Synergistic effects of cadmium and NaCl on the growth, photosynthesis and ion content in wheat plants

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Abstract

The addition of NaCl to cadmium had significant synergistic effect on the wheat root and shoot fresh mass, relative growth rate and net assimilation rate, while showed no significant effects on the dry mass production, leaf area, leaf area ratio, leaf mass ratio and specific leaf area. Additive depression of the rate of photosynthesis and the stomatal conductance was recorded, while no significant effect on the transpiration rate was observed. The Cd stress disturbed the mineral nutrition of the wheat plants either directly or indirectly, NaCl markedly reduce the uptake and internal concentration of K and Ca in the shoot. The combination of cadmium and NaCl showed no additive effects on the content of ions in the root as well as in the shoot of wheat plants.

Key words: growth analysis, net photosynthetic rate, stomatal conductance, *Triticum aestivum*, water use efficiency

Introduction

Salinity can inhibit plant growth by low external water potential, ion toxicity and ion imbalance (for review see *e.g.* Greenway and Munns 1980). The degree to which each of these factors affect growth depends on the plant genotype and environmental condition. Under saline conditions mutual effects of ions on their absorption are of particular interest. Ions in high concentration in the external solution (*i.e.* Na ions) are taken up at high rate, which lead to excessive accumulation in the tissue. This ions may inhibit the uptake of other ions into roots (*i.e* K or Ca) and their transport to the shoot through the xylem, eventually leading to their deficiency in the tissue. The effect of high NaCl salinity on micronutrient nutrition have been studied to a much lesser extent than those on macromutrient nutrition (Dahiya and Singh 1976). There have been some studies on the uptake of cadmium by food crops both from the soils (Miller *et al.* 1976) and nutrient solution (Jarvis *et al.* 1976). Photosynthesis has been

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reported to be the most sensitive process affected by the heavy metals (Cligsters and Van Asshe 1985, Mohanty and Mohanty 1988, Sheoran *et al.* 1990).

Materials and methods

Seeds of wheat (*Triticum aestivum* cv. Sakha 69) were surface sterilized, washed several times in deionized water and germinate in moist vermiculite for 10 d. After germination uniform size seedlings were transferred to plastic pots, each contained 600 cm^3 of continuously aerated half strength Hoagland solution (pH 5) which was renewed twice a week. Plants were distributed randomly in a glasshouse at (day/night) temperature 25/20 °C, relative humidity 70 % and a photoperiod 14 h at irradiance 250 μmol(PAR) m^2 s^{-1}. Seedlings remained in the aerated nutrient solution for 10 d and aliquot of concentrated $CdSO_4$ solution was added to achieve levels 10 mol(Cd^{2+}) m^{-3}. NaCl was added up to a final concentration of 100 mol m^{-3} by increasing concentration 50 mol m^{-3} at alternative days. Each treatment was replicated six times. Plants were harvested for growth analysis every third day, and divided into roots and shoots. Fresh mass was measured and dry mass was obtained after drying at 60 °C to constant mass. Leaf area was measured using *LI 3100 area meter (LI/Corp.,* Lincoln, USA*)*. The rate of net photosynthesis and transpiration were measured 4, 10 and 13 d after the final cadmium and salt application. using and infrared gas analysis by clipping a single leaf in a Parkinson leaf chamber of a portable *ADC-LCA3 System* (*The Analytical Development Company Ltd*, Hoddesdon, UK) at a photon flux density of about 250 μmol(PAR) m^{-2} s^{-1}. Five replicates were taken each time from dried material. Nine cations *i.e.* Na, K, Ca, Mg, Fe, Cu, Zn, Mn, and Cd were measured in triplicate by spectrophotometry using atomic absorption after acid digestion of dried plant material in concentrated HNO_3:HCl (4:1, v/v) mixture. Analysis of variance was carried out according to procedures in Sokal and Rohlf (1981). The significance of differences between mean values for treatments was estimated using log transformed data.

