ACTA AGROBOTANICA
Vol. 33, z. 1 — 1980
59-71

Effect of foliar fertilization of *Capsicum annuum* L. together with optimal root fertilization in hydroponic culture on fruit yield and its capsaicin content

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(Received: November 8, 1977)

Abstract

The Wrocław version of hydroponic culture was applied. The optimal dose of mineral nutrient solution for root-fertilizing was found to be 19.6 g and 22.4 g of mineral salts per one plant during the whole vegetation season. In a separate experiment plants with optimal root fertilization were sprayed with multicomponent solutions of mineral salts. The sprays were applied weekly for 15 weeks. The concentrations of solutions for spraying were: 0.28, 0.84 and 1.4 per cent. The greatest increase of fruit yield was noted after the 0.84 per cent solution. At optimal concentration of spray solution (0,84%) chelating agents added (EDTA or humate) had no effect. Addition of the chelating agents to the 1.4% solution attennated its inhibitory effect. The humate gave a better effect than EDTA. A tenfold increase of micro-elements content (6 mg/l of each instead of 0.6 mg/l) in 0.28 per cent spray solution produced a marked increase of the yield of fruits and of their capsaicin content.

INTRODUCTION

Foliar application of fertilization is mostly done as a supplementary treatment, when some element is lacking or deficient in the plant culture (Boynton, 1954; Duczmal, 1974). Some papers suggest the possibility of foliar fertilization when supply of fertilizer to the roots is difficult (Hodossi, 1974). A number of authors consider that

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foliar application is more effective than soil fertilization (Byszewski and Sadowska, 1974).

In recent years more and more frequent studies of this problem tend to the development of new multicomponent preparations and to an exhaustive testing of the already known preparations of the type Murphy Foliar Feed, Wuxal and others (Byszewski and Kalinowska-Zdun, 1974; Rumińska, 1974; Trzecki and Kibil, 1974).

It seemed of interest to investigate the effect of foliar application with optimal supply of fertilizer to the roots. Moreover, one the basis of results of studies on the interaction of chelators with root fertilization (Gumiński et al., 1965), it was undertaken to establish the action of humate and EDTA together with the hydroponic nutrient solution applied to the leaves.

MATERIAL AND METHODS

The experiments were carried out in a polyethylene tunnel in the years 1974 and 1975. As experimental objects served *Capsicum annuum*, variety 'Bronowicka ostra' (hot). The seeds were received from the Institute of Medicinal Herbs Industry in Poznań. The plants were cultivated according to the Wrocław version of hydroponics (Gumińska, 1966) in 1l type Weck jars coated with black paint to prevent light penetration to the medium and with white on top to prevent excessive warming. Plastic bowls 7-10 cm deep and 12 cm in diametre with a perforated bottom (perforations of 10 and 12 mm) were placed on the jars. The bowls were filled with hydroponic matrix and in each one plant was set. As matrix a mixture was used of brown coal with particle size 5-15 mm with peat in 1:1 v/v proportion. The peat was alkalised with NaOH to pH 6.0-6.2. The nutrient solution was prepared after Hampe in Gumińska's modification (1966). The basic composition (g/l tap water) was as follows:

superphosphate (16-18% P_2O_5)	1.0
$CaNO_3 \cdot 4H_2O$	0.7
KNO_3	0.7
$MgSO_4 \cdot 7H_2O$	0.3
$Fe_2(SO_4)_3 \cdot nH_2O$	0.1

$MnSO_4 \cdot 5H_2O$, $ZnSO_4 \cdot 7H_2O$, $CuSO_4 \cdot 5H_2O$, H_3BO_3 and $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ — 0.0006 of each.

Beside the basic solution (n), double ($2n$), 3-fold ($3n$) and 5-fold ($5n$) concentrations were used. Higher concentrations were prepared by increasing in the same proportion the amounts of all the chemical compounds. The pH of the medium was maintained at 6.6-6.8, and

checked during vegetation. If necessary the solution was alkalised with NaOH or acidified with H_3PO_4.

