INFLUENCE OF SOIL AMENDMENTS ON DRY MATTER PRODUCTION, CONCENTRATION AND ADSORPTION OF BORON BY BROADBEAN (*Vicia faba*) UNDER IRRIGATION WITH WATERS HAVING DIFFERENT BORON CONCENTRATION LEVELS

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1. ABSTRACT

The experiment followed through the development of broadbean plants grown in the greenhouse in medium-textured soil containing the soil amendments calcium carbonate and peat moss organic matter, both separately and in combination, under irrigation with water at different boron concentrations. Samples were taken from the plants at five different stages of growth, from the seedling to the mature plant, and were analysed in terms of dry matter yield, concentration and uptake of boron by plants. The statistical analysis showed that the boron concentration in irrigation water did not significantly influence plant yield, whereas the organic matter present in the soil had a highly significant influence on dry matter production, and $CaCO_3$ influenced only at a 5% probability level. When considered all three variables taken together, the influence on plant dry matter production was highly significant. The similarity in the statistical data between boron uptake and concentration in plants confirms that organic matter has an important role in plant adsorption of boron, whereas calcium carbonate does not, and that both uptake and concentration of boron in plants are functions of the boron concentration in the irrigation water.

KEYWORDS : Irrigation, Boron, $CaCO_3$, Organic Matter, Broadbean

2. INTRODUCTION

Boron is essential to the normal growth of all plants, but the quantity required is very small. A deficiency of boron produces striking symptoms in many plant species. Boron is very toxic to certain plants species and the concentration that will injure these sensitive plants is often similar to that requires for normal growth of very tolerant plants.

All natural waters contains boron, though usually in low concentration. However, because boron tends to accumulate in the soil from low concentrations in the soil solution, continuous irrigation with waters even with low boron concentrations might lead to the incidence of boron toxicity symptoms, especially in plants with a high sensitivity to this element.

In many zones, especially arid and semi-arid ones, the lack of fresh water is the main factor limiting the expansion and increase in crop production. Using other available water resources, such as wells, underground reserves, drainage and sewage waters is a must. The majority of these water resources are high in boron, and many cases, the continuous irrigation with such water could create severe boron toxicity problem. It is also known that excess boron in soils is not removed as readily by leaching with low boron waters as are excess chloride and sulfate salts (Reeve et al., 1955).

Researchers as early as Eaton (1935) recognized that an equilibrium exists between the dissolved and undissolved boron in soils, and noted that, upon application of irrigation waters having similar boron concentrations, injury occurred more quickly on coarse-textured than on fine-textured soils. Moreover, he observed that, when irrigation waters having a low boron concentration were applied, boron toxicity was alleviated more rapidly on coarse-textured than on fine-textured soils.

The effect of soil texture on the relationship between the water-soluble boron in the soil and the boron content of the plants was studied by Wear et al., 1962. They found that alfalfa (*Medicago sativa*) grown in a coarse-textured soil had the greatest uptake of boron hand that's plants grown in a fine-textured soil had the least. It has also been shown that a toxic effect on some crops was obtained with lower rates of boron application in the case of sandy soils, as compared to clay soil (Rogers, 1947).

Hatcher et al., (1959) found that plants respond only to boron in solution and are not directly influenced by the presence of adsorbed boron. When the soil and water are in equilibrium, the boron concentration of the soil solution is equal to that of irrigation water, so after equilibrium is attained, the effect of boron in irrigation water on plant growth can be predicted directly from the boron concentration in the water.