Results

Root length, shoot height, roots and shoot dry mass production, number of leaves and final leaf area of wheat plants were reduced by the application of Cd, NaCl, and Cd-NaCl stresses, especially 15 d after treatment (Fig. 1). Relative growth rate (RGR) and net assimilation rate (NAR) of wheat plants were high at the beginning of stress application but depressed significantly with the plant age and were affected by Cd, NaCl and Cd-NaCl stresses (Fig 2). Leaf area ration (LAR), leaf mass ratio (LMR) and specific leaf area (SLA) was significantly reduced by NaCl and the combined Cd-NaCl stress but the Cd-treatment showed no significant effect (Fig. 2). SLW was significantly enhanced with NaCl and Cd-NaCl (Fig. 2). Cd, NaCl and Cd-NaCl content negatively correlated with the rate of photosynthesis and stomatal conductance. A highly significant inhibition of the transpiration rate by NaCl was recorded after 13 d from application, while no significant effect was recorded in water use efficiency under the same conditions. In contrast to NaCl treatments, Cd stress showed a highly significant depression of the water use efficiency after 13 d of exposure but no effect was recorded on the transpiration rate.

In plants treated with Cd and Cd-NaCl stress, Cd accumulation in both shoots and roots was highly significant. The total amount of this element in the shoot was lower than in roots, while no Cd accumulation in NaCl treated plants was observed in both shoots and roots (Fig. 4). In plants treated with NaCl and Cd-NaCl stress, the increased Na uptake was highly significant in both shoots and roots, while the Na uptake in Cd treated plants was not changed (Fig. 5). Potassium and calcium accumulation in both shoots and roots recorded a highly significant depression under NaCl and Cd-NaCl treatments especially after 15 d of stress, while in Cd treated plants nonsignificant affect on the accumulation of this elements was recorded (Fig.

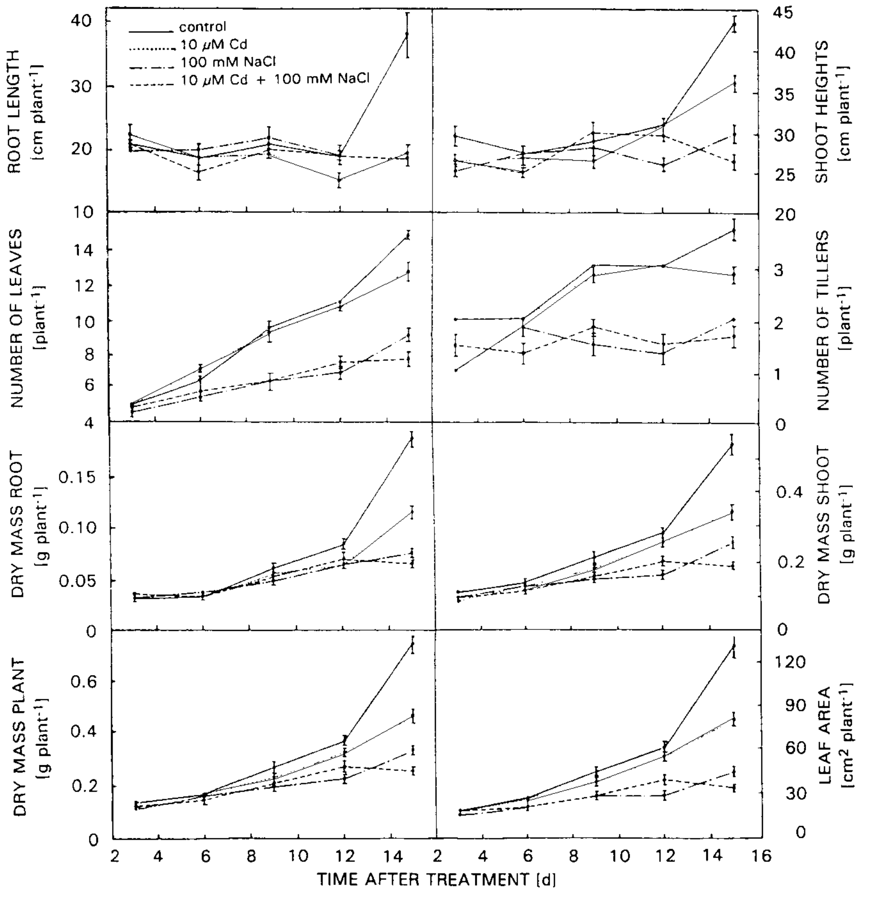

Fig. 1. The effects of Cd, NaCl and Cd-NaCl stresses on root length, shoot height, the number of leaves, tillers production, dry mass of root, shoot and plant and leaf area during growth after treatments. Bars show S.E. of six replicates.