In the course of the experiments protective agents against aphids were applied: Nogos GEC 50, mszycol and Bi 58.

The outdoor meteorological conditions during the experiments are shown in Table 1.

Table 1

Meteorological data during the experiments

Month	Year	t (°C)	r.h. (%)	S (h)	t_{max}	t_{min}	t<13°C
VI	1974	18.8	80	130.9	19.4	14.2	3
	1975	21.4	86	129.1	22.6	12.4	7
VII	1974	21.4	83	131.1	23.4	12.8	0
	1975	25.1	87	198.9	26.8	13.6	0
VIII	1974	24.6	87	181.3	27.6	13.9	1
	1975	23.7	79	235.0	27.3	13.8	1
IX	1974	17.4	84	150.7	20.2	11.0	7
	1975	21.6	82	158.8	24.2	12.6	3
From 20 V	1974	19.5	83	634.3	22.4	12.4	24
to 6 X	1975	21.5	85	774.3	23.6	13.1	18

Explanation of symbols: t — average air temperature (outdoor), r.h. — relative humidity, S(h) — sun irradiation (hours in the month), t<13°C — number of days with average day and night temperature <13°C.

The effect of the variable parametres on the fresh weight of fruits, their dry weight, the per cent of ripe fruits and the capsaicin content of the latter and its yield were determined in the experiments.

Measurements and determinations were done of fruits with the peduncle not longer than 2 cm. The dry weight of the fruit was established by weighing in mean random samples in 3 replications. The per cent of ripe fruits was determined for all the plants in the given combination. As ripe fruits were assumed the red ones with a slight brown spot and those which had completely changed colour.

Capsaicin content was determined in the fruits by the colorimetric method with the use of ammonium vanadate (Jończyk, 1967) in air-dry material with moisture content determined. Fully coloured fruits were taken for analysis, dried at 24-28°C without sun light access (Borkowski et al., 1957). Analyses were three times replicated on mean random samples in each combination. The mean capsaicin yield was determined as the product of dry weight yield of fruits and the amount of capsaicin in one dry weight unit.

Each experimental combination was replicated 6 times. One repli-

cation consisted of one plant growing in one jar. Statistical elaboration was done by analysis of variance for experiments with one variable (Uliński a, 1957). The significance of differences between all pairs of means was estimated by Duncan's multiple range test (Waller and Duncan, 1969).

DETAILS OF METHOD APPLIED IN DETERMINATION OF OPTIMAL ROOT FERTILIZATION OF *CAPSICUM ANNUUM* L.

The seeds were sown on 20 March into the coal-peat matrix in the glasshouse. The seedlings were transplanted on 17 April to 10-cm pots, and set in the jars on 20 May. Mineral salts were added in increasing doses (Fig. 1). Basic nutrient medium *n* was used, before setting in the jars. The plants were fertilized twice weekly. The solution volume necessary for one fertilization in the given combination was calculated by the formula.

$$V = \frac{(d_1 - d_2 - d_3)}{n} \cdot \frac{1}{c}$$

where: V — volume of nutrient solution necessary for one fertilization treatment (ml), d — amount of mineral salts (g/plant), d_1 — for the whole vegetation period, d_2 — supplied during seedling production, d_3 — supplied when setting plants in jars, n — number of fertilization treatments, c — indicates the amount of salts (g) per 100 ml medium.

For achieving an appropriate medium level in the jar (2-4 cm air layer between medium and hydroponic matrix), tap water was added when necessary. After the end of the experiment the amount of mineral salts taken up by the plants and the matrix was determined by subtracting from the quantity of salts supplied over the entire experimental period, the amount which remained in the medium at the end of the experiment.

