g of soy sauce cake or desalted cake decreased DW compared with 20 g applications. On the other hand, the application of poultry manure increased by the increasing rate from 0 to 50 g.

Figure 2 shows the N concentration in the shoot of a potato plant at the flowering stage. The N concentration was quite constant in ammonium sulfate treatments about 28 mg N/gDW. The application of soy sauce cake, desalted cake and poultry manure increased the N concentration in the shoot in correspondence with the application rate. At 20 g and 50 g application resulted in about 40 mgN/gDW.

Similar results were observed in the roots of the potato plants at harvest (Figure 3). N concentrations in the roots with ammonium sulfate were constant about 16 mgN/gDW and did not be changed by the application rates of ammonium sulfate. The application of soy sauce cake, desalted cake, and poultry manure increased the N concentrations in the roots

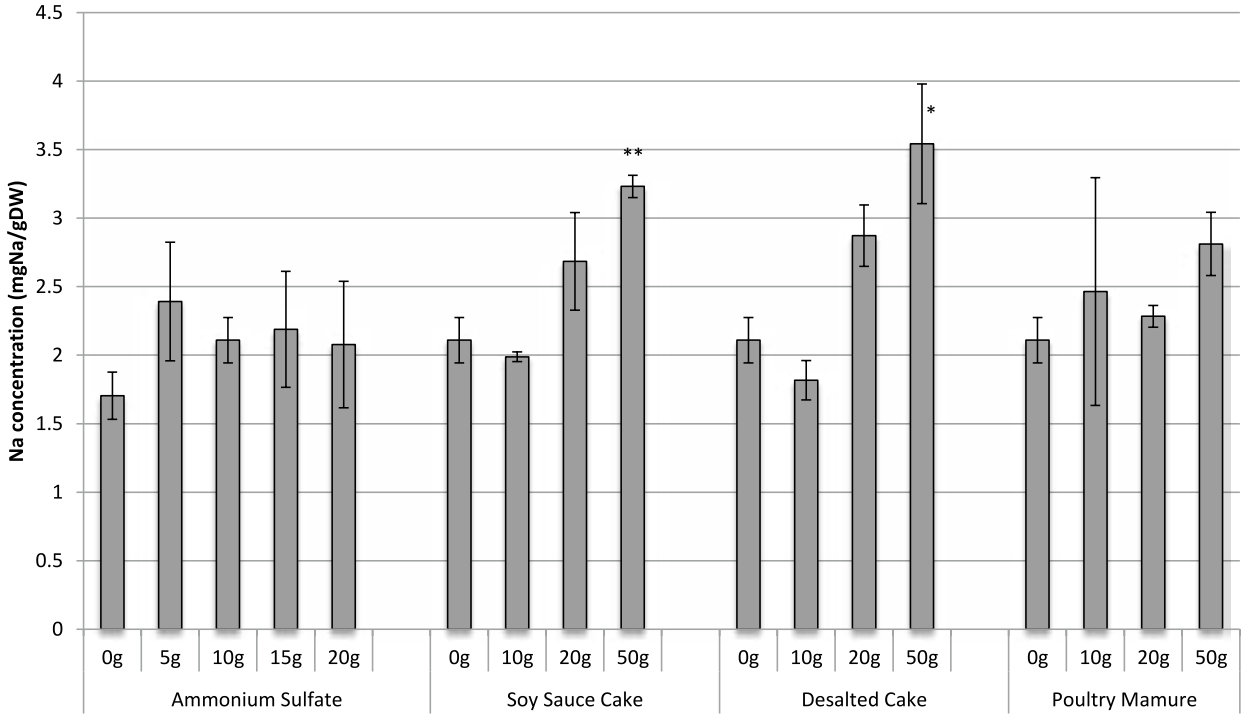


Figure 7. Na concentration in potato roots at flowering stage.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