4 and 5). A slightly significant increase in Na/Ca ratio and Na/K ratio was evident with NaCl treatment but no effect with Cd and Cd-NaCl treatment in shoot and roots. Magnesium accumulation in roots showed a significant depression under NaCl and Cd-NaCl treatments but an increase of Mg in Cd treated plant was observed (Fig. 4). The depression of Mg in the shoot under Cd and Cd-NaCl treatments, while no effect appeared in treated plants (Fig. 4). Cd and Cd-NaCl treatments increased significantly the Cu content in the roots, whereas NaCl treatments induced a significant reduction of the Cu in roots, similarly Cd and Cd-NaCl treatments decreased significantly the Cu content in the shoots, while Cd-NaCl treatments did not affect the Cu content in shoots (Fig. 4). Zinc and manganese content in both shoots and roots were significantly depressed by all treatments particularly after 15 d of treatments (Fig. 5).

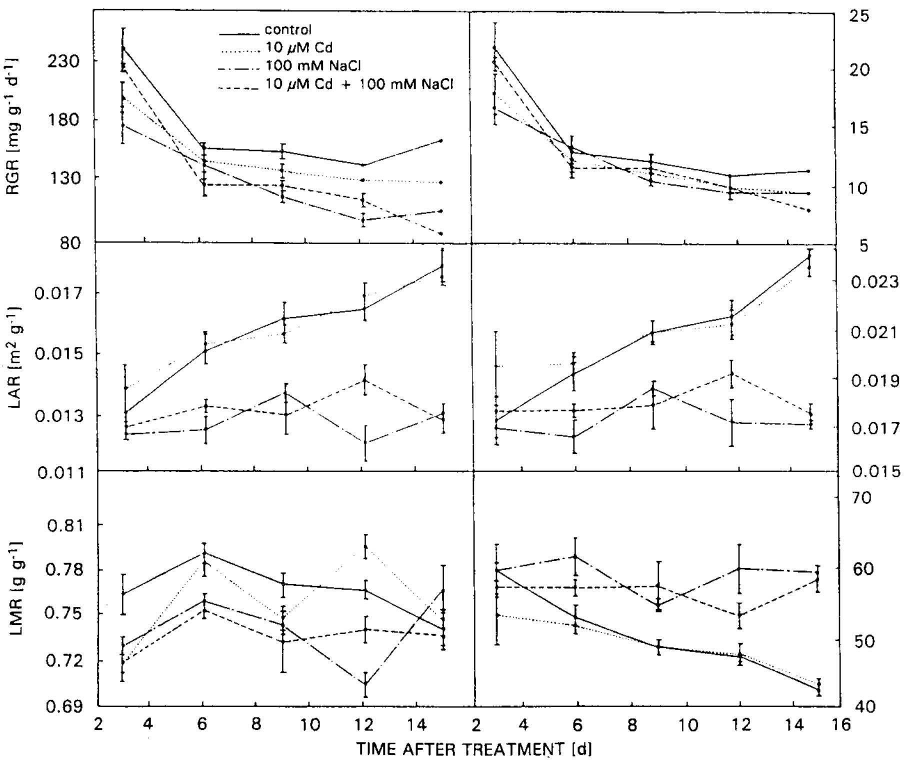

Fig. 2. The effect of Cd, NaCl and Cd-NaCl on the relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), specific leaf area (SLA) and leaf mass ratio (LMR) of wheat plant. Bars show S.E. of six replicates.