DETAILS OF METHODS IN EXPERIMENT ON INFLUENCE OF FOLIAR-APPLIED FERTILIZATION

The seeds were sown on 20 May into the hydroponic matrix. During the entire vegetation period each plant received 19.6 g of mineral salts applied to the roots in the form of medium *n*. This dose proved optimal for hydroponic culture of *Capsicum annuum* (Fig. 1). With optimal supply of salt to the roots, the plants were additionally fed foliarly nutrient solution of the following compostition and concentration:

1) basic concentration (0.28%) *n*
2) threefold higher concentration (0.84%) *3n*

3) fivefold higher concentration (1.4%) *5n*

4) basic concentration with 10 times increased amounts amount of microelements (6 mg of each) *n10m*

5) moreover, to the same combination EDTA or sodium humate was added +E +H

Beside control spraying with water, sprayings were done solely with EDTA and solely with humate.

EDTA was used in 10 mg/l amounts and sodium humate (extracted from brown coal) in the amount of 100 mg soluble in water per litre of the tested solution (Gumińska and Gracz-Nalepka, 1972). The biological activity of sodium humate was checked by the test of unaerated hydroponic cultures of tomato seedlings (Gumińska et al., 1968) and compared with the action of humate obtained from compost.

Foliar application was done in the form as spraying. The treatment was applied in early morning hours at air temperatures 20-25°C (Nelson and Krauskopf, 1974), once weekly, after the roots had reached the medium. Up to the beginning of flowering each plant was sprayed with 30 ml of the tested solution (6 times), and later with 40 ml (jointly 15 sprayings).

RESULTS

Fertilization both through roots and leaves had a strong influence on the yield of *Capsicum annuum*.

As the dose of root fertilization was increased within the range of 2.8 to 19.6 g mineral salts per one plant over the entire vegetation period, the yield of fruit fresh weight increased considerably (Fig. 1). Doses of 19.6 and 22.4 g proved optimal for the hydroponic culture. The fruit yield with these doses was 101.6 and 98 g, respectively, per plant. Fertilization more intensive than optimal through the roots reduced the yield the more the higher were the doses. It was noted that fertilization with quantities of mineral salts higher than the optimal requirements of *Capsicum annuum* reduced fructification less than did fertilization with amounts lower than optimal. An increase of the optimal dose by about 20 g diminished the fruit yield by about 40 g, whereas fertilization with an amount about 8 g lower than optimal reduced the yield by 80 g. The fructification of *Capsicum* was not proportional to the quantity of taken up mineral salts. The salinity of the medium increased in proportion to the amount of salts applied and was highest (1%) with highest fertilization doses. With the remaining doses it did not exceed 0.53 per cent.

The capsaicin content in the fruits did not depend on quantitatively different fertilization of the roots with basic medium and was 1.83 (dose 5.6 g) to 2.09 mg/g dry weight (dose 89.6 g). Only with the lowest dose (2.8 g) was the capsaicin content lower as compared with that corresponding to the highest fertilizer dose and it amounted to 1.76 mg/g dry weight.

No influence of root fertilization on dry weight content in the fruits could be detected. Dry weight varied within 16.86 to 18.70 per

