# THE CALCIUM UPDATE: IMPACT OF CALCIUM NUTRITION ON TUBER QUALITY AND YIELD

by
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Recent evidences implicate that potato tuber quality can be improved by increasing the calcium content of the tubers. Benefits from supplemental calcium application include reduced incidence of internal defects such as internal brown spots (IBS) and hollow heart (HH). Furthermore, data from several studies also suggest that higher calcium tubers store better and have reduced incidence and severity of soft rot. Recently we have obtained some evidence that in some cultivars the seed piece tuber quality can be improved through calcium application. In this study we found that seed piece tubers given calcium nitrate during their development gave higher yield in the following season.

In addition to these issues, in our work, we have also investigated practical means of delivering soluble Ca products, timing and source of application of calcium. Since two of the common products (calcium nitrate & NHIB) supply calcium and nitrogen, we have also investigated the interaction of Ca and nitrogen application on tuber quality and yield. In this article I have attempted to address the three common questions being asked by growers. (i) Why calcium?, (ii) Is it feasible to improve tuber calcium on a practical level? and (iii) Is there a benefit?

## Why Calcium?

***Calcium is important for healthy cell membranes and sturdy cell walls (Fig. 1). In addition, Ca acts like a hormone (Fig. 2)!***

Calcium has long been known to play an important role in the growth and development of plants. It has been well recognized that the cell membrane health is very crucial to the survival and health of the plant cell. It is now well established that the health of the cell membranes cannot be maintained in the absence of a critical level of Ca around the membranes. If the level of Ca associated with the membranes is reduced the membranes become leaky resulting in an unabated loss of cellular salts and organic compounds. Such loss, if not reversed leads to the eventual death of the cell.

It is also well recognized that calcium is an integral part of the cell wall where it provides stable, but reversible intramolecular linkages between pectic molecules, resulting in cell wall rigidity. In addition to its role in the membrane and cell wall Ca is now regarded as a messenger just like a hormone.

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As a secondary messenger Ca has been shown to regulate various cell functions. Changes in the cellular Ca levels can help a plant react to the impact of environmental (drought, heat, cold) and biotic (bacteria, fungus) stresses.

Environmental stresses such as heat, cold and drought are known to cause perturbation of the cell membrane functions. Soft rot causing bacteria also cause membranes to be leaky and digest cell walls by using hydrolytic enzymes. Since Ca is able to protect the cell membranes and gives strength to the cell walls, it is not surprising therefore that Ca would have an important role in tuber quality and plant growth.

**Tubers being a low transpiring organ are naturally deficient in calcium**

Tuber is botanically a stem tissue. As compared to above ground stem portion of the plant, tubers contain very little calcium. On average, calcium concentration in the tuber is less than one fifth of the Ca of the stem tissue. Transpiration is the main driving force for calcium transport in plants. Calcium therefore, moves along with water in the xylem. Potato tubers, being surrounded by moist soil, will have much less transpiration as compared to the above-ground part of the plant. Consequently low transpiring organs, such as tubers, accumulate much less calcium per unit fresh weight than leaves. Deficiency of calcium in tuber tissue is even greater for potatoes grown in sandy soil, such as in central Wisconsin, the major potato growing area of the state, because of the very low level of exchangeable Ca in these soils. Moreover, with constant irrigation, water Ca is leached from the hill. Thus the soil surrounding the tubers will contain very low soluble calcium, especially during the later part of the season when tubers develop.

**Is it feasible?**

**Discovery of tuber roots: Application of soluble Ca around the tuber area can enhance tuber Ca uptake**

Over 11 years ago, we provided evidence for the existence of functional roots on the tuber and at the tuber-stolon junction. In a follow-up study, we showed that these tuber roots displayed normal root anatomy and they appear to derive from parenchyma cells adjacent to the vascular tissue. By feeding a water-soluble dye, we demonstrated that these roots were able to supply water to the tuber whereas the main root system supplied water to the top part of the plant. Since water and calcium are known to move together, we suggested that these tuber and stolon roots are able to supply calcium to the tuber. In a follow-up study we found that addition of Ca to the main root system did not increase the Ca concentration of the tuber tissue. However, application of Ca to the tuber and stolon area resulted in a 3-fold increase in the Ca concentration in the tuber peel and medullary tissue.

