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ON THE MOVEMENT AND DISTRIBUTION OF CALCIUM IN WHITE CABBAGE IN DEPENDENCE OF THE WATER STATUS

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SUMMARY

The uptake and distribution of Ca in white cabbage have been measured under controlled climatic conditions. The uptake of Ca has been determined by continuous β-intensity measurements of ^{45}Ca simultaneously at an outer transpiring leaf and at an inner head leaf. In the outer leaves the Ca content increased during the day in dependence of the transpiration amplitude. Within the inner head leaves Ca was transported mainly during the night when the head mass additionally measured by γ-absorption increased due to the increasing plant water potential. At the end of the experiment the stable and active Ca concentration has been measured.

INTRODUCTION

Many cultivated plants suffer from shortage of calcium in organs of low transpiration. The internal tipburn of headed cabbage, which is a Ca deficiency disease, starts with the dying of the veins at the edges of those leaves which are situated in an inner head region. Experiments of Krug *et al.*[3] with cauliflower, Krauss and Marschner[2] with potatoes and Wiebe[6] with white cabbage have shown that there is a correlation between the Ca content of low transpiring organs and the climate-dependent variation of the plant water potential. The higher the diurnal transpiration amplitude, the more Ca-containing xylem sap will be transported by swelling and shrinking into and through these organs.

In the field the diurnal periodical variation of the mass of a cab-

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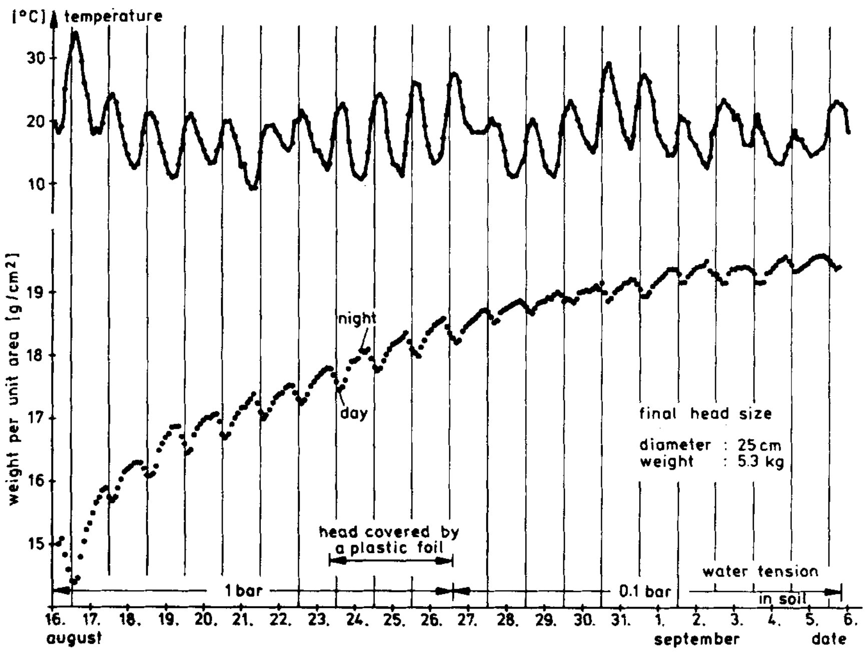


Fig. 1. Growth curve of a cabbage head in the field.

bage head can be measured by the γ-absorption method. Fig. 1 shows the growth of a cabbage head including the temperature curve. Although the dry matter of the head is increasing during the day, the total head mass decreases due to the transport of water into the transpiring outer leaves. Even a covering of the head has no influence on this process (Fig. 1). During the night the mass is increasing due to the uptake of water.

In the following investigations the correlation between the diurnal variation of the water budget of the plant and the Ca-movement within the plant will be shown by using ^{45}Ca.