Discussion

Cadmium is a highly phytotoxic affecting plant growth and yield (Kloke and Shenke 1979). The results of these investigation showed that inhibition of growth parameters of wheat by Cd is time dependent. NaCl inhibited all the growth parameters. Growth inhibition by NaCl is commonly accepted to be mostly due to a lowering of the water potential of growth media (Greenway and Munns 1980, Rozema 1991). The combination Cd-NaCl have shown no significant synergistic effects on the root,

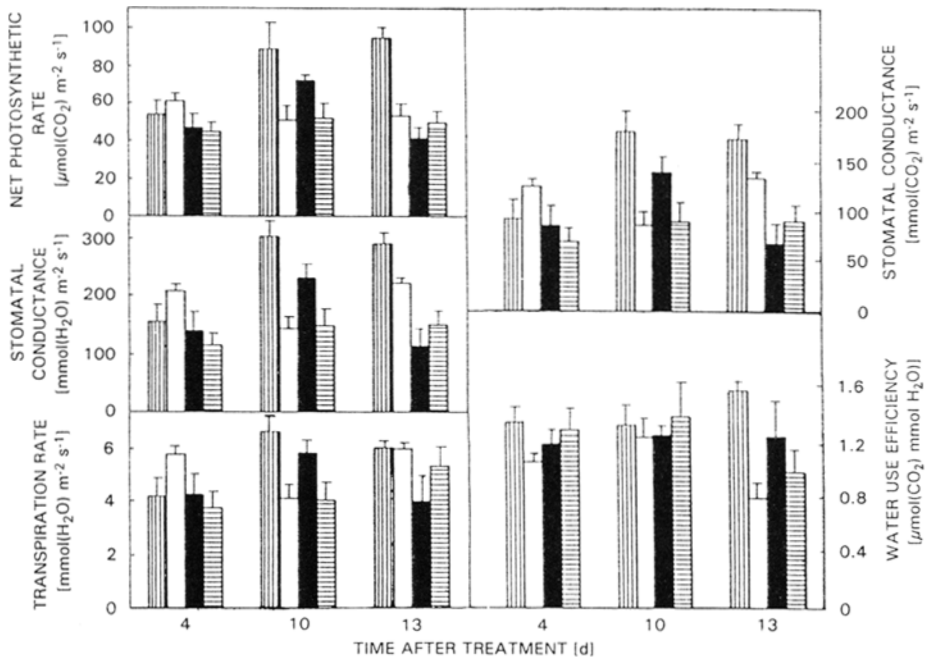

Fig. 3. The effect of Cd, NaCl and Cd-NaCl on the net photosynthetic rate, stomatal conductance for water vapour, stomatal conductance for CO_2, transpiration rate and water use efficiency of wheat plant. Error bars show SE of six replicates.

may not influence its availability. The leaf area showed a highly significant negative response to Cd. This is in agreement with Barcelo *et al.* (1988); they suggested that the decrease of the leaf area may not only be due to the reduced cell size, but also to decrease the intercellular spaces. The highly significant depression in the leaf area by NaCl treatment agree *e.g.* with Drew *et al.* (1988), who reported that the reduction of leaf area by salt may be due to reduction on the leaf expansion (probably due to the effect of NaCl on cell division or cell expansion or both). Depression of RGR by Cd-NaCl treatment may be due to the inhibition of NAR as well as LAR in NaCl treated plants, while LAR may not be involved in Cd treated plants. The reduction of LAR may mainly be due to the redaction of SLA and a little reduction of LMR. SLW increased significantly with NaCl application. These results agree with Rawson (1986), who found that SLW was increased with salinity in wheat and barley plants.

The rate of photosynthesis, water use efficiency and stomatal conductance were depressed, while there was a little reduction in the transpiration rate with Cd application. The rate of photosynthesis as well as water use efficiency may be reduced by Cd and other heavy metals when added to nutrient solution as reported *e.g.* by Bazzaz *et al.* (1975). They probably act on chloroplast functions, as reported by Kirkham (1978). Li and Miles (1975) suggested that Cd alters the reaction center of PS 2. De Filipps *et al.* 1981 have suggested that Cd acts as a photophosphorylation shoot and plant dry matter production, these may be due to using suplhate

