FOLIA UNIVERSITATIS AGRICULTURAE STETINENSIS
(antea: Zeszyty Naukowe Akademii Rolniczej w Szczecinie)
Abbrev.: Fol. Univ. Agric. Stetin. 193 Agricultura (73): 197–206, Ann. 1999

*CEZARY PODSIADŁO, STANISŁAW KARCZMARCZYK, ZDZISŁAW KOSZAŃSKI, EWA RUMASZ*

# INFLUENCE OF SUPPLEMENTAL IRRIGATION AND MINERAL FERTILIZATION ON SOME PHYSIOLOGICAL PROCESSES AND YIELD OF THREE LEGUME PLANTS CULTIVATED ON A SANDY SOIL

# WPŁYW DESZCZOWANIA I NAWOŻENIA MINERALNEGO NA AKTYWNOŚĆ PROCESÓW FIZJOLOGICZNYCH ORAZ PLONOWANIE TRZECH GATUNKÓW ROŚLIN STRĄCZKOWYCH UPRAWIANYCH NA GLEBIE LEKKIEJ

Department of Plant Production and Irrigation, Agricultural University of Szczecin
Słowackiego 17, 71-434 Szczecin, Poland

Key words: irrigation, fertilizer doses, small bean, pea, lupine, yield, physiological processes.
Słowa kluczowe: deszczowanie, dawki nawozu, bobik, groch, łubin, plon, procesy fizjologiczne.

The study was aimed at the assay of the effects of overhead irrigation and high mineral fertilization on pigment content, enzyme activity, photosynthesis, and the yield of small bean, pea and white lupine cultivated on a sandy soil.

It was found that irrigation and high doses of fertilizers caused an increase of pigment content in the tested plant leaves, and modified the activity of red-ox enzymes. The intensity of photosynthesis, transpiration and diffusive conductance of the leaves was also enhanced.

As effect of the increased physiological activity caused by the applied treatments, the yields of grain and straw markedly increased.

## INTRODUCTION

Intensification of agricultural production on sandy soils which cover over 60% of Poland's arable soils will always be the subject of research. One of the means enhancing yields of plants cultivated on such soils is providing the plants with sufficient water and proper mineral fertilization which makes the cultivation of such demanding plants as small bean and pea, possible. Of the scarce papers dealing with the influence of intense agrotechnique of legumes planted on sandy soils, the ones published by Borówczak (1997), Dzieżyc (1989), Karczmarczyk (1979), Grabarczyk et al. (1995), Panek (1983), Stock et al. (1981) should be mentioned.

Better growth of legume plants when irrigation was applied and the ensuing higher yield can be explained by enhanced activity of the plant's physiological processes during vegetation. Therefore this study was aimed at the assessment of the influence of overhead irrigation and high doses of mineral fertilizers on the content of chlorophyll and carotenoides in the plants, intensity of photosynthesis and enzyme activity of small bean, pea and white lupine, cultivated on a sandy soil.

## MATERIALS AND METHODS

The field and lab experiments were done in 1995-1996 on a sandy soil (5 Bw, pgl:pgm). The humus content was 1.3-1.5%, floatable parts 11-13%, $pH_{KCl}$ 5.2-5.6.

The temperature and rainfall were close to the average. Although these years were not extremely dry, rain deficit occured in 1995 in April, May and July, and in 1996 in April and June. The irrigation doses were 80-100 in 1995, and 40 mm in 1996. The first factor of the experiment was irrigation (O and W), the second - 4 levels of mineral fertilization (0, 120, 240, 360 kg NPK/ha). The proportion of NPK was 1:2:3. The irrigation doses and timing were determined by the plants' 10-day water requirement (Dzieżyc et al. 1987).

Samples for the assay of pigments were taken from the top leaves of small bean (cv. Tinos), and of white lupine (cv. Bardo), stipule and tendrils of pea (cv. Tegma), at the stage of fruit formation. The pigment content was assessed colorimetrically in N,N-dimethylformamide extracts, at 440, 645 and 663 nm. The activity of enzymes and nitrate content was assessed in the same plant organs. The nitrate content was measured by an ionselective electrode, the nitrate reductase using reduced NADH as hydrogen donor, the phosphatase and peroxydase activity - by colorymetry. The leaf surface was measured by the Delta-T Image Analysis System (DIAS). Intensity of $CO_2$ assimilation, transpiration, $CO_2$ concentration in the substomatal cells, stomatal conductance, leaf temperature were measured by the LCA-4 analyser of British production. The measurements were taken at the fruit forming stage. These analyses, and the pigment content were done for the 0, 1, 3 NPK plots, non watered and watered. The crops were harvested from 18 $m^2$ plots and calculated as tons per 1 ha. All results were subjected to statistical analysis of variance.