MATERIALS AND METHODS

The experimental plants of the variety 'Frühseptember' have been cultivated in quartz sand under outdoor conditions. At the beginning of the experiment the plants had a fresh weight of about 260 g and a head diameter of 6 cm. The experiment was performed in a growth chamber at 400 ppm CO_2. Fluorescent lamps of 20 000 lux illuminated the plants twelve hours a day. The air temperatures and the dew points are seen from Fig. 4. The nutrient solution contained the following ions (mval/l): 10 Ca, 6 K, 2 Mg, 10 Na, 4 NH_4, 4 H_2PO_4, 2 HPO_4, 6 SO_4, 6 Cl, 14 NO_3 and trace elements.

The following experiments have been performed on different plants under the same climatic conditions.

1) Measurements of the transpiration by gravimetrical mass determination of 3 pots several times per day.

2) Continuous measurement of the mass variation of the head by γ-absorption (^{241}Am, 60 keV, Kühn *et al.*[4]). For the experimental set-up see Fig. 2.

3) Uptake of ^{45}Ca from the nutrient solution and continuous measurements of the β-intensity at an outer leaf and at an inner head leaf (see Fig. 3).

The tracer experiments were started in the evening by adding 4 mCi ^{45}Ca to the nutrient solution. The specific activity within the pot was 5 μCi/ml. On the following days radioactive nutrient solution with the same specific activity has been added to compensate the transpiration loss. The β-intensity measurements were performed by two 50 mm^2 surface barrier detectors included in light tight capsules with thin Al-windows. One of the detectors was smoothly pressed onto an outer leaf (see Fig. 3 and drawing in Fig. 5). A small hole was carefully drilled into the wrapper leaves in order to reach a position for the second detector at an inner head leaf (Fig. 3 and Fig. 5). To avoid incoming light to the inner leaf the hole has been additionally covered by a small piece of dark plastic foil. Preliminary experiments concerning the temperature influence on the β- and γ-intensity measurements showed a stability of the count rate of better than $\pm 1\%$ within the temperature range in question. The

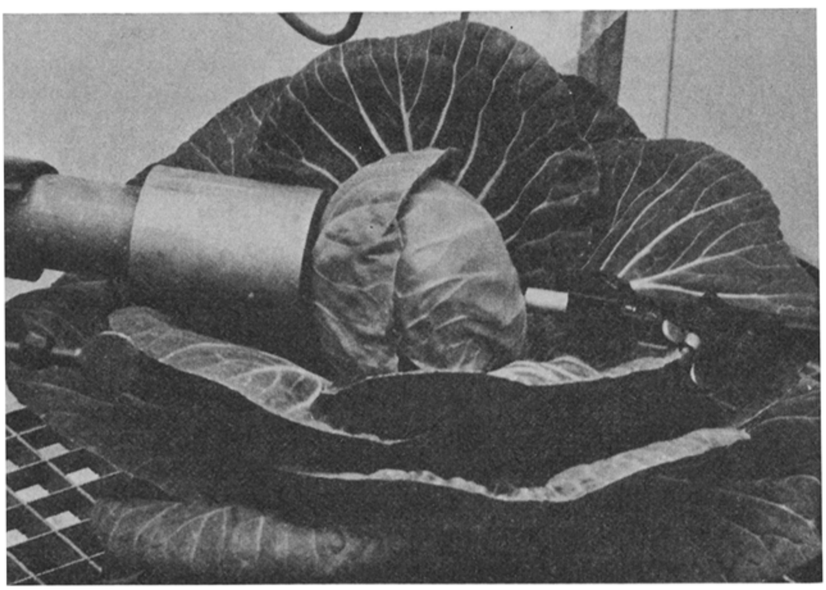


Fig. 2. Continuous measurement of the head mass by gamma-absorption.