These results showed that tuber Ca content can be increased by placing Ca in the tuber and stolon area. Thus, on a practical level, these results indicated that **placement** of Ca is important for enhancing Ca uptake by the tuber.

**Spoon feeding potatoes during bulking: A new concept in potato nutrition**

Our discovery of tiny roots on tubers has changed the concept of potato nutrition. Previously, it was believed that the potato plant's main roots supplied all the water and nutrients to the leaves, and the leaves in turn feed the tubers. In contrast, our results clearly show that potato tubers are like 'underground plants' that draw their water and nutrients, such as calcium, directly from the soil. Since tubers are surrounded by relatively moist soil, they cannot compete with leaves for transpirational water uptake. Tubers thus have to rely on the roots that are in their close proximity (tuber roots, tuber-stolon junction roots, stolon roots) to extract water from the soil. Since calcium moves in xylem along with water, it follows that potato tubers must extract calcium from the soil in their close proximity. These results have lead to the development of a concept of 'spoon feeding' the tubers with calcium during the bulking period.

**Practical Applications**

**Placement:** To enhance calcium concentration in the tubers, it is important that calcium be added in upper portion of the hill where tubers develop.

**Timing:** To enhance tuber calcium uptake, we need to 'spoon feed' potatoes during bulking with calcium fertilizer. Prior to our research, potato growers used to complete fertilization at hilling. This was a necessity, since no nutrient application could be made by tractor after hilling without damaging the plants. Our results show application of calcium need to be made much later in the season and that this can be easily achieved by injecting calcium fertilizer directly into the irrigation line. Since tubers develop during late part of season it would be important to add supplemental calcium during tuber bulking, which is even more critical in sandy soils. Due to low moisture holding capacity, sandy soils are irrigated 2-3 times a week. Thus, the top portion of the hill is continuously washed by the irrigation and rain, with water moving soluble nutrients to the lower portion of the hill. These nutrients remain accessible to vegetative growth via the main root system. However, the tubers developing during late season will not have access to these nutrients via the tuber and/or stolon roots.

**Source and Quantity:** Calcium should be applied in water soluble form to facilitate uptake by the tuber. Common sources of calcium used in agriculture are lime and gypsum. These chemicals have very low water solubility. Since we are injecting the fertilizer into the irrigation line, we have used two water soluble sources of calcium available in the market, these are calcium nitrate (Hydro Agri of North America) and NHIB (Stoller Chemical Co). We have injected these two products separately and found them to be effective in increasing tuber calcium. Applications were made during tuber bulking in three split doses (hilling, 3 and 6 weeks after hilling). Our results demonstrate that it is possible to improve tuber calcium content and, thereby, tuber quality, by application of 100-200 lbs Ca/acre during bulking. This, our results show is possible even in a soil that contained sufficient calcium for potato plant growth.

**Is there a benefit?**

**Impact of Ca application on internal defects**

Internal defects such as brown center (IBS) and hollow heart (HH) produce no external symptoms on effected tubers and, therefore, cannot be culled out before sale. We have examined the impact of Ca fertilization on internal defects over several seasons. Individual tubers were analyzed for this purpose. Split applications (1/3 at hilling, 1/3 at 3 weeks after hilling, 1/3 at 6 weeks after hilling) of either calcium nitrate or NHIB at 100 lbs Ca/acre or 200 lbs Ca/acre (100 lbs from calcium nitrate or NHIB + 100 lbs Ca from calcium chloride) resulted in significant reduction in internal defects in Russet Burbank potatoes grown at Hancock experimental station. Both peel and medullary calcium concentration was improved by these calcium applications. In the same study we found that as the average calcium concentration in tuber increased from about 0.01 to 0.03% (dry weight basis), the incidence of internal defects was reduced from over 20% to 5%. **However, it is important to point out that at a given level of tuber calcium there is a large variability (especially at low Ca concentration) among tubers for the incidence of internal defects. In other words, in addition to Ca there are other factors that contribute to development of internal defects.**

Our recent studies also suggest that timing of nitrogen application and interaction between Ca and nitrogen may influence the incidence of tuber internal defects. Consistent in 1993 and 1994 we found that plots receiving nitrogen or calcium + nitrogen through the bulking period (split schedule) produced half the number of defected tubers than the plots receiving identical nutrients applied by hilling (non split schedule).