## RESULTS

The plant's content of photosynthetic pigments is influenced by the environment, particularly by naturient and water supply, as by insolation. Data presented in Tables 1, 2, 3 proved that the applied agrotechnical measures significantly changed the pigment contents of all tested plants.

The highest content of chlorophyll and carotenoides was found in small bean leaves (Table 1). The chlorophyll content increased as effect of fertilization by 26%, (chlorophyll a by 31, chlorophyll b by 41%). The effect of irrigation was only 10%. Of the pigments which are active in photosynthesis, a big role play the carotenoides which, according to Devlin and Barker (1971) protect the chlorophyll against photooxydation, transmit the light energy to chlorophyll and also take part in the carbon dioxide assimilation. As effect of irrigation the carotene content increased by 8%, but as effect of fertilizer by 15%.

Table 1. Pigment content in small bean leaves (μg/g fr. wgt.)

| Irrigation | Mineral fertilization (kg/ha) | Chlorophyll a | Chlorophyll b | Total chlorophyll | Carotenoides |
|---|---|---|---|---|---|
| Not irrigated | 0 | 1395 | 428 | 1823 | 709 |
| | 120 | 1454 | 482 | 1936 | 782 |
| | 360 | 1570 | 579 | 2149 | 812 |
| Mean | | 1473 | 496 | 1969 | 768 |
| Irrigated | 0 | 1453 | 458 | 1911 | 754 |
| | 120 | 1469 | 509 | 1977 | 863 |
| | 360 | 1870 | 670 | 2539 | 875 |
| Mean | | 1597 | 545 | 2142 | 831 |
| Effect of fertilization | 0 | 1424 | 443 | 1867 | 731 |
| | 120 | 1461 | 495 | 1957 | 823 |
| | 360 | 1720 | 624 | 2344 | 843 |
| $LSD_{0.05}$ for: | irrigation | 78 | 33 | 101 | 45 |
| | fertilization | 124 | 47 | 116 | 51 |
| | interaction | 179 | 69 | 146 | 73 |

The chlorophyll content in pea was much smaller than in small bean (Table 2), but the impact of irrigation and fertilizers was larger. Irrigation caused a 30% increase of chlorophyll content in the stipule, the high fertilizer dose - even by 60%; the carotenoides content increased by 22 and 52%, respectively. The stipule which are leaf substitute, contained approximately half the amounts of the tendrils, and increases caused by irrigation and fertilization were also much smaller. The white lupine leaves contained also large amounts of pigments, though not as large as small bean; irrigation caused an increase of chlorophyll content by 27%, fertilization - by 40%. Ratio of chlorophyll b to a was approximately 1:4, and was almost the same in all compared plants.

Table 2. Pigments content in the tendrils and stipules of pea (µg/g fr. wgt.)

| Irrigation | Mineral fertilization (kg/ha) | Chlorophyll a | | Chlorophyll b | | Total chlorophyll | | Carotenoides | |
|---|---|---|---|---|---|---|---|---|---|
| | | stipules | tendrils | stipules | tendrils | stipules | tendrils | stipules | tendrils |
| Not irrigated | 0 | 635 | 483 | 177 | 102 | 813 | 585 | 402 | 307 |
| | 120 | 999 | 542 | 354 | 125 | 1353 | 667 | 539 | 369 |
| | 360 | 1365 | 617 | 444 | 142 | 1809 | 759 | 715 | 392 |
| Mean | | 1000 | 547 | 325 | 123 | 1325 | 670 | 552 | 356 |
| Irrigated | 0 | 1230 | 505 | 328 | 107 | 1558 | 612 | 564 | 350 |
| | 120 | 1255 | 561 | 365 | 133 | 1619 | 694 | 697 | 410 |
| | 360 | 1520 | 670 | 463 | 228 | 1983 | 927 | 752 | 433 |
| Mean | | 1335 | 589 | 385 | 156 | 1720 | 744 | 671 | 398 |
| Effect of fertilization | 0 | 933 | 494 | 253 | 104 | 1185 | 598 | 483 | 329 |
| | 120 | 1127 | 552 | 359 | 129 | 1486 | 681 | 618 | 390 |
| | 360 | 1443 | 658 | 453 | 185 | 1896 | 843 | 733 | 412 |
| $LSD_{0.05}$ for: | irrigation | 89 | 11 | 15 | 13 | 111 | 28 | 17 | 15 |
| | fertilization | 116 | 21 | 29 | 23 | 139 | 34 | 33 | 24 |
| | interaction | 158 | 29 | 43 | 41 | 198 | 54 | 58 | 30 |