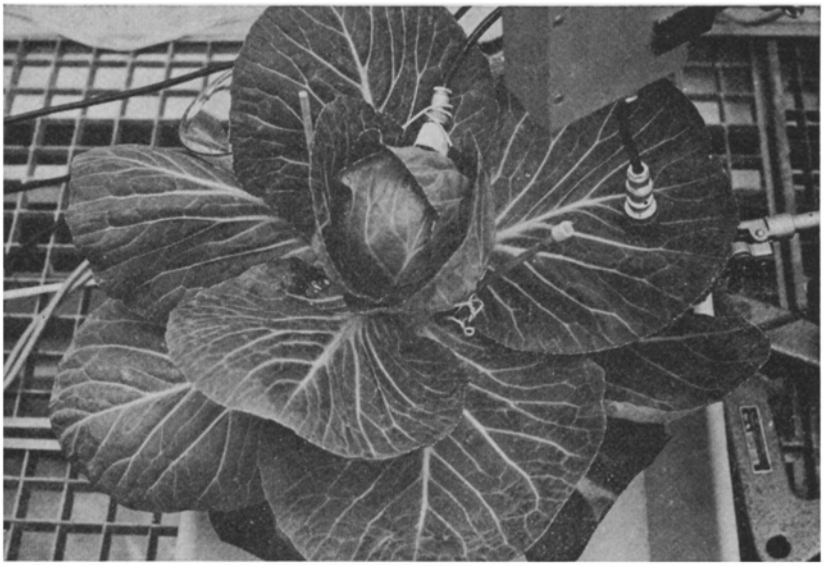


Fig. 3. Positions of the surface barrier detectors at the plant for the β-intensity measurements.

γ- and the β-intensities were recorded continuously. The experiments were stopped after nine days by removing the active plant. The ^{45}Ca distribution within different leaves has been directly measured at 3 positions with one of the surface barrier detectors. Samples were taken from the inactive plants at the corresponding positions in order to perform chemical analysis of the total Ca-content by atomic absorption spectroscopy.

RESULTS AND DISCUSSION

a) Movement of calcium

In Fig. 4 the results of only the first three days are shown since from the fifth day on an unusual behaviour of the outer leaf concerning its Ca-uptake was noticed. As the measuring position was covered by the detector the photosynthesis of this part of the leaf was disturbed. Therefore in the following days ^{45}Ca concentration only showed a small increase. Therefore the influence of the different temperature – and humidity conditions will not discussed separately, although there is an indication that the Ca-uptake is higher when the humidity is low.

