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ABSORPTION AND TRANSLOCATION OF BORON AND COPPER IN SUGARCANE

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Boron (B) was initially recognized as being essential to the growth and reproduction of plants in 1910, and specifically for sugarcane in 1934 (4). However, copper (Cu) was not considered to be essential for plant growth until about twenty years later. Although the essentiality of B and Cu has now been recognized and accepted for many years, little research has been conducted on the processes by which these micronutrients are absorbed and translocated in plants, or on the physiology and biochemistry of these two nutrients. The data presented in this report are the results of a study started at the Hawaii Agricultural Experiment Station in 1967 in an effort to gain knowledge of various aspects of the B and Cu nutrition of sugarcane. Much of this research has been concerned solely with the mechanisms by which B and Cu enter the roots, and the subsequent translocation of these nutrients to the shoots of the plants.

Absorption or uptake, as used herein, refers specifically to the transport of B and Cu from the external solution into the root. Translocation is defined as the movement of these nutrients from the roots to the shoots. Boron and Cu will be considered separately in this paper in an effort to avoid confusion.

Although there is no direct evidence presently available, it is assumed herein that B is absorbed from the soil solution, as opposed to a direct contact exchange mechanism. The absorption of B by plant roots is effected through two types of processes, one passive and the other under metabolic regulation (1, 2). The passive absorption of B is a physical diffusion phenomenon and does not require the expenditure of metabolic energy. In addition, passive uptake of B is usually completed within thirty minutes after the roots are exposed to the B solution, and regardless of time, passive absorption ceases when the B concentration within the root tissue reaches equilibrium with the external solution. Further, B absorbed via passive uptake is reversible absorbed and can be washed out of the roots. The H_3BO_3 molecule is the passively absorbed molecular species, and its absorption is independent of the presence of other anions in the solution.

Active B absorption, on the other hand, occurs much more slowly than passive absorption, and continues for several hours after the roots are exposed to the solution containing B. A most significant feature of the active absorption process is that B can be concentrated against a gradient; i.e., even though the B concentration within the root exceeds the external B concentration, B will continue to be transported into the root in an "uphill" fashion. Actively absorbed B irreversibly enters the root and generally cannot be leached out of the root. Another important characteristic of active absorption is that it requires metabolic energy; i.e., active absorption does not occur in roots that are not functional metabolically. Since active uptake is coupled to metabolism, the environmental variables that affect metabolic rates also affect active absorption; e.g., temperature and pH.

There are two independent systems, or mechanisms, for the active absorption of B in sugarcane tissue. Each mechanism is dependent upon the external B concentration, as follows: Mechanism 1 is functional over the external B concentration range of 0.002 to 0.20 mM (approximately 0.02 to 2.2 mg B/L), and mechanism 2 operates over the range of 0.5 to 10 mM (approximately 5.4 to 108 mg B/L. These two systems operate in parallel at the cytoplasmic membrane of the cells of the root. The optimum pH for active B absorption through each mechanism is approximately 5.7, and the optimum temperature is about 40° C (104° F). In the sugarcane plant, B absorption mechanisms 1 and 2 are highly specific for the $B(OH)_4^-$ anion, and are not affected by the presence in the solution of Cl^-, SO_4^{2-}, or phosphate anions. Furthermore, Ca^{2+}, K^+, and Na^+ have no effect upon the rates of active B absorption.

In other plant species, such as Lemna, active B absorption is reduced by the addition of Cl^- and phosphate anions to the external solution (5, 6).

The functioning of two mechanisms, both highly specific for $B(OH)^-_4$, to transport B into cells seems logical when consideration is given to certain properties of H_3BO_3. Since $B(OH)_4^-$ is the ion of importance, a solution containing 1 mg/L of H_3BO_3 would contain only 3.6×10^{-4} mg/L $B(OH)_4^-$ (0.006 μM) at pH 5.7. Thus, a highly specific mechanism is essential for transport of this ionic species of B into the root cells.

Once B has been absorbed by the roots, it must be transported to the shoot of the plant. Some work has also been done along this line with sugarcane. The rates of B accumulation and water utilization by 3-month-old sugarcane plants were altered by changes in temperature, relative humidity, light intensity, and duration of exposure to light. The effects of these environmental variables upon active B absorption by roots were not directly related to the effects on water utilization. This result is to be expected since it was shown previously that B uptake by roots is under metabolic control. In subsequent experiments, absorption of B by roots was experimentally separated from its translocation to the shoot. An estimate of the amount of B expected in the shoots was calculated from the known B concentration in the roots and the rate of transpiration by the plant. Inherent to such calculations of estimated B concentrations is the assumption that B translocation is strictly passive and occurs in the transpiration stream. The actual B contents of the plant tops were compared statistically to these estimated values. The agreement was quite good and the X^2 value for the difference between estimated and actual B levels was not significant, thus showing that B was in fact translocated passively to the shoots via the transpiration stream.

Note that the concentration of B in the roots of sugarcane appears to be constant at about 4 μg/g fr wt regardless of the rate of water utilization. Thus, 4 μg B/g fr wt must represent a balance between the rate of active absorption of B from the external solution and the rate of removal of B from the roots in the transpiration stream. A high rate of transpiration with its concomitant rapid movement of water through the roots would mean that B was also removed from the roots to the plant tops at a faster rate. This means in turn that more B is absorbed by the roots and also that more B will accumulate in the plant tops. Therefore, an increased transpiration rate must be accompanied by an increase in both absorption and translocation of B. This is so because the concentration of B in the roots has been maintained more or less constant at about 4 μg B/g fr wt, presumably through a metabolically-mediated regulatory mechanism. In this sense B absorption is not independent of transpiration, but on the other hand, neither is the active absorption of B directly dependent upon transpiration.