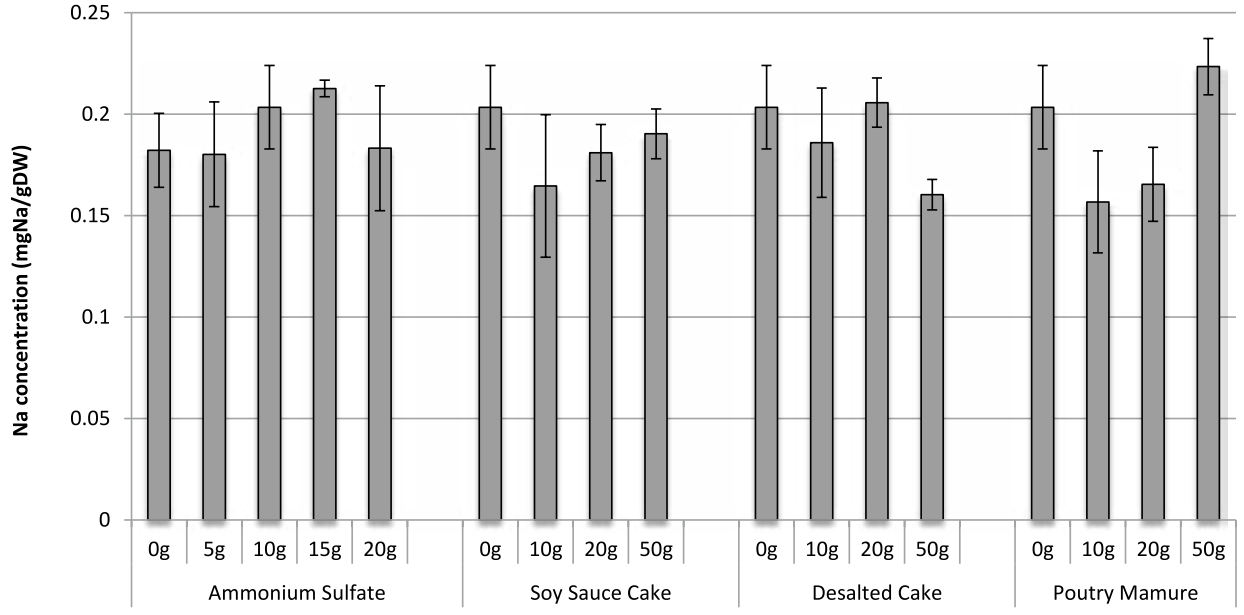


Figure 8. Na concentration in potato tubers at flowering stage.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

of potato plants in correspondence with the application rates.

Figure 4 shows the nitrate concentrations in petiole juice of potato plants at the flowering stage. The nitrate concentration was very low (less than 300 mgN/L) by the application of ammonium sulfate irrespective of the application rate. The application of soy sauce cake, desalted cake, and poultry manure significantly increased the nitrate concentrations. This supported that these organic matters are efficiently decomposed in the soil and it releases a large amount of nitrate to the potato plant to support the vigorous growth of the potato.