Table 3. Pigment content in white lupine leaves (µg/g fr. wgt.)

| Irrigation | Mineral fertilization (kg/ha) | Chlorophyll a | Chlorophyll b | Total chlorophyll | Carotenoides |
|---|---|---|---|---|---|
| Not irrigated | 0 | 878 | 192 | 1071 | 526 |
| | 120 | 1140 | 223 | 1364 | 678 |
| | 360 | 1164 | 272 | 1436 | 690 |
| Mean | | 1061 | 229 | 1290 | 631 |
| Irrigated | 0 | 1049 | 249 | 1298 | 576 |
| | 120 | 1354 | 366 | 1720 | 738 |
| | 360 | 1458 | 423 | 1882 | 750 |
| Mean | | 1287 | 346 | 1633 | 688 |
| Effect of fertilization | 0 | 964 | 220 | 1184 | 551 |
| | 120 | 1247 | 295 | 1542 | 708 |
| | 360 | 1311 | 348 | 1659 | 720 |
| $LSD_{0.05}$ for: | irrigation | 58 | 21 | 124 | 16 |
| | fertilization | 79 | 25 | 150 | 24 |
| | interaction | 102 | 41 | 226 | 39 |

Studies done by Sestak and Catsky (1962), and by Wojcieska et al. (1983) showed that the content of pigments is not directly related to the intensity of photosynthesis and biomass production, but if considered jointly with the assimilation surface of the whole plant, it may affect the biomass synthesis, hence the yield.

In Table 4 the surface of the leaves is presented. Both irrigation and fertilization visibly increased the total surface of the leaves, which combined with the pigment content enhanced the yield of both the seeds and the straw. The leaf surface of small bean increased as effect of irrigation by 48%, pea stipule by 64%, tendrils by 86%, lupine leaves by 12%. High fertilizer doses caused the leaf surface to increase by 197, 205, 366 and 71%, respectively. These results correspond with those described by Karczmarczyk et al. (1993) and Zbieć et al. (1988).

Table 4. Assimilation area of leguminose plants (mean of 2 years)

| Irrigation | Mineral fertilization (kg/ha) | Species of leguminose plant | | | |
|---|---|---|---|---|---|
| | | Pea | | Small bean | White lupine |
| | | tendrils | stipules | | |
| Not irrigated | 0 | 24.7 | 90.6 | 229.0 | 370.2 |
| | 120 | 73.9 | 181.5 | 397.5 | 448.2 |
| | 240 | 124.9 | 219.7 | 666.5 | 585.9 |
| | 360 | 126.5 | 244.5 | 605.5 | 596.9 |
| Mean | | 84.5 | 184.1 | 474.6 | 500.3 |
| Irrigated | 0 | 62.4 | 148.6 | 380.7 | 389.4 |
| | 120 | 104.2 | 244.0 | 425.1 | 461.0 |
| | 240 | 183.0 | 329.4 | 805.1 | 696.2 |
| | 360 | 278.7 | 486.0 | 1204.7 | 703.4 |
| Mean | | 157.1 | 302.0 | 703.9 | 562.5 |
| Effect of fertilization | 0 | 43.5 | 119.6 | 304.8 | 379.8 |
| | 120 | 89.0 | 212.7 | 411.3 | 454.6 |
| | 240 | 153.9 | 274.5 | 735.8 | 641.1 |
| | 360 | 202.6 | 365.2 | 905.1 | 650.1 |
| Mean | | 122.3 | 243.0 | 589.2 | 531.4 |
| $LSD_{0.05}$ for: | irrigation | 34.2 | 57.3 | 146.0 | 32.4 |
| | fertilization | 25.5 | 33.6 | 121.0 | 18.3 |
| | interaction | 46.4 | 70.6 | 208.4 | 75.7 |

Enzymes are the motor of all processes, and their activity depends on nutrients and water supply. Of the red-ox enzymes, nitrate reductase is vital since it is responsible for the transformation of nitrogen, phosphatases control the phosphorus conversion, and peroxydase protects the phytohormons against biological oxydation. The results pertaining to the activity of enzymes in the tested plants are presented in Tables 5, 6, 7.

