# Trial Focus

**Photo 1.** Organic cabbage field, nine weeks after planting. Photo by FiBL.

## Testing Polyhalite as a Tool to Overcome Nutrient Deficiencies in Organic Cabbage Culture

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### Abstract

In addition to regular nitrogen (N), phosphorus (P), and potassium (K) requirements, Brassica crops need significant amounts of calcium (Ca), magnesium (Mg), and sulfur (S). The organic farming approach restricts the use of chemical fertilizers, considerably challenging balanced mineral nutrition of cole crops such as cabbage (*Brassica oleracea* var. oleracea). Polyhalite, a natural mineral, is an authorized fertilizer (Polysulphate®) for producers of organic crops in many countries. Consisting of 14% $K_2O$, 48% $SO_3$, 6% MgO, and 17% CaO, polyhalite can be considered a useful supplementary fertilizer of four essential nutrients in organic farming. The objectives of the present study were to evaluate the effects of polyhalite application on cabbage performance and compare it with equivalent commercial organic fertilizers. When used on fertile soil, rich with K, Ca, and Mg, the effects of supplementary nutrition on crop performance were absent. Sulfur uptake tended to be greater with polyhalite than in the non-fertilized control ($p = 0.071$), driven by a combination of increased marketable yield as well as S concentration in

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leaves. Sulfur nutrition appeared key to enhancing cabbage crop performance. Polyhalite displayed a strong tendency to enhance and stabilize yields, compared to alternatives. It tended to be better as a Ca donor compared to foliar Ca application, and was at least equivalent to gypsum. Harbouring four essential nutrients, polyhalite may be a suitable fertilizer, particularly for the organic market. It is advantageous being natural and easy to spread. However, in order to fully demonstrate the advantages of polyhalite, it should also be tested at sites with much weaker soil fertility.

*Keywords: Brassica oleracea* var. oleracea; calcium; magnesium; potassium; Polysulphate; sulfur.

## Introduction

The genus *Brassica* is known for its important agricultural crops, which include species and varieties of cole crops such as broccoli, cauliflower, and cabbage, root crops such as turnip and radish, herb crops like ruccola and choy sum, and oil and spicy seeds such as canola and mustard. World production of cole crops in 2017 was 71 million tonnes (FAO, 2020). Cabbage (*Brassica oleracea* var. oleracea) – a good source of vitamin K, vitamin C and dietary fiber (White and Broadley, 2005) – is consumed in many different ways: pickled, fermented, steamed, stewed, sautéed, braised, or raw.

Cabbage plants perform best when grown in well-drained soil in a location that receives full sun. Different varieties prefer different soil types, ranging from lighter sand to heavier clay, but all prefer fertile ground, with a pH from 6.0-6.8 (White and Broadley, 2005). For optimal growth, there must be adequate levels of nitrogen (N) in the soil, especially during the early head formation stage, and sufficient phosphorus (P) and potassium (K) during the early stages of expansion of the outer leaves (Wien and Wurr, 1997). In addition to NPK, brassica cole crops require significant amounts of calcium (Ca), magnesium (Mg), and sulfur (S). Calcium deficiency impedes cole development, which might induce physiological disorders and post-harvest damage, particularly following exposure to high temperature events during the growing period (Fig. 1).

**Figure 1.** Example of physiological disorders due to Ca deficiency. Photo by A. Vieweger (FiBL).

Crops in the Brassicaceae have been the focus of intense research based on their human health benefits (Björkman *et al*., 2011; Wang *et al*., 2020). Sulfur-containing secondary metabolites, such as glucosinolates, have been associated with some anti-cancer activities (Sarıkamış, 2009) and with a reduced risk of degenerative diseases, cardiovascular diseases and diabetes (Björkman *et al*., 2011, and references therein). Glucosinolates contents largely depend on S availability and significantly varies with S fertilization (Falk *et al*., 2007; Sung *et al*., 2018). Sulfur-deficient plants are typically small and spindly, characterized by interveinal chlorosis of young developing leaves that may become curved and brittle and eventually may fail to grow (Haneklaus *et al*., 2008). Additionally, N is known to positively interact with S; in many plant species, elevated availability of S promotes N uptake, and vice versa (Abdallah *et al*., 2010; Jamal *et al*., 2010).