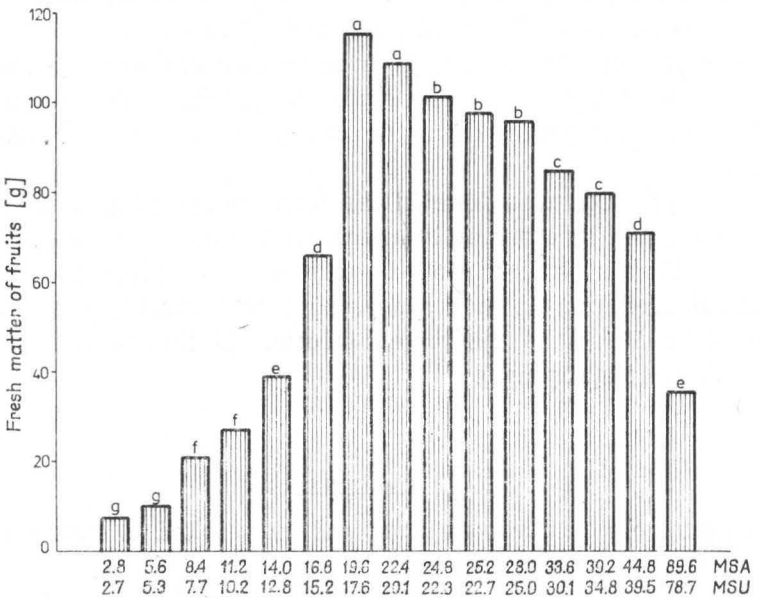


Fig. 1. The influence of different doses of mineral salts given to roots in the hydroponic culture on the fresh matter of *Capsicum annuum* L. fruits

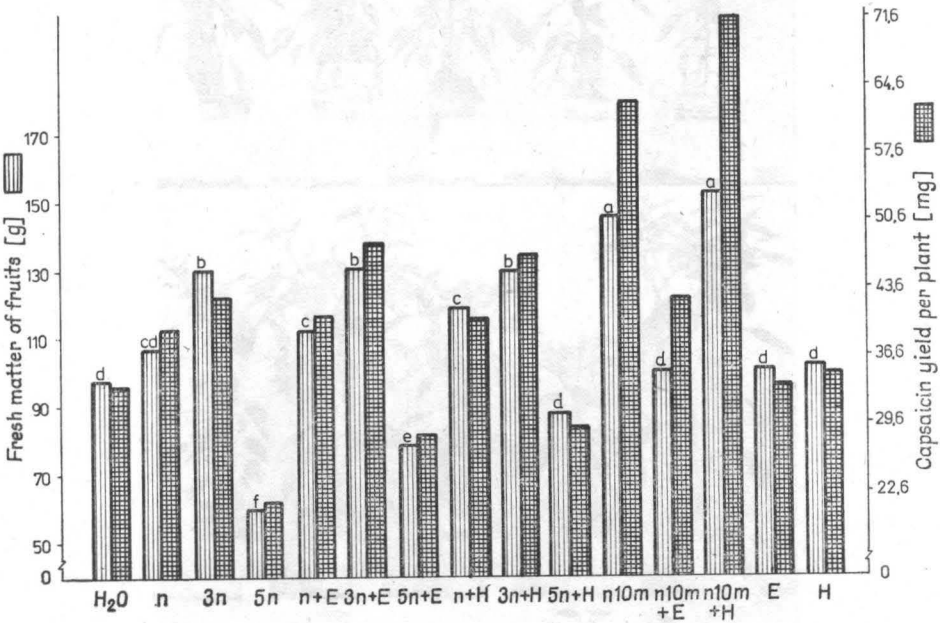
MSA — mineral salts added (g per one plant), MSU — mineral salts used (g per one plant with substrate), (c) — control; Values followed by the same letter are not significantly different at the 0.05 level after the Duncan's multiple range test

cent. The number of ripe fruits varied between 90 and 100 per cent with lowest salt doses up to 44.8 g, and with the highest dose it was 81 per cent. The capsaicin yield varied in the range of 2.3 to 39.2 mg/per plant and was the higher the greater was the fruit harvest.

Foliar application with optimal root fertilization influenced the fruit yield and their capsaicin content. Foliar application of medium *n* gave no effect (Fig. 2). Spraying with *3n* medium increased the weight of fresh fruits, whereas a *5n* concentration proved too high and reduced the fruit yield. Addition of EDTA to medium *n* and *3n* was without effect. When added to medium *5n* EDTA attenuated the unfavourable effect of the too high salts concentration. Humate added

to medium *n* evoked a tendency to an increase in yield. With the dose *3n* it had no effect, but when applied with the toxic dose (*5n*) it abolished its inhibitory action on the yield. The action of humate was, therefore, stronger than that of EDTA in the case of the toxic dose.