**Impact of Ca application on seed piece decay due to soft rot:**

For the last three years we have investigated the possibility of improving seed piece quality by enhanced calcium uptake. For this purpose we have worked with seed piece growers in Northern Wisconsin (Antigo area). The soils in this area test at over 1500 lbs of available Ca per acre. We applied 150 lbs of Ca in three split applications (Hilling, Hilling + 3 weeks, Hilling + 6 weeks). Two sources of calcium (calcium nitrate and NHIB) and three cultivars (Atlantic, Dark Red Norland and Superior) were used in this study.

Tubers were harvested and stored over winter. Next season their performance was tested. In order to understand the link between seed piece calcium and quality, individual tubers were analyzed for calcium by removing a slice from the center of the tubers. The tuber was split in two halves and inoculated with suspensions of a *bacteria (Erwinia carotovora)*. Tubers were then planted in the Hancock soil.

From the Ca analysis we found that in both the cultivars seed piece Ca content increased by Ca application. Both sources of Ca were effective in this regard. The percentage of seed piece potatoes having calcium content >150 ppm nearly doubled in Atlantic and Dark Red Norland. Whereas in Superior this percentage increased from 72 to over 90%. Interestingly, Norland and Atlantic seed tubers given calcium nitrate during the previous season gave higher yield. This was not true for Superior.

In other studies we have found that calcium application to seed piece tubers during their growth and development can increase the resistance of this seed piece against the attack by soft rot bacteria. We also found significant cultivar variations. Atlantic and Burbank showed higher incidence and severity of seed piece decay than Superior and Dark Red Norland. These results show genetic variations for this trait and suggest exciting opportunities for future work. Analyses of the data showed that calcium application resulted in reduced severity and incidence of seed piece decay in Atlantic and Dark Red Norland.

**Role of Calcium in Heat Stress**

**Potato: A cool season crop and sensitive to heat stress.**

Heat stress is known to reduce potato plant growth and reduce partitioning of photosynthate to the tubers. Although there are differences among cultivars in their response to heat stress, in general, heat tends to increase stem length and branches while reducing the leaf size and total leaf . In addition, high temperatures also reduce the net photosynthesis. The overall result of the effects of heat stress on potato plants is a decrease in plant growth and tuber yield.

**Heat Stress Effects on Potatoes Can be Mitigated by Calcium**

The summer of 1988 was unusually warm and dry in Wisconsin. The daily maximum temperature at Hancock Experimental Station between June 1 and Aug. 18 was at or above 90 °F for 46 days. The rainfall during the months of June, July and August was about 2, 5.5 and 4 inches respectively at this location. On average, there was 25% decrease in tuber yield in the central sands (where Hancock Experimental Station is located) of Wisconsin, the potato growing area of the state. In our field trails, at Hancock we found a 20 to 30% increase in tuber yields where soluble calcium (calcium nitrate or NHIB) was applied during tuber bulking period. There was no significant difference in tuber yield among the two sources of calcium. These results suggested that calcium fertilization during bulking could mitigate the adverse impact of heat stress on tuber yield.

Following these observations in 1988, we have conducted several studies on the impact of heat stress on potato plants under controlled environmental conditions. In these studies, side by side comparisons were made on the impact of calcium nutrition on potato plants grown at either normal or heat stress conditions. Plants were grown in a sandy loam soil that tested at about 1300 lbs/acre of available Ca/acre (adequate amount of Ca for potato growth). Plants under heat stress had reduced total leaf fresh and dry weights as compared to the control. However, plants receiving calcium under heat stress had significantly higher total leaf fresh and dry weights as compared to plants with no supplemental Ca under the identical conditions. This beneficial effect of calcium was absent under nonstress (normal, cool) conditions. In addition, under heat stress, plants receiving supplemental calcium had higher leaf calcium contents and higher stomatal conductance. These results show that application of calcium during heat stress can mitigate heat stress effects and that the maintenance of certain level of calcium in leaf tissue is important under heat stress.

Although we do not know mechanism by which calcium is able to mitigate heat stress effects on potatoes, our results provide some insight. For example, we found that stomatal conductance was higher in calcium-treated than control plants under heat stress. Maintenance of stomatal opening could be important in avoiding heat stress effects via enhanced transpirational water loss. We found a decrease in the calcium concentration in leaves of potato plants exposed to heat stress but the Ca concentration was maintained at the same level as prior to heat stress in the leaves of plants given calcium fertilization during heat stress. Thus our results suggest that maintenance of a certain level of Ca during heat stress is essential for the normal function of the stomata. We are currently investigating the mechanisms by which Ca is able to mitigate heat stress effects on potato plant.