The recent growing interest in organic farming has not skipped cabbage production (El-Shabrawy *et al*., 2005; Cordeiro *et al*., 2018; Farjana *et al*., 2019; Lee *et al*., 2019). Providing cabbage crops with an adequate, balanced, and timely supply of mineral nutrition is especially challenging under the tight restrictions of the organic approach, which prohibit chemical fertilizers and negates foliar mineral application. A promising solution may be found in polyhalite, a natural mineral which occurs in sedimentary marine evaporates, and consists of hydrated sulfates of K, Ca, and Mg with the formula: $K_2Ca_2Mg(SO_4)_4{\cdot}2(H_2O)$. The deposits found in Yorkshire in the UK typically consist of 14% $K_2O$, 48% $SO_3$, 6% MgO, and 17% CaO. The S content of gypsum, a common S and Ca supplement alternative, is only 18.6%. Polyhalite, available under the trade mark Polysulphate® (Cleveland Potash Ltd., UK), is approved as an input for organic farming systems in many countries.

The objectives of the present study were to evaluate the effects of polyhalite application on cabbage performance, comparing it with equivalent commercial fertilizers that have been approved and permitted to be used in the organic farming of high Ca and K demanding crops, such as potato, leek, and cabbage. We hypothesized that polyhalite would be at least as efficient as other commercial products commonly used in the market; polyhalite would bring a better long-term supply of S, K, and Ca; and that it would improve produce shelf life and prevent disorders through enhanced supply of K and Ca.

## Materials and methods

The experiment took place at Müller Steimaur farm, Stegacher plot, Bachs (47°30′56.786″N 8°26′53.048″E), Switzerland. The trial was conducted ‘on-farm’ in order to be as close as possible to organic practices, improving applicability of the results obtained. The trial field had not been fertilized with compost nor lime for the last two seasons before the experiment and, therefore, the soil was expected to poorly deliver K and Ca during the crop cycle. Unfortunately, soil tests revealed quite high K, Ca and Mg availability (Table 1). In fact, organically managed soils with low K levels are very rare in Switzerland due to frequent compost and manure applications.

Fertilizer application took place on calendar week (CW) 22, a week before planting. Feather meal application provided 126 and 21 kg ha$^{-1}$ of N and S, respectively, throughout the field. The experiment included four fertilizer treatments: unfertilized control; PatentKali + $CaCl_2$ sprays; PatentKali + gypsum; and, polyhalite (Polysulphate®). A detailed description of the fertilizer treatments is given in Table 2.

The experiment was designed in four blocks, with treatments randomly distributed within each block. The blocks were aligned along the slope of the field, in order to minimize variation within blocks and maximize the variation between blocks. The field size was 140 m$^2$ and plot dimensions were 3.6 × 10 m each.

**Table 1.** Soil available and reserve nutrient status before the experiment.

| Nutrient | Available ($H_2O10$) | Reserve (AAE10) |
|---|---|---|
| | ---------------------------------*mg kg$^{-1}$ soil*--------------------------------- | |
| Nitrate | 16.8 | - |
| Phosphorus | 5.6 | 130.2 |
| Potassium | 40.4 | 227.3 |
| Calcium | 55.3 | 2387 |
| Magnesium | 7.9 | 157.5 |

**Table 2.** A detailed description of the fertilizer treatments executed in the organic cabbage experiment in Switzerland.

| Treatment | Fertilizers | Dose | Nutrient input | | | |
|---|---|---|---|---|---|---|
| | | | $K_2O$ | Mg | Ca | S |
| | | *kg ha$^{-1}$* | ------------------*kg ha$^{-1}$*------------------ | | | |
| Control | - | - | - | - | - | - |
| PatentKali + $CaCl_2$ | PatentKali[a]<br>$CaCl_2$ | 667<br>5[b] | 200 | 40 | - | 113 |
| PatentKali + gypsum[c] | PatentKali<br>Gypsum | 667<br>900 | 200 | 40<br>17 | -<br>174 | 113<br>131 |
| Polyhalite | Polysulphate® | 1429 | 200 | 51 | 174 | 274 |

*Note*: [a] PatentKali composition: $K_2O$ (30%); Mg (6%); S (17%). [b] Foliar application of $CaCl_2$ took place 3 times, at CW 32, 35, and 38. [c] Gypsum composition: Mg (2%); Ca (20%); S (15%).