Lal & Lal (1978) made an evaluation of water quality with respect to boron for wheat (*Triticum vulgare*) and barley (*Hordeum vulgare*) grown on loamy sand soil. Six levels of boron (0,7 to 8,7 ppm) were used for irrigating. The data obtained revealed that the grain and straw yields of wheat increase significantly up to 1,7 ppm of boron in water. Above this level, a decrease was observed. The yields at 4,7 ppm were almost equal to those observed at 0,7 ppm. In case of barley, they noted that the grain and straw yields increased to as much as 2,7 ppm boron in irrigation water. Further increase in boron concentration resulted in reduced yields but yields obtained at 8,7 ppm of boron in water were not statistically different from those obtained at 0,7 ppm. Their results indicate that wheat and barley can be safely grown on loamy sand soils deficient in boron with waters containing up to 4,7 and 8,7 ppm of born respectively. Pathak et al., (1975) studying the effect of different concentrations of boron in irrigation water on sunflower, found that the results obtained from this experiment show that successful cropping of sunflower can only be possible with irrigation water having B concentration of less than 1 ppm. Although 1 and 2 ppm lies within the safe limit, it requires better cropping management. Beyond a concentration of 2 ppm B, water is unsafe for irrigation surfaces on a sunflower crop.

From the literature cited,, it is quite clear that in most cases, tolerance to boron is judged by development of visual injury symptoms rather than by reduction in yield. The suitability of irrigation waters has been evaluated on the basis of criteria which determine the potential of the water to provoke plant injury and yield reduction. In assessing the boron concentration in irrigation water, however the physical-chemical characteristics of the soil most be taken into consideration because of the interaction between boron and soil.

Thus, it is important to clarify under which conditions the soil can act as a buffer with respect to boron in the soil solution. This knowledge may improve the efficiency of using waters of difference qualities, since water with high boron levels could be used to irrigate boron-sensitive cropping in soils that show a high affinity to boron. However, existing criteria make no reference to differences in soils type. Therefore, the suitability of an irrigation water with respect to boron must be evaluated in consideration of the specific conditions under which it will be used, including crops to be grown, the physical-chemical properties of soils, irrigation management, cultural practices and climatic conditions.

A variety of soil properties have been identified as affecting the behavior of boron in soils: clay mineral types (Hingston, 1964; Keren & Mezuman, 1981), clay content and specific surface area (Biggar & Fireman, 1960; Hatcher & Bower, 1967; Sims & Bingham, 1968; Keren & Gast, 1983); organic matter content (Berger, 1949; Gupta, 1968), soil pH (Hingston, 1964; Keren et al., 1981; Keren & Mezuman, 1981; Keren & Gast, 1981; Sems & Bingham, 1967) and soil salinity (Couch & Grim, 1968; Keren & O'Connor, 1982) have been reported to influence the boron distribution between the liquid and the solid phase in soil. Elrashidi & O'Connor (1982), related soluble native and adsorbed boron to some physical and chemical properties of 10 soils statistically and found that clay content, organic carbon content, cation exchange capacity, specific surface and electrical conductivity of the saturation extract were significantly correlated with the adsorbed boron.

The detoxification of boron, can be achieved by following one of the following two methods. The first involves treating the irrigation water directly with salts such as calcium or magnesium, which precipitate boron in and insoluble form; the second is addition of some of the soil amendments to the soil with the aim of changing its chemical characteristics and creating soil condition favorable to the detoxification of boron by reducing its availability and solubility.

The effect of organic matter on boron availability has been studied by several workers. In general it was observed that soils containing considerable amounts of organic matter were often high in available boron, while soils containing less organic matter very often low in this respect. Berger & Prati (1963), stated that a large part of the total boron in soils is associated with the organic matter in tightly bound compounds. However, this boron can be released to the soil solution, in forms available to plants, by microbial activities. Mezuman & Keren (1981), studied the effect of organic matter on boron adsorption by a soil containing 1,2 % organic matter and found it to be negligible.

The addition of organic matter to soils could be one of the practicable approaches in lowering the harmful effect of irrigation with waters of relatively high boron concentration level, due to its high capacity for retaining boron in a complex forms. On the other hand, on the mineralization of organic matter due to microbial activities, the retained boron is once more released to the soil solution. Thus, the addition of organic matter is still a matter of controversy.

Injury symptoms in plants (from boron deficiency) have been noted on limed acid soils. In acid soils, boron deficiency in plants has often been ascribed to a phenomenon of overliming. Midgley & Dunklee (1940) and Scott et al., (1975) concluded that such injury was the result of boron adsorption by the soil induced by pH increases. In addition to the indirect effect of calcium carbonate on boron distribution between the liquid and solid phases in soil, it is possible that coprecipitation of boron with calcium carbonate can occur in calcareous soils. This behavior of boron in a calcium carbonate solution has been studied by Kitano et al. (1978). They found that the amount of boron precipitated with calcium carbonate was proportional to the concentration of boron dissolved in their parent solution, and this relationship is affected by the crystal form of calcium carbonate precipitated and the concentration of NaCl dissolved in the parent solution.