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**For details see the following articles:**

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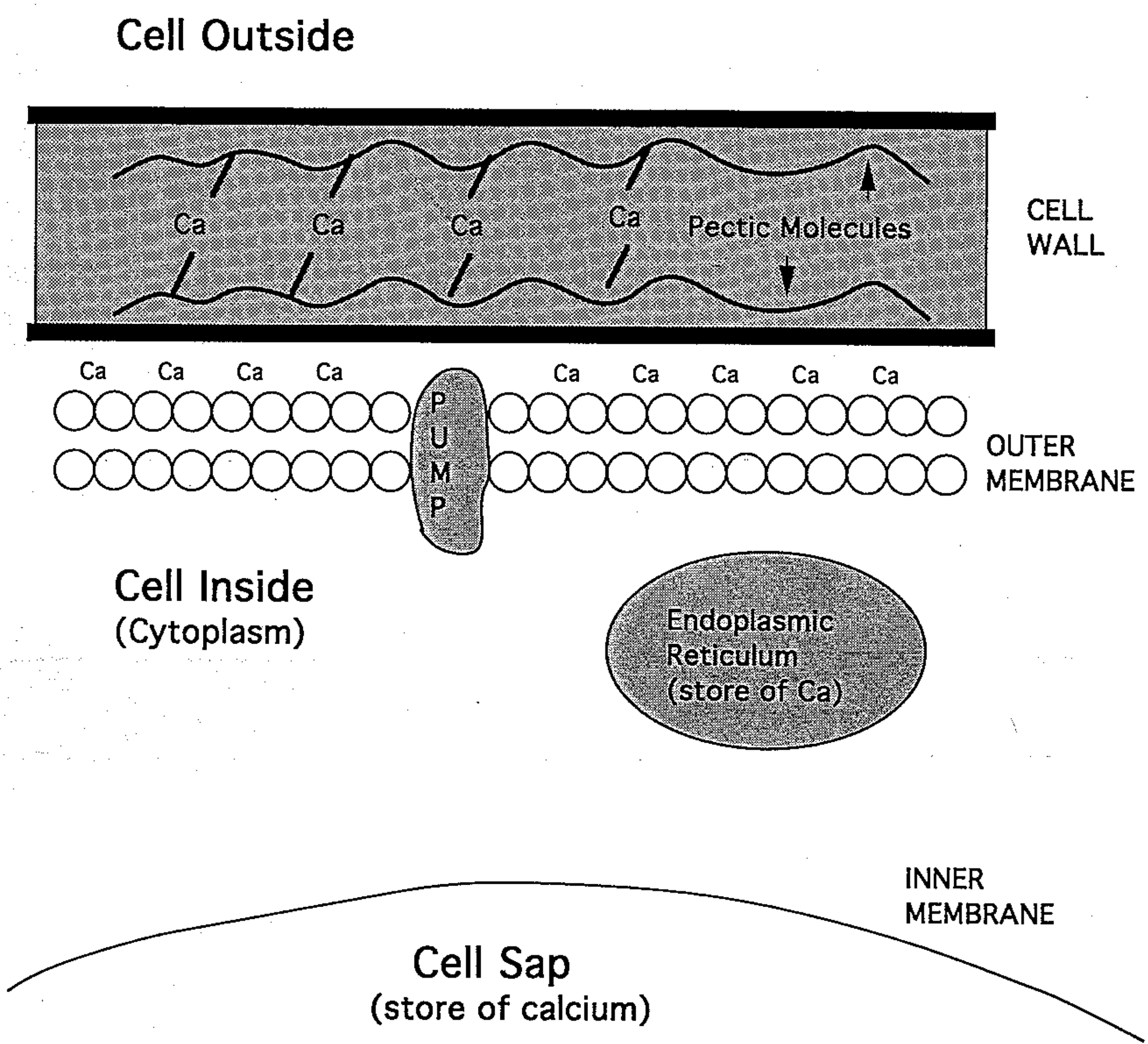