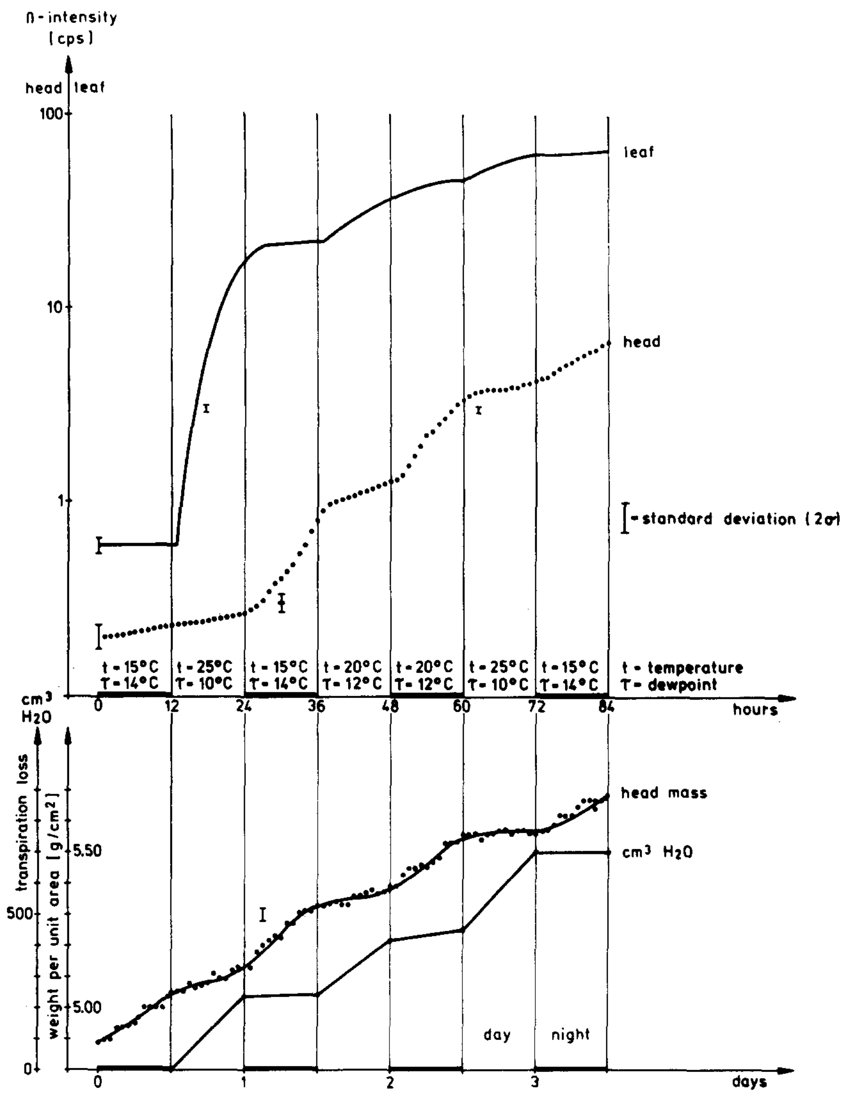


Fig. 4. Uptake of ^{45}Ca in dependence of the plant water status.

Transpiration occurred during the day. At night the mass of the head strongly increased. In contrast to measurements performed under field conditions (Fig. 1) or even in a growth chamber with soil cultivated plants (Kühn *et al.*[4]) a decrease of the head mass during the day could not be measured. Whereas in normal soil the velocity of the water movement to the roots strongly decreases with decreasing water potential, the water supply of the roots might be much enhanced in the present experiments.

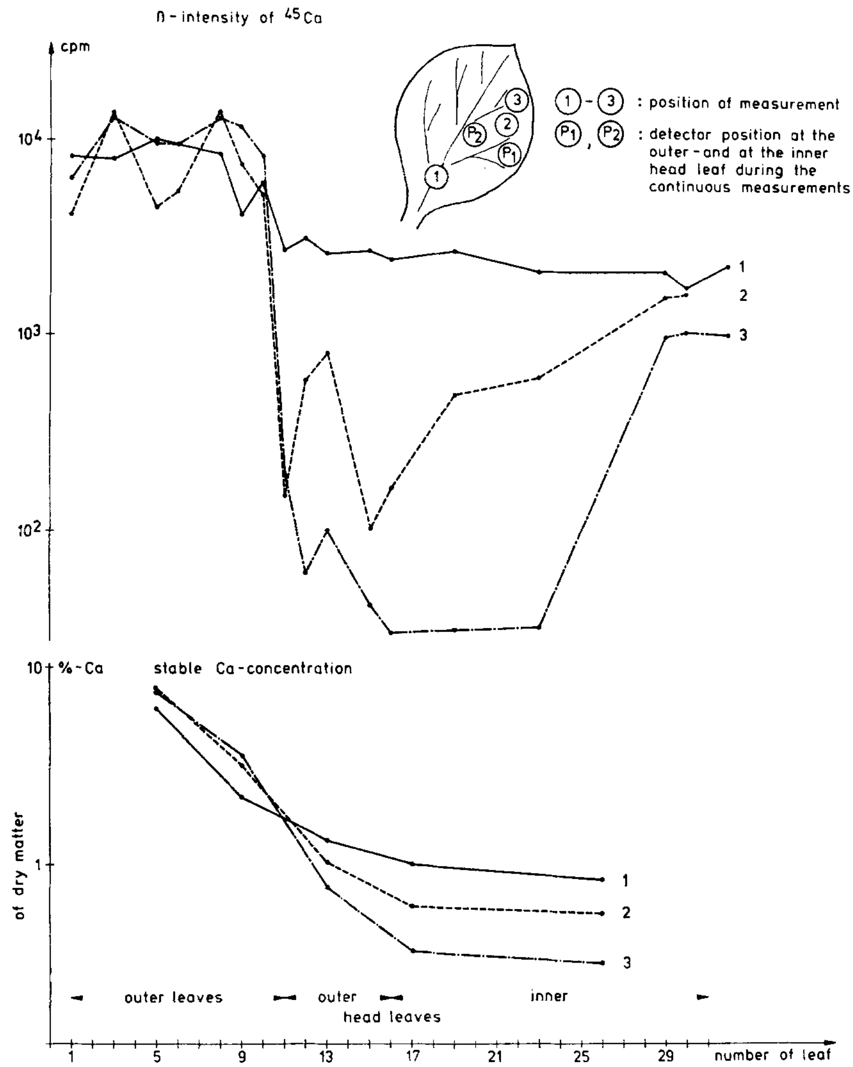
In the outer leaf ^{45}Ca could not be detected until 13 hours after the application *i.e.* one hour after the beginning of the transpiration. The further increase of the activity at the measuring position mainly occured during the day parallel to the course of transpiration. Within the head ^{45}Ca was measured in significant amounts about 10 hours after the application. The increase of the active calcium concentration mainly taken up during the night was always weaker than in the outer leave. The strong correlation between the mass- and the activity increase of the head is obvious.