All three plants showed an increased activity of nitrate reductase caused by high mineral fertilizer dose, and this activity was also related to the nitrate content in the leaves. A lower content of nitrate and decreased nitrate reductase activity were probably connected with a faster reduction of the former and incorporation of nitrogen into aminoacids in plants which were able to assimilate more carbon dioxide, hence more carbohydrates could be produced. These theses find confirmation in a higher chlorophyll and carotene content (Table 1, 2, 3), a larger leaf surface (Table 4), and intensity of photosynthesis (Table 8).

The activity of peroxydase in pea stipule was by 46% higher if the plants had been irrigated, and by 15% as effect of high fertilizer doses (Table 6). The increase of that enzyme activity in the other plants increased only by several percent (Table 5, 7).

Table 5. Nitrate content and some enzyme activity in small bean leaves during flowering stage

| Obiect | | N–$NO_3$ (mg/kg) | Nitrate reductase (μmol·g·h$^{-1}$) | Peroxydase (unit)* | Phosphatase (mmol·kg$^{-1}$) | |
|---|---|---|---|---|---|---|
| Irrigation | NPK (kg/ha) | | | | acid | alkaline |
| Not irrigated | 0 | 100 | 187 | 46 | 12.7 | 30.8 |
| | 120 | 115 | 225 | 50 | 10.6 | 31.7 |
| | 360 | 120 | 244 | 57 | 9.9 | 32.4 |
| Mean | | 112 | 219 | 51 | 11.1 | 31.6 |
| Irrigated | 0 | 78 | 131 | 47 | 11.3 | 30.0 |
| | 120 | 85 | 150 | 52 | 10.6 | 32.6 |
| | 360 | 93 | 206 | 59 | 10.3 | 33.4 |
| Mean | | 85 | 162 | 53 | 10.7 | 32.0 |
| Effect of fertilization | 0 | 89 | 159 | 47 | 12.0 | 30.4 |
| | 120 | 100 | 188 | 51 | 10.6 | 32.2 |
| | 360 | 106 | 225 | 58 | 10.1 | 32.9 |
| Mean | | 98 | 191 | 52 | 10.9 | 31.8 |

* - ΔE/S·100 g.

Table 6. Nitrate content and some enzyme activity in pea leaves during flowering stage

| Obiect | | N–$NO_3$ (mg/kg) | | Nitrate reductase (μmol·g·h$^{-1}$) | | Peroxydase (unit)* | | Phosphatase (mmol·kg$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation | NPK (kg/ha) | | | | | | | alkaline | | acid | |
| | | stipules | tendrils | stipules | tendrils | stipules | tendrils | stipules | tendrils | stipules | tendrils |
| Not irrigated | 0 | 85 | 70 | 140 | 130 | 83 | 63 | 15.2 | 8.5 | 54.4 | 66.6 |
| | 120 | 98 | 74 | 150 | 146 | 94 | 74 | 16.5 | 8.2 | 68.2 | 75.3 |
| | 360 | 100 | 76 | 206 | 167 | 99 | 83 | 19.0 | 8.8 | 80.4 | 91.0 |
| Mean | | 94 | 73 | 165 | 148 | 92 | 73 | 16.9 | 8.5 | 67.7 | 77.6 |
| Irrigated | 0 | 65 | 58 | 112 | 98 | 125 | 73 | 16.6 | 9.2 | 64.8 | 73.5 |
| | 120 | 70 | 65 | 134 | 116 | 136 | 84 | 17.6 | 10.6 | 66.7 | 92.7 |
| | 360 | 85 | 70 | 168 | 132 | 140 | 88 | 18.3 | 9.8 | 68.2 | 111.8 |
| Mean | | 73 | 64 | 138 | 115 | 134 | 82 | 17.5 | 9.9 | 66.6 | 92.7 |
| Effect of fertilization | 0 | 75 | 64 | 126 | 114 | 104 | 68 | 15.9 | 8.9 | 59.6 | 70.1 |
| | 120 | 84 | 70 | 142 | 131 | 115 | 79 | 17.1 | 9.4 | 67.5 | 84.0 |
| | 360 | 93 | 73 | 187 | 150 | 120 | 86 | 18.7 | 9.3 | 74.3 | 101.4 |
| Mean | | 84 | 69 | 152 | 132 | 113 | 78 | 17.2 | 9.2 | 67.1 | 85.2 |

* - ΔE/S·100 g.