Mezuman & Keren (1981), showed that a boron adsorption model can be used for calcareous soils as well as non-calcareous soils, indicating that under the experimental conditions no interaction between boron and calcium carbonate occurred. It is possible, however, that when calcium carbonate precipitates from the soil solution, both blockage of adsorption sites and coprecipitation with calcium carbonate occur.

In this respect, this study was carried out to elucidate the role the soil amendments, particularly organic matter and calcium carbonate, could play in the detoxification of boron in the irrigation water.

3. MATERIAL AND METHODS

Two soils samples were selected for this study: a clay soil, representing the fine-textured soils, and a sandy soil sample, as a representative of the coarse-textured soils. The soil samples were thoroughly mixed with the soil amendments calcium carbonate and peat moss, as a source of organic matter.

The calcium carbonate was mixed with the soil at two differents ratios, 1:10 and 1:5, corresponding to the calcium carbonate percentage 10 and 20 respectively. The peat moss was mixed with the soil at 5 and 8% levels. Twenty five kg of the treated soils were placed in plastic pots 36 cm in diameter contain a layer of gravel at the bottom to maintain proper drainage.

Ten broadbean seeds (variety supersimonia) were planted in each pot. The pots were arranged in a randomized block design with three replicates for each treatment. The arrangement of the pots was changed each week so as to minimize as much possible effects of light and temperature in the greenhouse.

Four irrigations water treatments were applied to the investigated soils. The first, a control treatment, was irrigated with normal water having the following composition: Ca^{++} 5,75 meq/L, Mg^{++} 2,21 meq/L, Na^{+} 2,23 meq/L, K^{+} 0,45 meq/L, HCO_3^{-} 8,0 meq/L, Cl^{-} 3,3 meq/L, SO_4^{--} 0,5 meq/L and EC of a value 850 mmhos/cm. The other three irrigation treatments were with water having a boron concentration of 2, 5 and 10 ppm. The moisture content of the soil was kept constant at 60% of the water saturation capacity throughout the cropping period and the losses in water due to evapotranspiration were compensated for by addition by weight. Two weeks after germination the plants were thinned to 6 per pot and each pot received 0,67g N, 0,80g P and 1g K using the corresponding amounts of the chemicals pure NH_4NO_3 and KH_2PO_4 administered in solutions.

To follow the boron content and concentration in broadbean plants as a function of the addition of soil amendments and successive irrigations of waters having differents boron concentrations, plant samples were taken at different stages of growth after a certain number of irrigations. After 3, 8, 14, 18 and 23 irrigations, one broadbean plant was harvested, washed and drieded and the dry way weight/plant was recorded.

The total boron in plants was determined: one gram oven-dried and finely ground plant sample was wet digested by nitric, perchloric and sulfuric acids (Jackson, 1960). After digestion it was chemically transferred and filtered to a suitable volume, and a second 2 ml aliquot of the filtrate was taken for boron determination using the carmine sulfuric acid procedure, as described by Hatcher & Wilcox (1950).

4. RESULTS AND DISCUSSION

The dry matter production of broadbean plants in g/plant at the different sampling times are presented in Figure 1, which shows average values for all water boron concentrations at the various concentrations of amendments.

The dry matter production when the soil was mixed with the $CaCO_3$ soil amendment and irrigated with waters having different boron concentration, after three irrigations, which provided total boron additions of 8, 20 and 40 mg/pot for the three B concentration respectively (first sampling), there no was practical variation in the development of the young plants, which mostly weighed 1,5-1,7 g each.

After 23 irrigations, plants that had been subjected to 355 mg/pot of boron weighed only 6,7 % less than those that had received none at all, and even in the presence of the maximum concentration of $CaCO_3$, the reduction remained 6,5 %.