Cabbage seedlings were planted on CW 23. Unfortunately, part of the cabbage trial, situated at the lower end of the field, was flooded due to two successively heavy rain events at the beginning of the season, during the middle of June. Thus, only three blocks were considered for analysis. The cabbage trial further suffered from heavy infestation of flea beetle, which retarded crop growth. Repeated application of organic insecticides minimized the damage, but harvest was delayed by two to three weeks.

All examinations were done in the core plots (4 middle rows, 2.4 m × 6 m), avoiding border effects. Root sampling took place on CW 31, eight weeks after planting. Four plants per plot were gently lifted with their roots using two spades. Roots were cleaned and washed, brought to the laboratory, weighed, oven-dried at 60°C for 48 hours, and weighed again. However, results might have been slightly biased as a result of considerable root loss due to the challenges of lifting plants and roots. Leaf sampling was done on CW 32, 35, and 38; from each plot, 20 leaves were collected, cutting the third fully developed one (counting from the base upwards). At harvest, 10 plants per plot were collected, washed, weighed, dried, and weighed again. All dry samples were sent to the lbu Labor für Boden und Umweltanalytik laboratory in Steffisburg, where they were digested using the Aqua Regia digestion method, followed by mineral analysis using ICP-AES.

Harvest was executed manually on CW 40 (30 Sep 2019, 17 weeks after planting), from each core plot (6 m length, four inner rows). The marketable heads were weighed and counted. All cabbage heads (excluding those sent for mineral analysis) were stored at 1.5°C for 64 days, after which a visual scoring for physiological disorders (Fig. 1) was carried out.

Statistical analysis was carried out using R (R version 3.6.1 (2019-07-05)). To check for normal and homogeneous distribution, Levene’s and Shapiro’s tests were carried out on the residuals of the results. Where the residuals of the results were distributed normally and homogeneously, a two-factorial ANOVA was run, estimating the effect of block and treatment. If ANOVA did not show any treatment effects, the Welch two sample T-test was carried out to test the polyhalite treatment against the control. If the distribution of the dataset did not allow for an ANOVA, the non-parametric test, Kruskal-Wallis, was used.