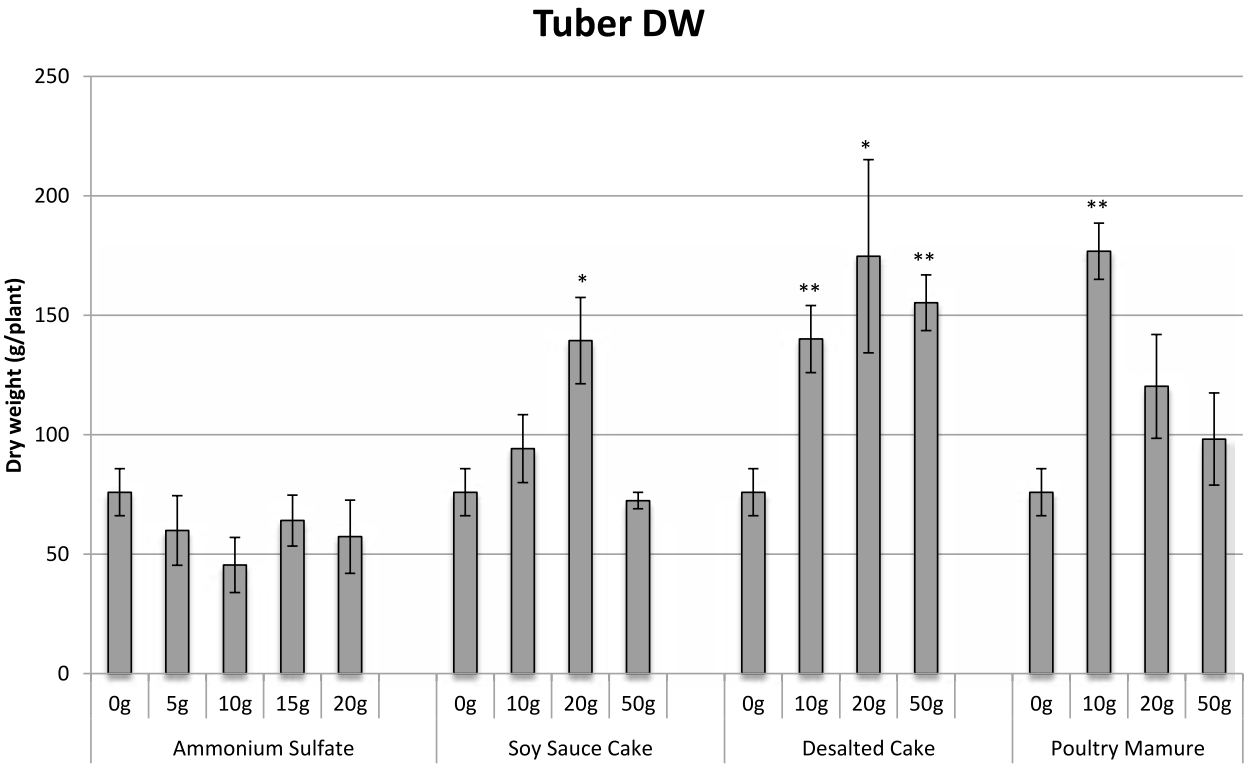


Figure 9. Dry weight of potato tubers at harvest.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