With respect to the plants treated with organic matter, while the first sampling produced yields very similar to those with $CaCO_3$, yet after subsequent samplings there was a consistent tendency towards a drop in yield at higher organic matter levels. This is particularly strinking with the 5th and last sampling, where the boron control showed a 26 % drop in yield at 6 % organic matter with respect to zero level. Comparing these final harvest for added organic matter with those for $CaCO_3$, we find no real difference in yield at any of the boron concentration levels, indicating that the separate addition of amendments in combination with boron has no influence on plant production, though there may well be differences in plant boron concentration and uptake.

When the two amendments were employed together, the first sampling showed the same results as when the amendments were used separately. At the second sampling, there was a slight increase with the 5 ppm boron treatment with respect to the others, as has already been observed for the $CaCO_3$ alone treatment. After subsequent samplings it was found that soils containing higher levels of organic matter (6%) consistently produced lighter yields, whatever the content of calcium carbonate. It should be noted that after the final harvest, the yield under the highest concentrations of $CaCO_3$, and organic matter combined was the lowest absolutely. Addition of boron resulted in reduced yield with respect to the control treatment, even though the actual quantity of boron added did not appear to make a great deal of difference. The addition of calcium carbonate to the soil did not depress yield significantly, while organic matter caused reductions, not only separately but also in combination with $CaCO_3$

The addition of $CaCO_3$ or organic matter, or a combination of both, appeared to protect the plants against higher concentration of boron, as yields did not continue to go down overall at higher boron levels, and indeed in a few cases increased in the presence of amendments.

The fact that dry matter production was not drastically reduced in the presence of high concentrations of boron should not lead to the illusion that boron makes no difference to crop yield. On the contrary, severe toxicity symptoms manifested themselves at all boron levels, in the form of the yellowing and burning of leaves. The leaf edges showed a yellow margin which gradually extend and became scorched as time went by.

The relative influences of $CaCO_3$ and organic matter soil amendments separately and in various combinations on plants boron concentration are illustrates in Figure 2, which shows average values for all water boron concentrations at the various concentrations of amendments. The lack of an overall tendency in the presence of $CaCO_3$ contrasts with the consistent drops in concentration associated with the proportions of organic matter added to the soil. The curves for the two amendments combined show depressions in plant boron concentration for those amendment combinations in which the proportion of organic matter is highest.

The data indicate that the boron concentration in plants increases in proportion to the increase in the boron concentration in irrigation water and to the amounts of boron added due to successive irrigation. In this respect it is worthy of note that after successive irrigation with waters having different boron concentration levels, a part of the added boron will be adsorbed by soil colloidal particles and a part will be free in soil solution. From the moment that the soil reaches it's maximum adsorption capacity, the majority of added boron will remain free in soil solution, leading to adsorption by plants and consequent severe toxicity symptoms.

As the plants respond to dissolved boron only (Hatcher et al., 1959), therefore the boron concentration at this early stage is met only from the soluble boron initially found in the soil, besides that found in the seed broadbeans.

Figure 3 compares the uptake of boron over the five samplings with respect to the two different soil amendments individually and in combination. It can be seen that $CaCO_3$ has no consistent influence on boron uptake, bearing in mind that the boron scale for the first two samples is very sensitive and shows differences which are in fact minimal. On the other hand, in the presence of organic matter, there is a definite trend towards reduction of uptake the greater the organic matter concentration. When the two amendments are mixed, the lowest B uptake values occur when the proportion of organic matter is highest: (10+6) and (15+6). Hence it is clear that B uptake is reduced by organic matter and not by calcium carbonate.

To examine the situation at the end of the growth period with regard to plant yield, boron concentration and boron uptake as a function of the soil and water variables independently and in a combination, a statistical analysis of the fifth sample findings was carried out, and is presented in Table (1). It is immediately evident that the boron concentration in the irrigation water did not significantly influence plant yield, whereas the organic matter present in the soil had a highly significant influence on dry matter production, and $CaCO_3$ influenced only a 5 % probability level. The yield was highly influenced by the interaction of water boron concentration and organic matter amendment, whereas the combination of the former with calcium carbonate showed only a 5 % influence and the interaction of the two soil amendments no significant influence. On the other hand, if we consider all three variables taken together, The influence on plant dry matter production was highly significant.