Table 7. Nitrate content and activity of some enzymes in white lupine leaves during flowering stage

| Obiect | | $N–NO_3$ (mg/kg) | Nitrate reductase (μmol·g·h$^{-1}$) | Peroxydase (unit)* | Phosphatase (mmol·kg$^{-1}$) | |
|---|---|---|---|---|---|---|
| Irrigation | NPK (kg/ha) | | | | acid | alkaline |
| Not irrigated | 0 | 100 | 150 | 42 | 22.0 | 52.6 |
| | 120 | 116 | 168 | 48 | 21.7 | 62.8 |
| | 360 | 120 | 206 | 57 | 19.6 | 66.6 |
| Mean | | 112 | 175 | 49 | 23.1 | 60.7 |
| Irrigated | 0 | 98 | 120 | 44 | 25.2 | 54.4 |
| | 120 | 110 | 146 | 50 | 18.8 | 66.7 |
| | 360 | 115 | 180 | 58 | 18.5 | 68.2 |
| Mean | | 108 | 149 | 51 | 20.8 | 63.1 |
| Effect of fertilization | 0 | 99 | 135 | 43 | 23.6 | 53.5 |
| | 120 | 113 | 157 | 49 | 20.3 | 64.8 |
| | 360 | 118 | 193 | 58 | 19.1 | 67.4 |
| Mean | | 110 | 162 | 50 | 21.0 | 61.9 |

* - ΔE/S·100 g.

The activity of phosphatases was not much affected by the applied measures, only the pea stipule showed an 45% activity increase as effect of fertilization, and 19% - caused by irrigation. These results are similar to those reported by Karczmarczyk et al. (1990, 1993), Wojcieska et al. (1991, 1994 a, 1994 b), Zbieć et al. (1988). It must be mentioned, that the differences in the enzyme activity, particularly of nitrate reductase were much larger in cereals, which can be explained by much higher fertilizer doses applied to cereals, particularly of nitrogen. It is evident that the increased enzyme activity, larger content of chlorophyll and carotenoides were beneficial as far as the photosynthesis and biomass production is concerned.

The measurements of the plant's photosynthesis were done the day after irrigation, at the active radiation (PAR) of 380 mmol·m$^2$·sec$^{-1}$. The photosynthesis of the top leaves of small bean increased on watered plots by 23%, pea by 32%, lupine by 12%. Higher doses of fertilizer caused increases of 19, 34, 20%, respectively.

The plants transpiration also increased, that of pea to the greatest extent - by 46%, the least of lupine - by 30%. The two processes are strictly related, a larger production of organic compounds increases the demand for minerals taken up from the soil, on the other hand a better supply of nutrients, particularly nitrogen and magnesium enhances assimilation and pigment synthesis.

The concentration of carbon dioxide in the substomatal cells ($C_i$) decreased on objects which showed an increased photosynthesis, this indicates a larger uptake and use of $CO_2$. The leaf conductance also increased as effect of the applied measures. This feature facilitates the transmission of carbon dioxide to the photosynthetic apparatus. The described results confirm those described by Wojcieska (1994c), Wojcieska and Szczypa (1971), Wojcieska-Wyskupajtys (1996), and Zbieć et al. (1988).

Enhanced activity of physiological processes found in plants which had received proper watering and fertilization increased their yield. Data of Table 9 show that small bean yielded by 40% better, and in 1995 even by 53%. The yield increase of pea was smaller, only 26%, and in 1995 by 45%. The crop of white lupine was by 17 and 28% larger, respectively. Since the years of the experiment were not very dry, the effect of fertilizer doses was much larger: the triple NPK dose increased the small bean yield by 84%, in 1996 by over 100%. The yield of pea was by 56%, that of lupine by 70% higher. The combined effect of both measures reached 136% in case of small bean seeds, 92% - pea, 102% of white lupine.