Foliar fertilization with *n10m* medium increased the fruit yield and, interestingly, also the capsaicin content in them. Addition of EDTA abolished this influence in respect to the fresh weight of fruits,



The influence of foliar fertilization with multi-component nutried solution and of chelating agents on the fruit yield of *Capsicum annuum* L. and on the yield of capsaicin

n — normal content of nutrients (19.6 g per plant and per vegetation season — see methods), 3n and 5n — nutrients content increased 3 times or 5 times, n10m — normal content of nutrients but the amount of microelements increased 10 times; E — EDTA added; H — humate; Values followed by the same letter are not significantly different at the 0,05 level after the Duncan's multiple range test

but not as regards the capsaicin level in them. Sodium humate was without effect on both the fruit yield and capsaicin content. Capsaicin content in fruits of plants treated with mediums: *n10m*, *n10m*+E and *n10m*+H was 2.23, 2.31 and 2.36 mg dry weight, respectively (in the remaining combinations it was 1.82 to 1.94 mg/g dry weight).

Spraying with EDTA or humate solely was without effect.

Capsaicin yield was the higher the greater was the yield of fruits (Fig. 2). In plants sprayed with *n10m* medium, capsaicin yield was also related to its level in the fruits.

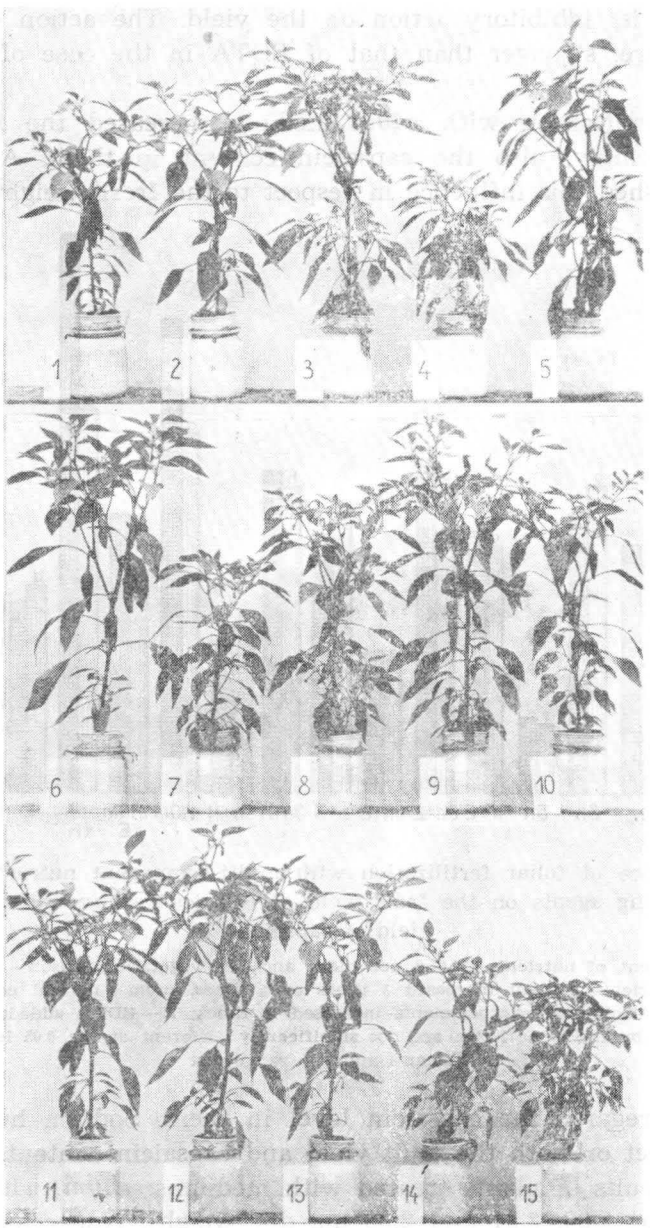


Fig. 3. The effect of foliar fertilization on the growth of *Capsicum annuum* L.