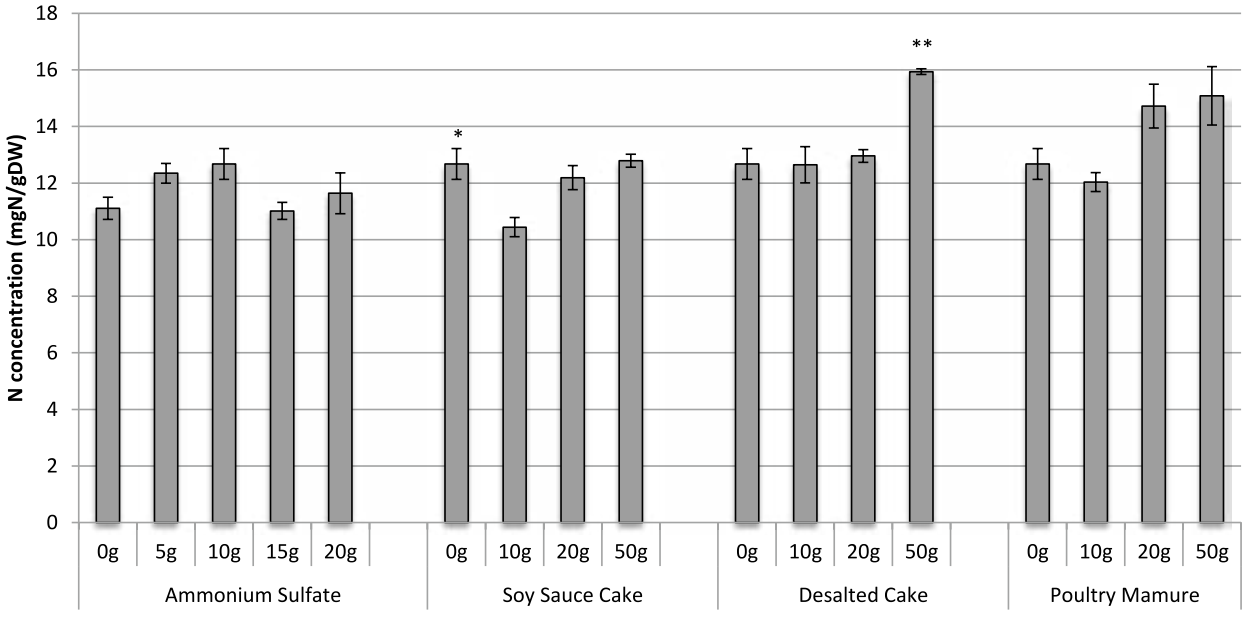


Figure 10. N concentration in tubers of potato plants at harvest stage.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

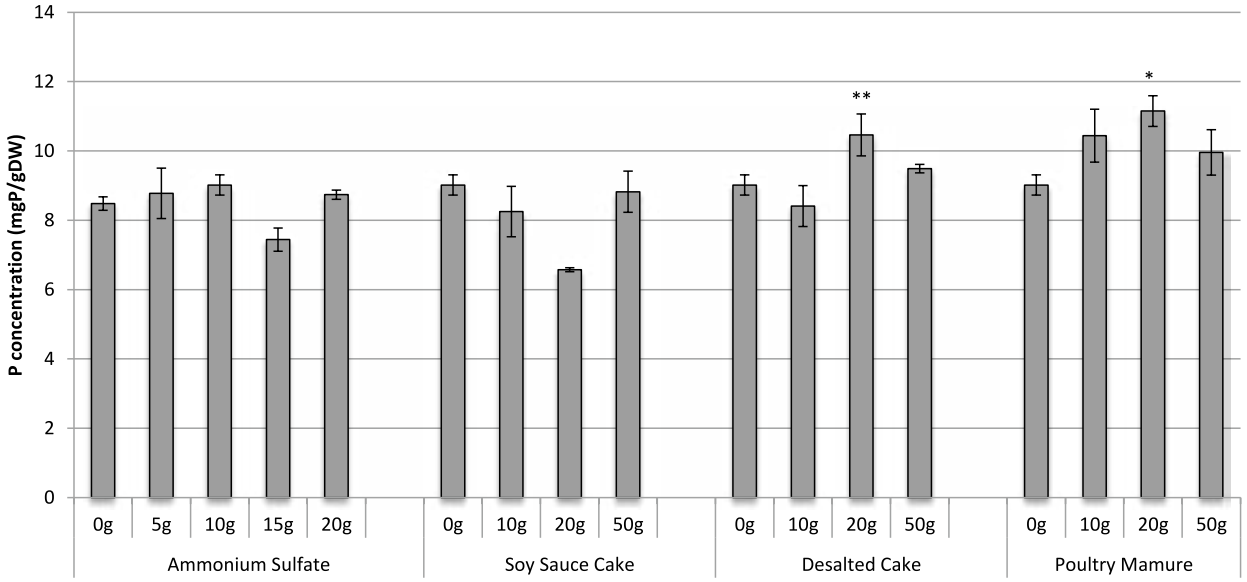


Figure 11. P concentration in tubers of potato plants at harvest stage.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