With respect to the boron concentration in the plants, in confirmation of what emerged from the figures, the only factors which did not show a significant influence were the calcium carbonate and the interaction of this amendment with the boron concentration in the irrigation water. The interaction of the two amendments did show a 5% influence, but this is attributable to the strong influence of the organic matter. Similarly, the interaction of the three variables under study showed a 5 % influence. The boron concentration in the water and the organic matter, together with the interaction between them, were the predominant influences on plant boron concentration.

The similarity in the statistical data between boron uptake and concentration confirms the previous impression that organic matter has an important role in plant adsorption of boron, whereas calcium carbonate does not, and that both uptake and concentration of boron in plants are functions of the boron concentration in the irrigation water.

Table 1. Analysis of variance for the yield, B uptake and B concentration in the last (5th) sampling of broadbean plants.

SOURCE OF VARIANCE	CALCULATED F. VALUES		
	Yield (g/plant)	B- uptake (mg/plant)	B concentration (ppm)
Concentration (A)	1,75 NS	910,4 * *	1496,8 * *
Organic Matter (B)	16,3 * *	49,0 * *	61,48 * *
$CaCO_3$ (C)	4,9 *	< 1	1,47 NS
Interaction (A x B)	10,0 * *	11,2 * *	19,3 * *
Interaction (A x C)	2,39 *	1,86 NS	< 1
Interaction (B x C)	< 1	2,65 *	3,1 *
Interaction (AxBxC)	2,71 * *	1,65 NS	2,8 *

(*) Significant
(**) Hihgly significant

5. CONCLUSIONS

The dry matter of the plants was influenced by boron and soil amendments only to a limited extent. Yield was only reduced at the later stages of growth by the presence of boron and this was true even when the boron concentration in the irrigation water was low. This tendency to reduced yield was accentuated by the organic matter amendment, while the calcium carbonate made no difference. Although yield was not greatly reduced as an effect of irrigation with boron, there was evidence of crop damage in terms of burnt and yellowed leaves, a typical symptom of boron toxicity. The statistical analysis confirmed that the boron concentration in irrigation water did not significantly influence plant yield, whereas the organic matter present in the soil had a highly significant influence on dry matter production, and $CaCO_3$ influenced only at a 5% probability level. The yield was highly influenced by the interaction water boron concentration and organic amendment, whereas the combination of the former with calcium carbonate showed only a 5% influence and the interaction of the two soil amendments no significant influence. On the other hand, if we consider all three variables taken together, the influence on plant dry matter production was highly significant.

The boron concentration of the plants increased in proportion to increases in the boron concentration in the irrigation water and to the amounts of boron progressively accumulating in the soil. Calcium carbonate had little influence on this, but in contrast there were consistent reductions in boron concentration in relation to the proportions of organic matter added to the soil. This effect was particularly marked at intermediate boron levels in the irrigation water. As regards the statistical analysis, the only factors which did not show a significant influence where the calcium carbonate and the interaction of this amendment with the boron concentration in the irrigation water. The interaction of the two amendments did show a 5% influence, but this is attributable to the strong influence of the organic matter. Similarly, the interaction of the three variables under study showed a 5% influence. The boron concentration in the water and the organic matter, together with the interaction between them, were the predominant influences on plant boron concentration.

The uptake of boron by the plants revealed itself to be greater, the higher the concentration of boron on the irrigation water, and the greater the plant development. Comparing the influence of the soil amendments, it was found that calcium carbonate had no definite effect on uptake, whereas organic matter reduced water boron levels. While moderate doses of organic matter performed this function well at low water boron concentrations, a higher organic matter proportion is required with high concentrations of boron. In the case of mixed soil amendments, those with higher proportions of organic matter were more effective in reducing uptake. Statistically the uptake was influenced in a similar way to concentration, with the difference that the interaction between all three variables was not statistically significant. This similarity confirms that organic matter has an important role in plant adsorption of boron, whereas calcium carbonate does not, and that both uptake and concentration of boron in plants are functions of the boron concentration in the irrigation water.