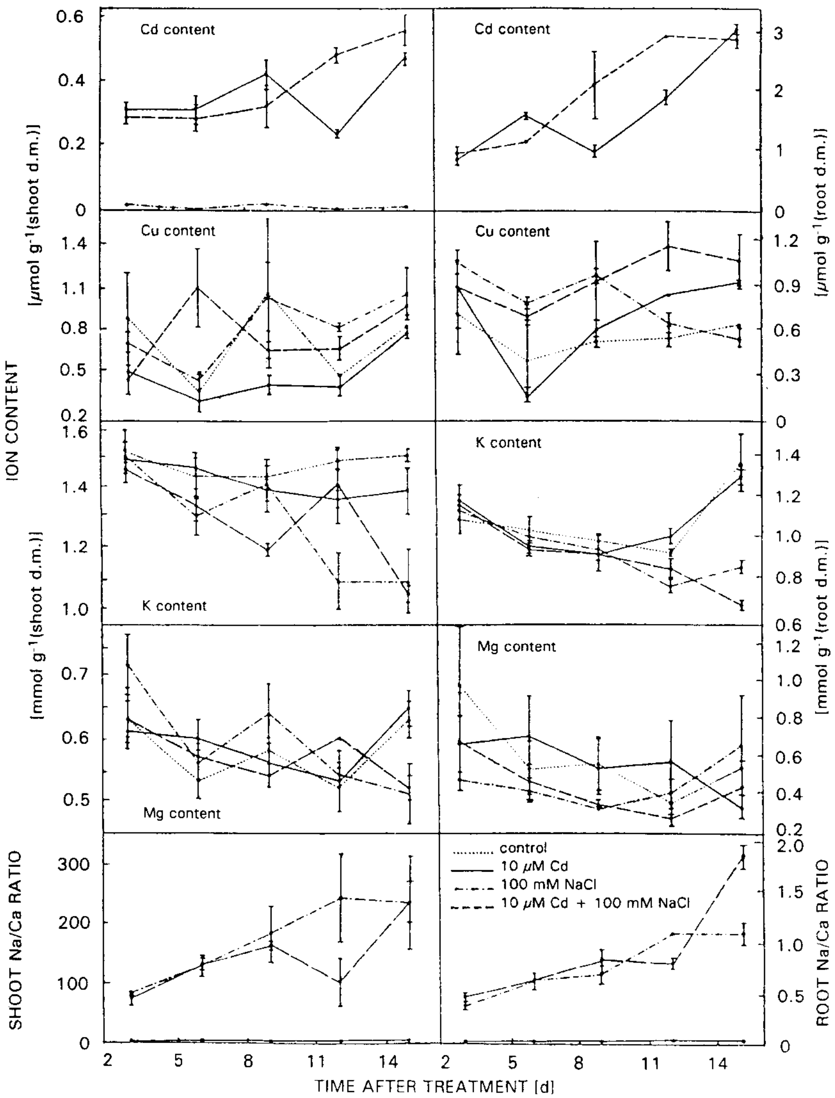

Fig. 4. The effect of cadmium, NaCl and Cd-NaCl on the Cd, Cu, K, Mg concentration and Na/Ca ratio in shoots and roots of wheat plants. Data are means of three replicates ± SE.

salt of Cd and Cd complexes readily with the chloride, and sulphate, hence increase in salinity inhibitor in spinach chloroplasts. On the other hand, Lamoreaux and Chaney (1978) proposed that Cd inhibits the net photosynthesis by decreasing both stomatal and mesophyll conductance to CO_2 uptake. Recently Sheorean *et al.* (1990) have reported that Cd and Ni reduced the rate of photosynthesis by affecting the electron transport system and stomatal conductance more than enzymes of