Ringoet *et al.*[5] as well as Krauss and Marschner[2] have shown that the fluxrate within the xylem is of the order of 30 cm/h. In the present experiments the velocity of the Ca-transport from the roots to the transpiring leaves of headed cabbage have the same magnitude. As the change of the countrate in the head is relatively low, it is impossible to measure exactly the velocity of Ca-transport in it. In the head water will only be moved through the xylem when there is an increase of the volume due to the growth or due to an increasing water potential within the plant. As the water potential is increasing at low transpiration rates, Ca will be transported mainly during the night. Baker and Moorby[1] found within the xylem of potato stolons a similar dependance of the Sr-transport from the daily alternation of the water status.

Under field conditions the mass of the head can decrease by 6–8% during the day when the transpiration is high. In that way Ca should also be removed from the head by the water flux. Krauss and Marschner[2] have shown a variation in the direction of the Ca motion within the stolons of potatoes. In the present experiments more Ca should therefore reach the head leaves. This hypothesis could not be clarified as during the experiments no shrinkage of the head could be observed mainly due to the better water supply of the roots.

b) Distribution of calcium

The Ca distribution within the plant has been determined by chemical analysis of the total Ca taken up during the whole growing period as well as by activity measurements of the ^{45}Ca. Fig. 5 shows



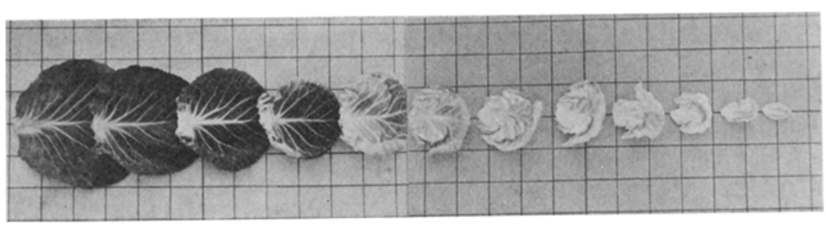


Fig. 5. Stable and radioactive Ca-distribution within the cabbage plant.

the Ca-content in % of the dry matter. It reaches over 7% in the outer free leaves, while at the edges of the inner head leaves the Ca concentration is only 0.3%. More Calcium is located at the edges of the transpiring leaves than within their veins which is in contrast to the inner head leaves.

The activity measurements substantially lead to the same distribution shape. The differences in the ^{45}Ca concentration between the edges of the outer and inner leaves and between the veins and edges of the inner head leaves are much greater. Before the experimental period the plants were grown outdoors, where the climatic conditions were completely different from those in the growth chamber. This could be a reason for the differences between the stable Ca- and the ^{45}Ca distribution. At the 16th leaf, for example, the ratio of the Ca content between the vein and the edge was 3 to 1 for the stable Ca, whereas it has been 80 to 1 in the activity measurement.

Tipburn normally occurs in regions of the lowest Ca concentration. In contrast to the free-standing leaves the inner head leaves are hardly able to transpire water. Therefore the Ca content strongly decreases from the vein to the edges of the leaf.

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