*Fig. 1. Schematic of a plant cell showing (a) association of Ca with pectic molecules in the cell wall and with membrane lipids, (b) internal stores of Ca, endoplasmic reticulum and cell sap and (c) membrane associated Ca pump that can move Ca across the outer membrane.*

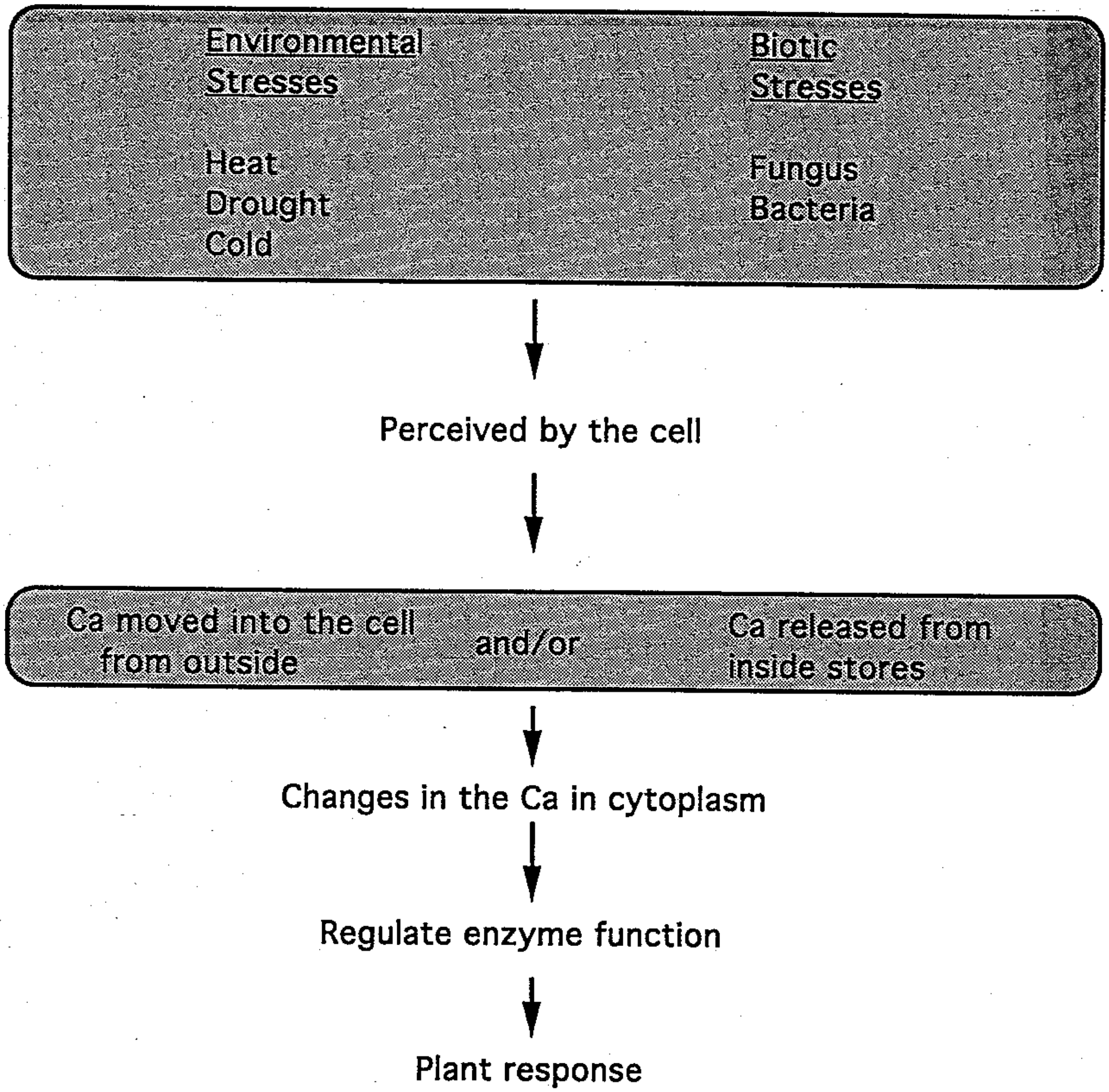


*Fig. 2. An outline of pathway demonstrating the role of calcium as a secondary messenger (like hormone). This scheme shows that an increase in the concentration of cytoplasmic Ca can help plant respond to environmental and biotic stresses.*