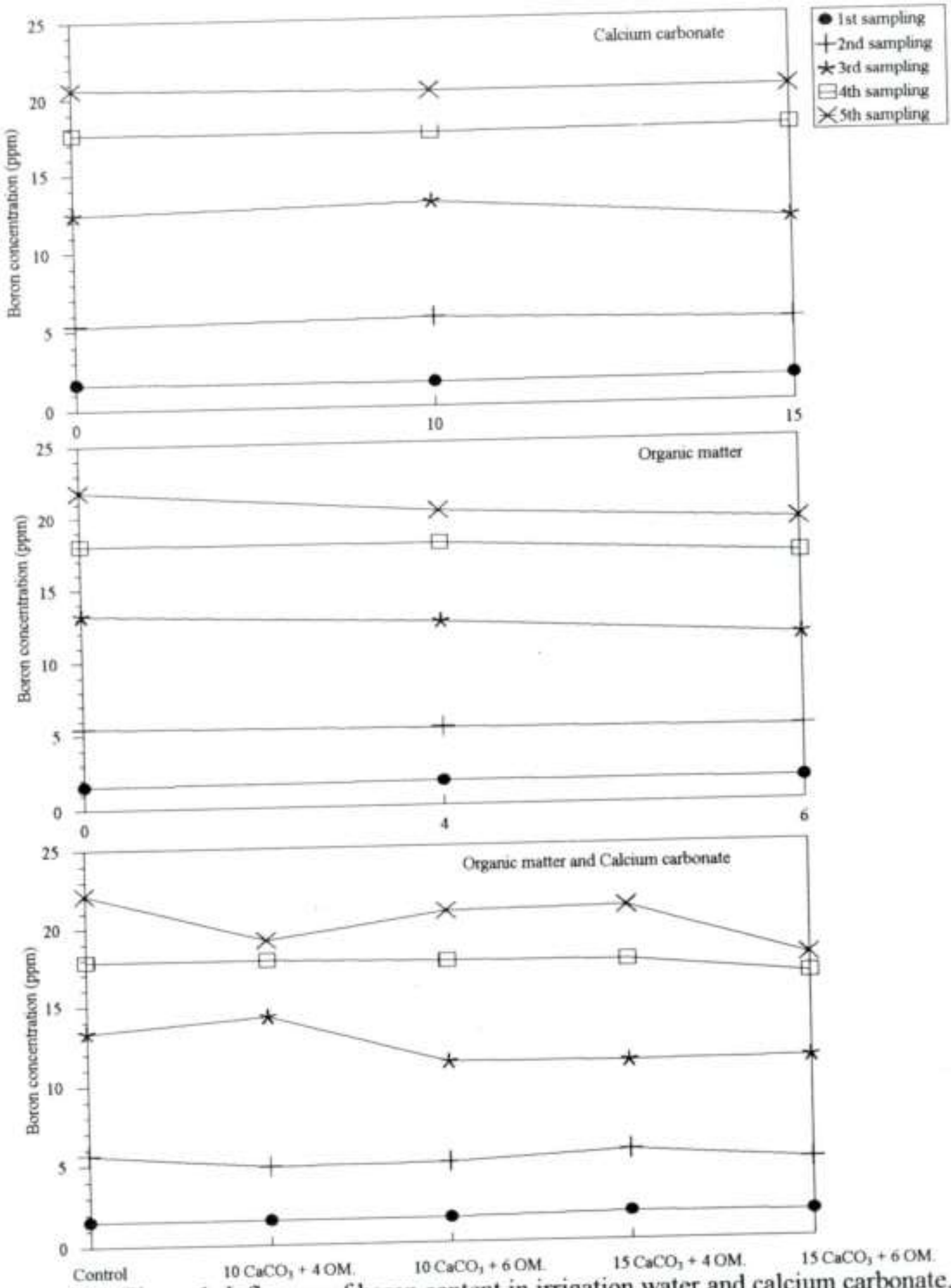

Figure 1. Influence of boron content in irrigation water and calcium carbonate, organic matter content and the various combinations of organic matter and calcium carbonate on dry matter production (g/plant).