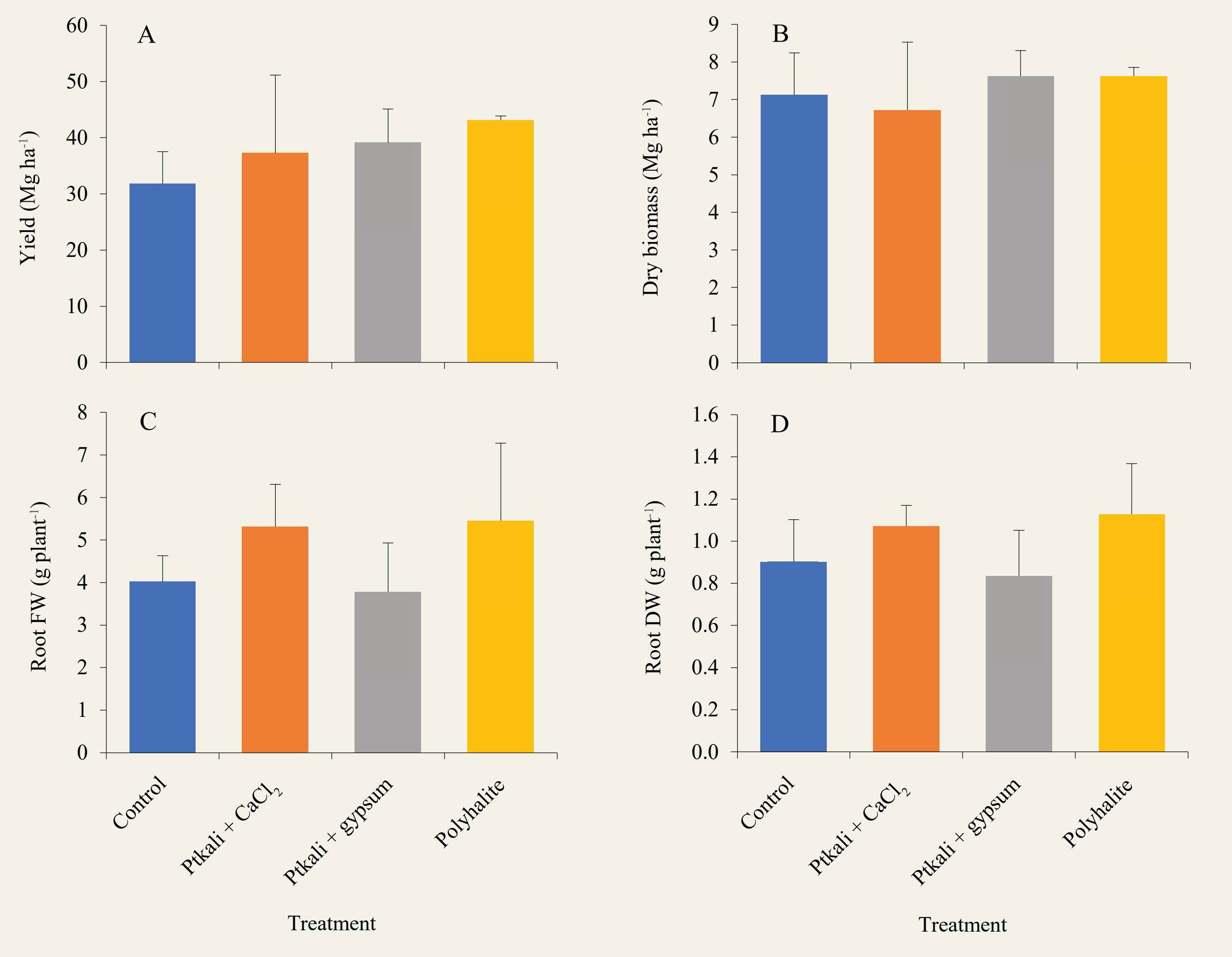

**Fig. 2.** Effects of the fertilizer treatments on cabbage commercial yield (A), total dry biomass (B), root fresh weight (C), and root dry weight (D). Bars indicate standard deviation.

## Results and discussion

Marketable cabbage yields in the organic sector usually range from 30-80 Mg ha$^{-1}$, and the yields obtained in the present study were at the lower part of this range (Fig. 2A). Yield was highest at the polyhalite application treatment ($p = 0.071$), 35% more than the control, but was not significantly higher compared to the alternatives, PatentKali with CaCl$_2$ or with gypsum, which both failed to display significant effects on yield (Fig. 2). Nevertheless, there was a clear tendency of yield enhancement by the fertilizer treatments, which might have been statistically interrupted by the loss of one block due to prolonged flooding. The polyhalite plants exhibited the greatest stability among treatments, as indicated by the smaller standard deviations of yields and total dry biomass (Fig. 2A, 2B).

It was postulated that more balanced crop nutrition, enriching the soil with additional sources of Ca, Mg or S, and with prolonged K availability, would enhance root biomass development. Nevertheless, no significant effects on fresh or dry root biomass could be observed at the ninth week of crop development (Fig. 2C, 2D). Root biomass tended to be greater under the polyhalite and the PatentKali + CaCl$_2$ treatment compared to the two other treatments, but the general variability level did not allow any concrete conclusions to be made.