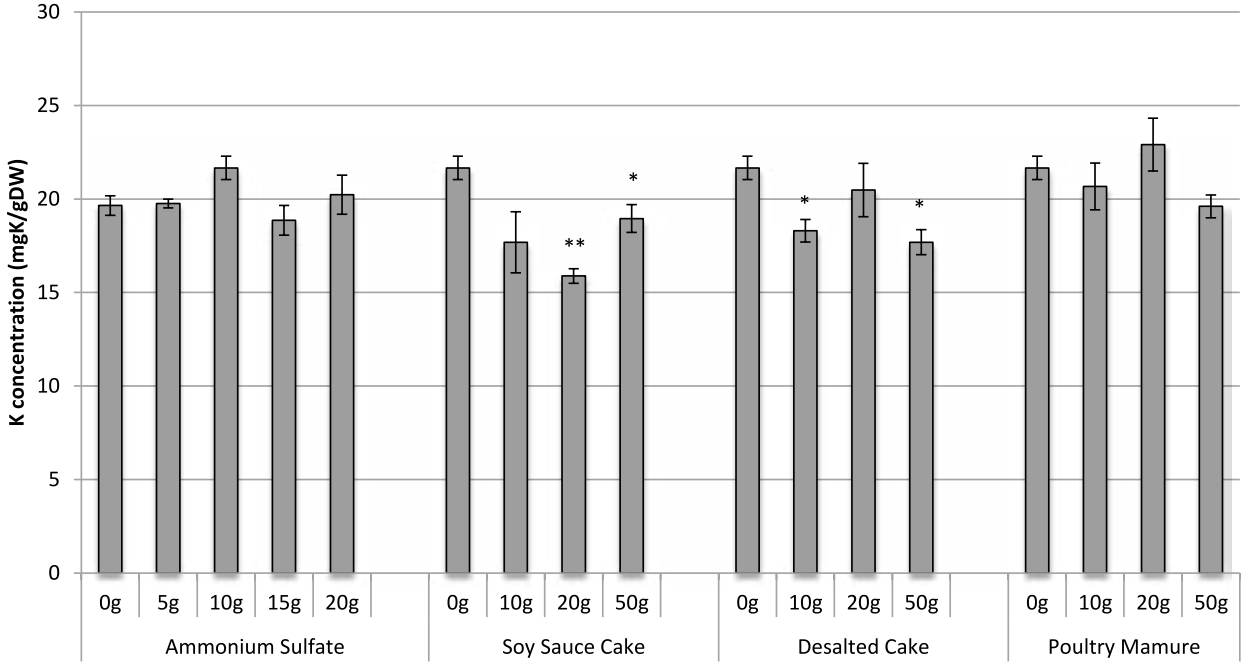


Figure 12. K concentration in tubers of potato plants at harvest stage.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

Different from the shoot and roots, the N concentrations in the tubers at the flowering stage were relatively constant among all treatment about 12 mgN/gDW (Figure 5). The tubers are sink organ and N concentration may be constant during the young stage.

The Na concentrations in the shoot were not affected by the application of soy sauce cake, which contains relatively a high concentration of NaCl (Figure 6). The average Na concentration in the shoot was about 0.25 mgNa/gDW. On the other hand, The average Na concentration in the roots was about 2-3 mgNa/gDW, about 10 times higher than the shoot (Figure 7). The Na concentration tended to increase by a high application of soy sauce canke and desalted cake. The Na concentration in the tubers at the flowering stage was constant about 0.2 mgNa/gDW among treatment and application rates (Figure 8).