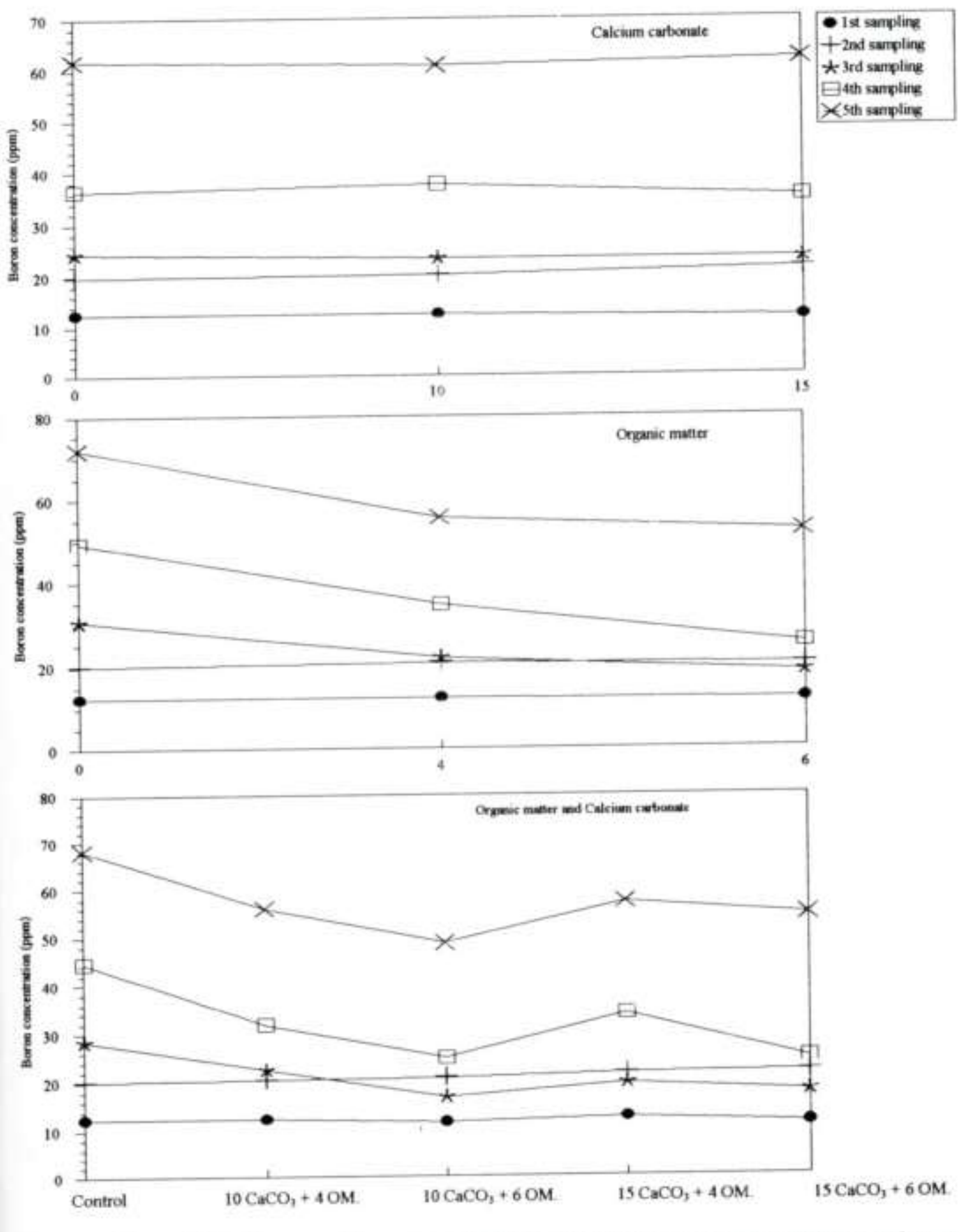

Figure 2. Influence of boron content in irrigation water and calcium carbonate, organic matter content and the various combinations of organic matter and calcium carbonate on boron concentration (ppm/plant).