1 — water; 2 — n; 3 — 3n; 4 — 5n; 5 — n+EDTA; 6 — 3n+EDTA; 7 — 5n+EDTA; 8 — n+H; 9 — 3n+H; 10 — 5n+H; 11 — n10m; 12 — n10m+EDTA; 13 — n10m+H; 14 — EDTA; 15 — H; For other details see Fig. 2

No influence was noted foliar nutrient application on dry weight content of fruits which varied from 16.44 to 19.55 per cent. The per cent of ripe fruits was 91 to 100. Addition of EDTA or humate to the spraying medium slightly reduced the number of ripe fruits.

DISCUSSION

The purpose of the present study was to find a way of increasing the capsaicin yield in *Capsicum annuum* cultures and to check the influence of foliar fertilization together with optimal supply of fertilizers to the roots.

The method of hydroponic culture was chosen because it makes possible strict control of fertilizer supply to the roots and it creates optimal water and air conditions (lower part of root system in water solution of mineral salts, upper part in air), hardly feasible under soil conditions. The composition of the medium used proved optimal for hydroponic culture of a number of plants (Gumińska, 1966; Gumińska and Gracz-Nalepka, 1972).

The effect of various mineral salts doses in hydroponic medium on the yield of *Capsicum annuum* (Fig. 1) is somewhat similar to that of soil fertilization (mainly NPK) on the yield of other plants (Voisin, 1972). The reaction of *Capsicum* to doses higher than optimal is interesting. Superfertilization of the plants reduced the yield much less than did a deficit of nutrient components. Although with doses higher than optimal the plants were not taller than with optimal dose (Fig. 3), nevertheless the quantity of mineral salts remaining in the medium after the harvest (salinity) was only slightly higher then with the optimal dose. This seems to indicate a certain regulation of the medium concentration by the plants. With high fertilizer doses the plants could take up more mineral salts and their content per dry weight unit of the plants could be increased. This regulation may also be achieved by passive translocation of the medium along the roots to the hydroponic matrix, where the salts remained after water evaporation. This problem requires further investigation, the more so since in the literature concerning soilless cultures no pertinent data have been found.

The nutritional requirements of *Capsicum annuum* in hydroponics as compared with those of other plants cultivated hydroponically (Gumińska and Graczówna, 1970; Nowak 1980b) are low. This is due to the relatively small biomass of these plants.

The various fertilization doses which failed to affect the capsaicin content in the fruits confirms indirectly the data of Jaruszewski and Owsiany (1958) and of Golcz et al. (1970) who reported

a lack of influence of NPK fertilization on the capsaicine amount in the fruits. A slight retardation of ruit ripening by high doses of mineral salts was probably due by an excess of nitrogen which prolongs vegetation and fruit ripening in *Capsicum* (M a t e v, 1966).

Foliar application of nutrition in the present experiments with optimal root fertilization was tested because no such data could be found in the literature. Most experiments with foliar fertilization have been run in early development phases of the plants (N o w o s i e l s k i and B e r e ś n i e w i c z, 1974) or over the entire vegetation season, but with a deficite of some nutrient components (B y s z e w s k i and S a d o w s k a, 1974) or under conditions favouring a deficiency of one of the nutrient components.

The results of the experiment shown in Fig. 2 prove that with optimal fertilization of the roots the fruit yield and the capsaicin level in them can be improved by addition al foliar feeding. Essential here are the concentration and composition of the solution used for spraying. In most cases of foliar application 2 per cent solutions are used (in urea spraying as high as 10%) in dependence on the plant species and its development phase (B y s z e w s k i and S a d o w s k a, 1974). As regards *Capsicum annuum* the optimal concentration proved to be 0.84 per cent, and a 1.4 per cent was already toxic (Fig. 2). Particularly important, beside the concentration, proved the microelements content which in the amount of 6 mg/l increased the capsaicin content of the fruits. This is very important since no other treatment seemed to affect the content of this substance, for instance growth regulators were of no avail (N o w a k, 1980b).