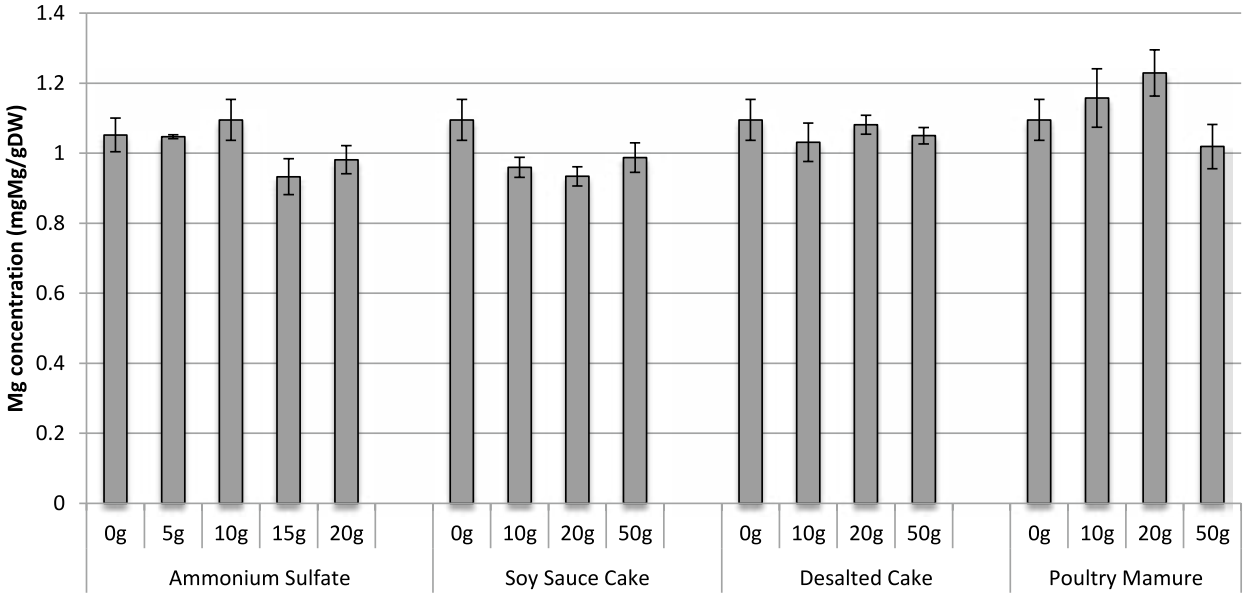


Figure 13. Mg concentration in tubers of potato plants at harvest stage.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

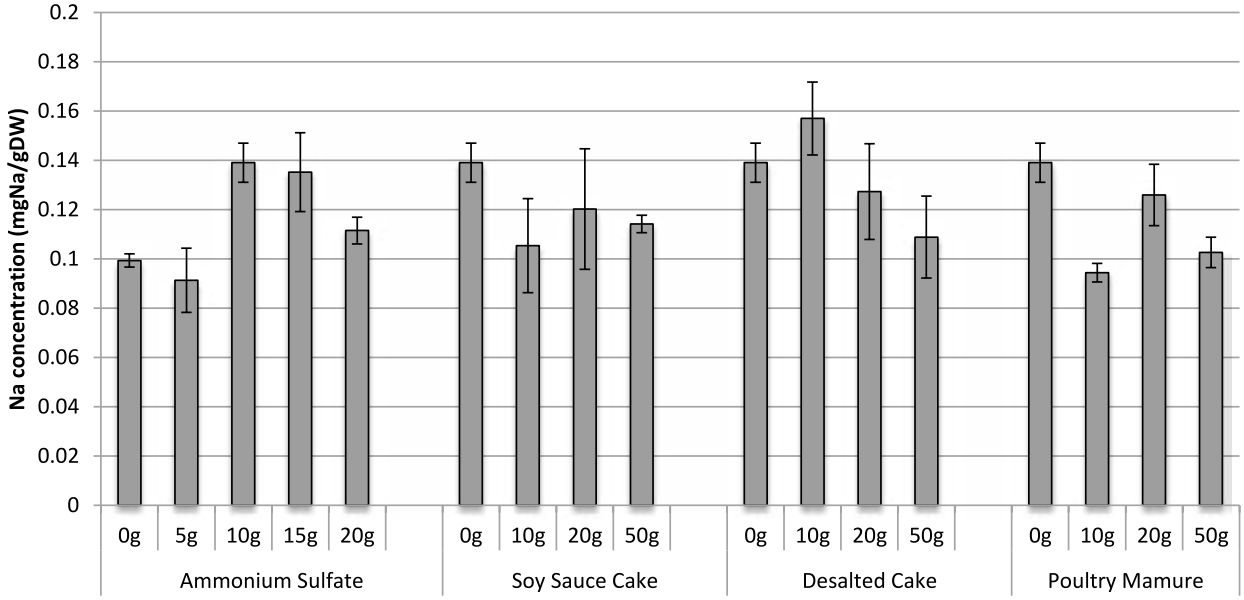


Figure 14. Na concentration in potato tubers at harvest stage.
*(P<0.05), **(P<0.01) by Student's T-test compared with 0 g treatment.