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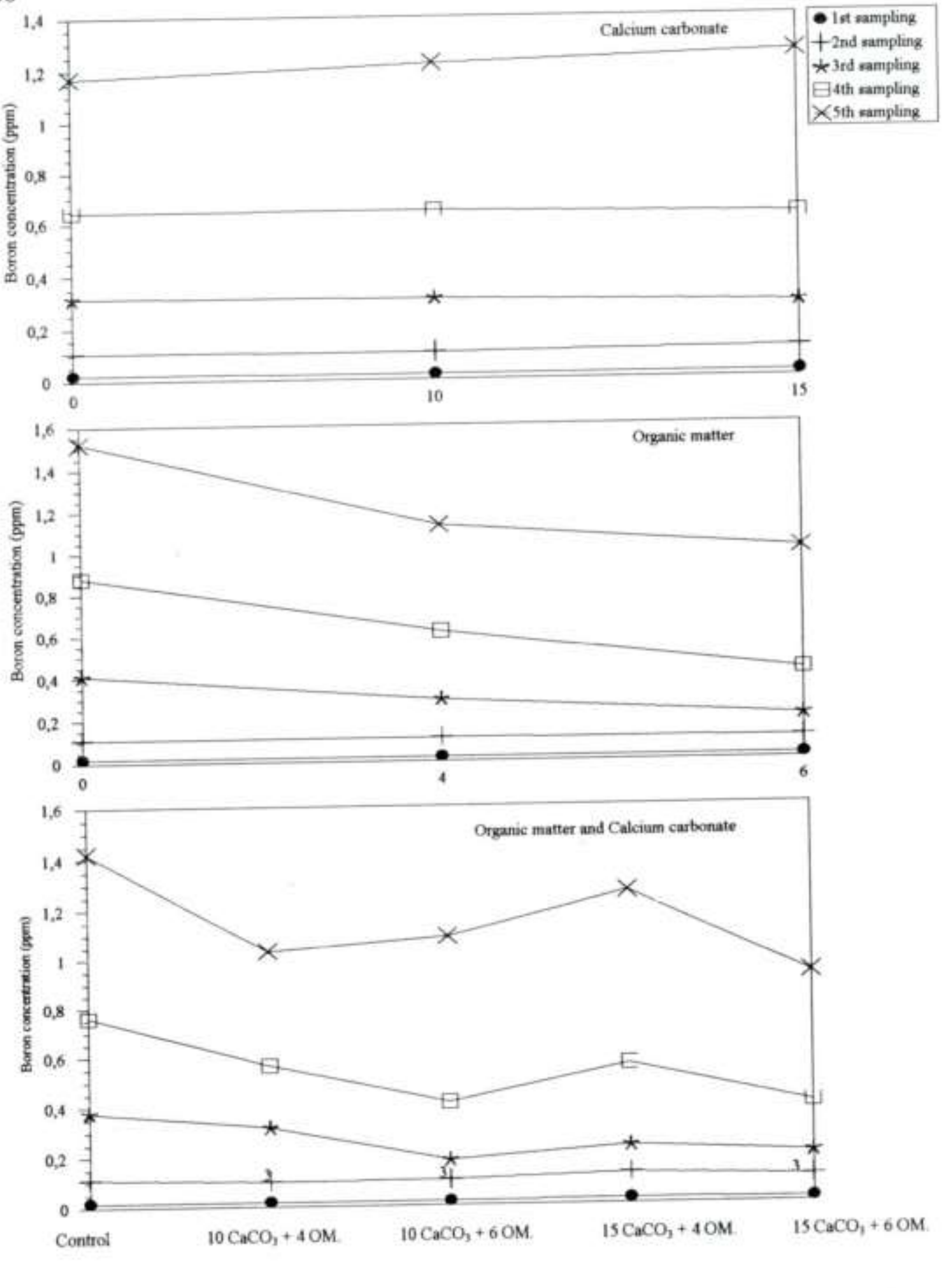

Figure 3. Influence of boron content in irrigation water and calcium carbonate, organic matter content and the various combinations of organic matter and calcium carbonate on boron uptake (mg/plant).

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