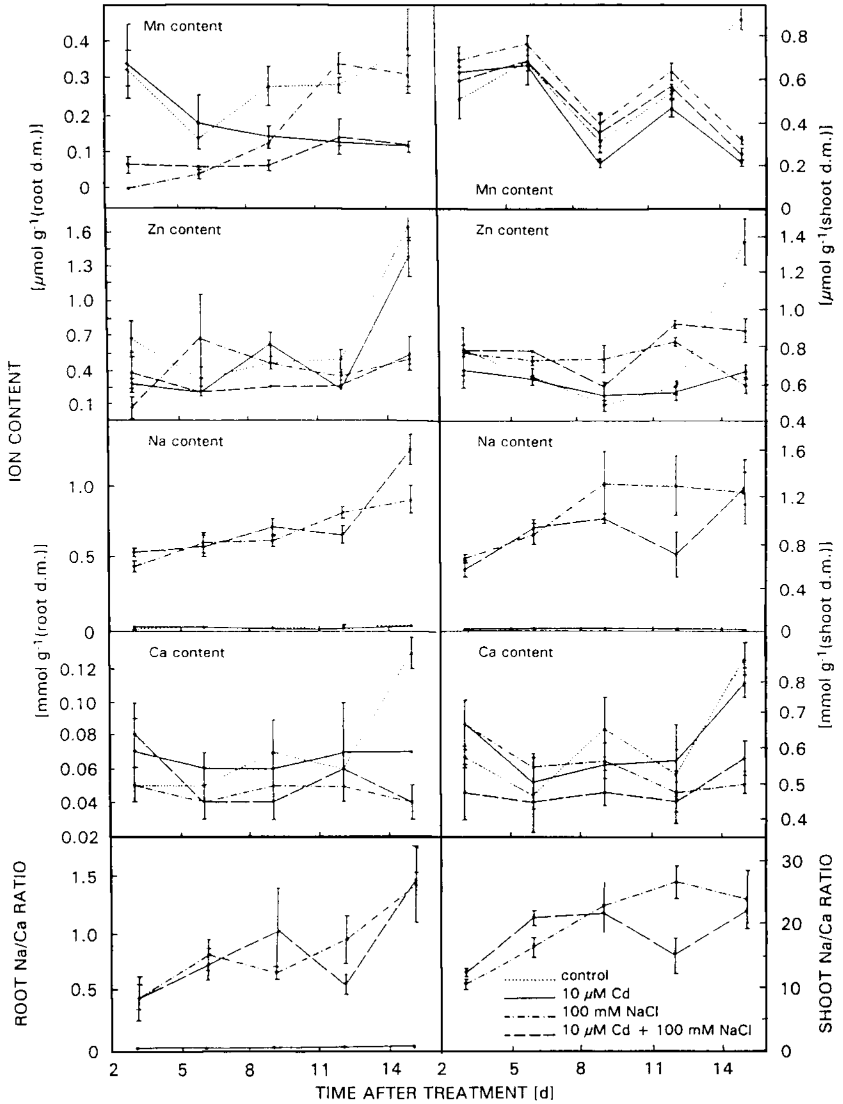

Fig. 5. The effect of Cd, NaCl and Cd-NaCl on the concentration of Mn, Zn, Na, Ca and on Na/K ratio in shoots and roots of wheat plants. Data are means of three replicates ± SE.

carboxylation. It is also clear that saline environment inhibited photosynthesis. The reduction of photosynthesis under NaCl stress was probably caused by stomatal as well as non-stomatal inhibition of photosynthesis (*e.g.* Walker *et al.* 1982) including the inhibition of activities of enzymes which may participate in the so-called dark phase of photosynthesis.

The Cd content of the roots as well as the shoots of Cd-treated plants indicated that Cd absorbed by roots was easily translocated within the plants (Leita *et al.* 1991). Nevertheless, the most of the total Cd was localized in roots. The combined Cd-NaCl stress caused a marked increase in the soluble Cd, as well as a significant increase in the Cd content of the roots and the shoots of wheat plants. These results are in agreement with the finding of Bingham *et al.* (1983). The presence of Cd in nutrient solution disturbed the uptake and consequently shoot content of the Mn, Fe and Zn. The Cd treatment induced Fe deficiency symptoms Barcelo *et al.* (1985) and reduced Zn absorption by plant (Chaney *et al.* 1976). There was no significant effects of combination of Cd with NaCl in these respects.

NaCl had major effects on the uptake and internal concentrations of mineral elements in wheat. The Na uptake by roots and its internal concentration in shoots of NaCl-treated plants were markedly increased. There was no additive effect on the Na content in roots as well as in shoots with the combined Cd-NaCl stress. The other ions such as K, Ca and Mg contents in the roots of NaCl treated plant were sharply decreased. The shoot ion content showed the same trend except for the Mg content of the shoot which was not significantly affected by NaCl as well as Cd-NaCl stress. The effect on Mn content in the roots of NaCl-treated plants support above mentioned results as Mn is a part of the water splitting enzyme of photosystem 2. Thus a Mn deficiency may cause a reduction of photosynthesis and growth.

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