Figure 9 shows the dry weight of potato tubers at harvest at 96 DAP. By the application of ammonium sulfate, the tuber dry weight was not significantly between treatment around 50g per plant. By application of soy sauce cake up to 20 g promoted the tuber dry weight, but the application of 50 g of cake did not increase potato tuber growth, which may be due to salt stress. On the other hand the application of desalted cake increased tuber dry weight by 10, 20, and 50 g application. By the poultry manure application, the highest yield was shown by 10 g application.

The concentrations of N (Figure 10), P (Figure 11), K (Figure 12) and Mg (Figure 13) and Na concentrations (Figure 14) in the harvested tubers were relatively constant among treatments and the application rates. Although the application of the soy sauce cake with the rate of 50 gN/m^2 repressed tuber DW (Figure 9), the Na concentration in the tuber was not affected (Figure 14).

Further field experiments with various crops are required to evaluate the beneficial and harmful effects of soy

sauce cake on the crop growth and yields.

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圃場栽培バレイショにおける醤油粕の施肥効果

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要　約

醤油粕は、高濃度のタンパク質を含み、家畜の餌や肥料として適している。しかしながら、塩濃度が高いため、使用には注意が必要である。肥料として施用する際には、作物の塩類ストレスや圃場の塩類集積に注意が必要である。

本報告では、醤油粕または脱塩醤油粕の肥料効果ならびに含有される塩による作物の生育と成分濃度への影響を調べるために、新潟大学農学部の砂丘地圃場においてバレイショの栽培試験を行った。今回用いた、醤油粕と脱塩醤油粕の窒素濃度は、41.5 mg/gDW と41.7 mgN/gDW で、比較に用いた鶏糞（42.2 mgN/gDW）とほぼ同程度であった。一方、醤油粕と、脱塩醤油粕のリン、カリ、カルシウム、マグネシウム濃度は鶏糞に比べて非常に低かった。醤油粕の肥料成分としては、主に窒素が期待できる。

1 区5.4m^2 (0.9m×6m) の区を設定し、バレイショは、株間30cm で 1 区20株を植えた。処理区は 3 連でランダムに配置した。全区に共通な施肥として、種イモ植え付け前に、過燐酸石灰25 g/m^2、熔成リン肥25 g/m^2、硫酸カリウム9.9 g/m^2、ケイ酸カリウム肥料25 g/m^2、石灰133 g/m^{2}を施用した。処理区は、1 ㎡あたり硫酸アンモニウム0gN、5gN、10gN、15gN、20gN を施用する区と、醤油粕、脱塩醤油粕または、鶏糞を10gN、20gN、50gN 施用する区を設けた。ただし、有機物施用区は、初期生育を確保する目的で、硫酸アンモニウム10gN を同時に与えた。サンプリングは、播種後46日目の開花期に、地上部、根、塊茎を、播種後96日目の収穫期に塊茎を収穫し、洗浄し、各部位に分けて通風乾燥機で乾燥し乾物重を測定した。試料は粉砕後、分解し、N、P、K、Mg、Ca、Na 濃度を測定した。開花時に葉柄汁液を採取し、硝酸濃度を測定した。

硫酸アンモニウム0gN、5gN、10gN、15gN、20gN を施用した区では、植物の乾物重、N、P、K などの成分濃度はほとんど変わらなかった。これは、砂質土壌のため、施用した硫安が早期に流亡してバレイショの生育にほとんど清なかったためと考えられる。一方、醤油粕、塩抜き醤油粕、鶏糞では、施用量に応じて生育促進が見られたが、醤油粕50g 区では、生育促進が見られなかった。これは塩害による可能性がある。植物体の窒素濃度と、葉柄汁液の硝酸濃度は、硫酸アンモニウム区では低く、有機物施用量に応じて高まったことから、醤油粕、塩抜醤油粕、鶏糞、いずれも、生育初期から分解を受け、無機窒素を供給していたことが確認された。

以上の結果から、醤油粕は、窒素肥料として作物栽培に有効であることが確認されたが、塩害を引き起こさないように施用量には注意が必要である。

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