The action of EDTA and sodium humate requires separate consideration. These chelating agents in the *n* and *3n* medium had no effect. When added to a toxic concentration of the medium (1.4%) they abolished or attenuated its unfavourable action, humate exerting a stronger effect than EDTA.

EDTA in medium with increased amount of microelements abolished their influence increasing fruit yield, but did not affect their action on capsaicin yield. Sodium humate, on the other hand, showed no such influence. The different action of these two chelators may be the result of their different complex-forming properties. The action of humate does not, moreover, consist exclusively in formation of complexes with cations, it is also manifested in a favourable influence on the plants at unappropriate pH (J u r k o w s k a, 1964; B a d u r a, 1965) and excessively high medium concentration (G u m i ń s k a et al., 1971) or when some nutrient components are lacking in the medium (G u m i ń s k i et al., 1965; C z e r w i ń s k i, 1967).

The question which of the microelements affects the capsaicin con-

tent in the fruits of *Capsicum annuum* is tentatively answered in another publication (N o w a k, 1980a).

The present results indicate that, with optimal fertilization through the roots, the fruit yield and their quality can be improved by foliar nutrient application. This indicates a possibility of increasing the yield by foliar fertilization with mineral salts not only under conditions of deficient nutrient, but also with optimal supply to the roots. It would seem useful to test whether foliar fertilization may increase the yield in other plants under conditions of optimal nutrition supply through the roots.

The author wishes to express his thanks to docent dr habil. Z. G u m i ń s k a of the Botanical Garden, Wrocław University for her valuable advice and indications in the course of the experiments and to docent dr habil. J. K o z ł o w s k i of the Institute of Medicinal Herbs Industry in Poznań for acquainting him with the problems of medicinal plants.

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Wpływ dolistnego dokarmiania pieprzowca rocznego (*Capsicum annuum* L.) przy optymalnym nawożeniu w hydroponikach na plon owoców i zawartość kapsaicyny

Streszczenie

Stosowano hydroponiczną uprawę pieprzowca rocznego w wersji wrocławskiej. Określono optymalną dawkę nawożenia dokorzeniowego w ilości 19,6 lub 22,4 g soli mineralnych na jedną roślinę na cały okres wegetacji. W osobnym doświad-

czeniu, przy optymalnym nawożeniu dokorzeniowym, rośliny opryskiwano cotygodniowo (łącznie 15 oprysków) wieloskładnikowymi roztworami soli mineralnych. Roztwory te podawano roślinom bez chelatorów lub z EDTA albo z humianem sodowym. Stwierdzono, że dolistne dokarmianie pożywką o stężeniu 0,28% jest bez znaczenia, pożywką o stężeniu 0,84% zwiększa plon owoców, a stężenie 1,4% jest za wysokie. Dodanie EDTA lub humianu do pożywki o stężeniu 0,28% lub 0,84% jest bez znaczenia. W pożywce o stężeniu toksycznym (1,4%) chelatory osłabiały lub znosiły ujemne działanie nadmiaru soli mineralnych użytych do oprysku, przy czym humian działał silniej od EDTA. Dziesięciokrotne zwiększenie ilości mikroelementów (6 mg każdego z nich na litr, zamiast 0,6 mg na litr) w pożywce, o stężeniu 0,28% zwiększyło plon owoców. Dodanie do tej pożywki humianu było bez znaczenia, natomiast EDTA znosiło to działanie. Różne sposoby traktowania dokorzeniowego i dolistnego na ogół nie wpływały na zawartość kapsaicyny w suchej masie owoców; dziesięciokrotne zwiększenie ilości mikroelementów w pożywce do oprysku liści istotnie podniosło zawartość tego składnika w suchej masie owoców.