In general, K, Ca, and Mg leaf concentrations were higher at the beginning of the season, after which they gradually declined until harvest (Fig. 3A, 3B, 3C). The gradual decrease in leaf nutrient concentration is attributed to the principal difference between two phases of leaf growth: cell division, which is typified by dry matter accumulation, and cell expansion, during which most of the cell components are diluted. No differences were observed between treatments, which might indicate that these nutrients

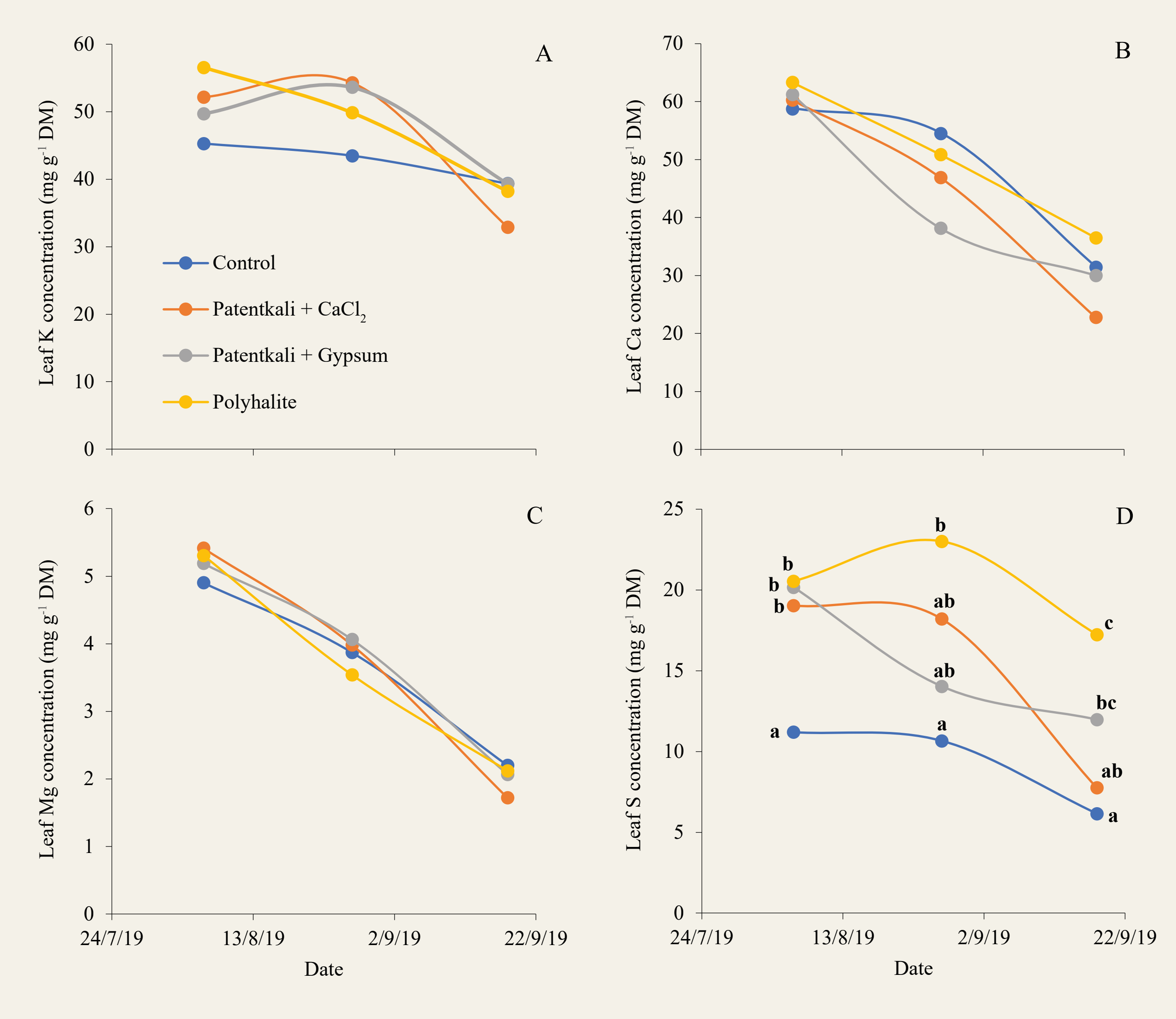

**Fig. 3.** Patterns of leaf K (A), Ca (B), Mg (C), and S (D) concentration changes during cabbage growth and development, as affected by fertilizer treatments. Different letters indicate significant differences between treatments within a date, at $P < 0.05$.

were not at risk of deficiency. Indeed, K, Ca, and Mg contents in the natural soil of the experiment site were quite high (Table 1). Alternatively, these results may indicate other factors that limit plant growth and yield and, consequently, reduce other nutrient requirements. Nitrogen, for instance, was applied at a seemingly adequate dose through feather meal. However, N is generally the most difficult nutrient to manage for organic crop production. While various organic N donor fertilizers can contribute substantial N for crops, it is challenging to synchronize N release from these materials with the plant demand. Careful management of organic N sources is required to meet crop requirements, while avoiding undesirable N losses to the environment (Mikkelsen and Hartz, 2008; Wild *et al*., 2011; Möller, 2018). Unfortunately, crop N status was beyond the frame of the present study, so assumptions concerning N as a limiting factor require further investigation.

The pattern of leaf S concentration during the season was substantially different from those of the other nutrients (Fig. 3D). The gradual reduction was much less pronounced, and significant differences occurred between treatments. Cabbage is well-known as an S-demanding crop (Satisha *et al*., 2016; Wang *et al*., 2020); accordingly, leaf S concentration displayed a linear positive response to rising S dose. Thus, polyhalite application

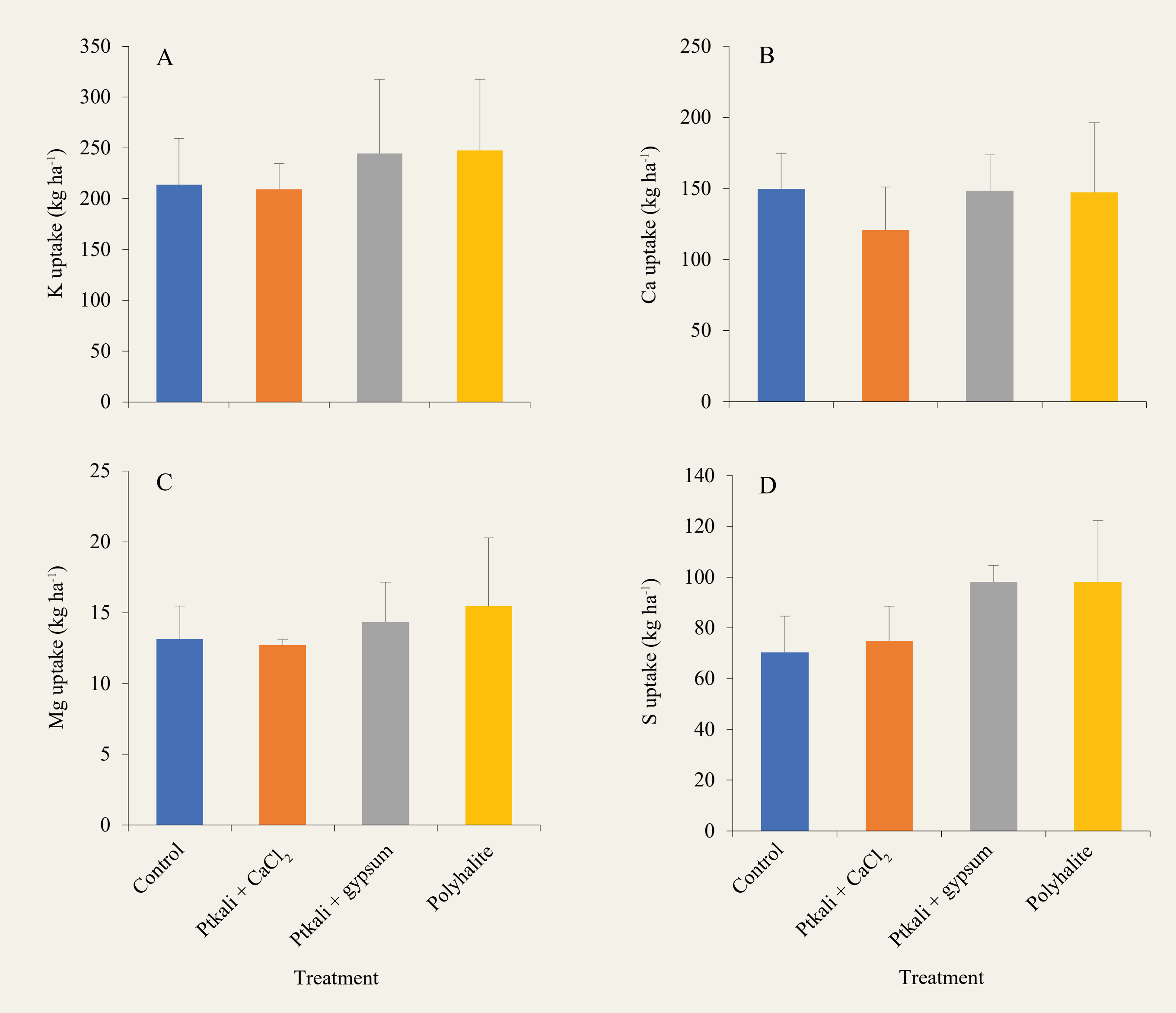

**Fig. 4.** Effects of fertilizer treatments on the total K (A), Ca (B), Mg (C), and S (D) uptake by organic cabbage plants. Bars indicate standard deviation.

brought about the highest leaf S concentration throughout most of the growing season, followed by PatentKali + gypsum, and PatentKali + $CaCl_2$ spray. Sulfur seems key to enhanced cabbage crop performance in the present study. Under N shortage, the synergy between N and S may improve N uptake and metabolism, and vice versa (Abdallah *et al*., 2010; Jamal *et al*., 2010). Alleviated S availability tended to increase the uptake of the other nutrients (Fig. 4), despite no significant differences occurring in crop biomass (Fig. 2B). Interestingly, $CaCl_2$ spray had no significant effect on leaf Ca concentration or Ca uptake. The slight advantage of polyhalite may well be an outcome of the higher S dose in this treatment; presumably, increasing the gypsum dose of the PatentKali + gypsum treatment to match the S level with the polyhalite treatment could have had a similar response.

No symptoms of S deficiency were observed. Sulfur deficiency is likely to occur in soils that have low levels of organic matter, light-textured sandy soils that have been leached by heavy rainfall or excessive irrigation, soils exhausted by intensive cropping, and soils derived from parent material that is inherently low in S (Jordan and Reisenauer, 1957). None of these conditions took place in the present study. Furthermore, soil tests carried out soon before planting indicate a relatively fertile soil, with adequate K, Ca, and Mg. Under such conditions, any significant advantages of supplementary fertilizers would be very difficult to show. This was also the case with the produce post-harvest quality parameters examined. No physiological disorders indicating a Ca deficiency were observed, on either the unfertilized control treatment or on the fertilized treatments, in spite of two extraordinary heat events that occurred at the end of June and end of July 2019.

## Conclusions

Using a fertile soil, rich with K, Ca, and Mg, the absent effects of supplementary nutrition on crop performance is expected. Sulfur uptake tended to be greater with polyhalite than in the non-fertilized control ($p = 0.071$), reflected by a corresponding increase in marketable yield as well as higher S concentration in leaves. Sulfur nutrition appeared key to enhancing cabbage crop performance. Polyhalite displayed a strong tendency to enhance and stabilize yields, compared to the alternative fertilizers. It tended to be better as a Ca donor compared to foliar application of $CaCl_2$, and was at least equivalent to gypsum. Harbouring four essential nutrients, the natural mineral polyhalite may be a suitable fertilizer, particularly for the organic market, as it is natural and easy to spread. In order to demonstrate polyhalite's advantages of enhancing crop performance and post-harvest produce quality, sites with much weaker soil nutrient status should be employed, providing enough room for statistical differences.

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**The paper "Testing Polyhalite as a Tool to Overcome Nutrient Deficiencies in Organic Cabbage Culture" also appears on the IPI website.**

**Photo 2.** Photo by iStock.