Table 8. Photosynthetic activity in small bean, pea and lupine leaves under influence of irrigation and mineral fertilization

| Obiect | | Small bean | | | | | Pea stipule | | | | | White lupine | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation | NPK (kg/ha) | Photosynthesis ($\mu mol \cdot m^{-2} \cdot s^{-1}$) | Transpiration $mol \cdot m^{-2} \cdot s^{-1}$ | $C_i$ $\mu mol \cdot mol^{-1}$ | $T_{leaf}$ ($^oC$) | $g_c$ $mol \cdot m^{-2} \cdot s^{-1}$ | Photosynthesis ($\mu mol \cdot m^{-2} \cdot s^{-1}$) | Transpiration $mol \cdot m^{-2} \cdot s^{-1}$ | $C_i$ $\mu mol \cdot mol^{-1}$ | $T_{leaf}$ ($^oC$) | $g_c$ $mol \cdot m^{-2} \cdot s^{-1}$ | Photosynthesis ($\mu mol \cdot m^{-2} \cdot s^{-1}$) | Transpiration $mol \cdot m^{-2} \cdot s^{-1}$ | $C_i$ $\mu mol \cdot mol^{-1}$ | $T_{leaf}$ ($^oC$) | $g_c$ $mol \cdot m^{-2} \cdot s^{-1}$ |
| Not irrigated | 0 | 6.04 | 1.49 | 291 | 20.6 | 0.19 | 6.65 | 0.98 | 251 | 20.6 | 0.06 | 5.34 | 2.22 | 350 | 22.9 | 0.65 |
| | 360 | 8.47 | 1.58 | 279 | 20.4 | 0.23 | 7.38 | 1.27 | 231 | 20.8 | 0.17 | 6.72 | 2.44 | 339 | 20.6 | 0.97 |
| Irrigated | 0 | 8.70 | 2.03 | 300 | 20.1 | 0.47 | 7.27 | 1.62 | 312 | 19.0 | 0.36 | 6.30 | 2.93 | 356 | 18.0 | 1.04 |
| | 360 | 9.09 | 2.12 | 272 | 20.4 | 0.48 | 11.30 | 1.66 | 270 | 19.3 | 0.50 | 7.21 | 3.12 | 340 | 18.0 | 1.10 |
| Effect of irri-gation | not irriga-ted | 7.25 | 1.53 | 285 | 20.5 | 0.21 | 7.01 | 1.12 | 241 | 20.7 | 0.11 | 6.03 | 2.33 | 344 | 21.8 | 0.81 |
| | irriga-ted | 8.89 | 2.07 | 286 | 20.3 | 0.47 | 9.28 | 1.64 | 291 | 19.1 | 0.43 | 6.76 | 3.03 | 348 | 18.0 | 1.07 |
| Effect of ferti-lization | 0 | 7.37 | 1.76 | 296 | 20.4 | 0.33 | 6.96 | 1.30 | 282 | 19.8 | 0.21 | 5.82 | 2.58 | 353 | 20.5 | 0.85 |
| | 360 | 8.78 | 1.85 | 276 | 20.4 | 0.35 | 9.34 | 1.46 | 250 | 20.0 | 0.33 | 6.97 | 2.78 | 339 | 19.3 | 1.04 |
| $LSD_{0,05}$ for: | | | | | | | | | | | | | | | | |
| irrigation | | 1.31 | 0.43 | n.s. | n.s. | 0.14 | 1.73 | 0.23 | 32.9 | 0.10 | 0.25 | 0.31 | 0.47 | n.s. | 0.33 | 0.11 |
| fertilization | | 0.91 | n.s. | 11.1 | n.s. | n.s. | 1.01 | n.s. | 21.3 | n.s. | 0.11 | 0.19 | n.s. | n.s. | n.s. | 0.07 |
| interaction | | 1.60 | n.s. | n.s. | n.s. | n.s. | 2.93 | n.s. | 44.4 | n.s. | 0.34 | 0.53 | n.s. | n.s. | n.s. | 0.29 |

$C_i$ sub - stomatal $CO_2$ concentration; $T_{leaf}$ – leaf temperature; $g_c$ - stomatal conductance.

Table 9. Effect of irrigation and mineral fertilization on the yields of seed and straw of small bean, pea and white lupine (means of 2 years in t/ha)

| Obiect | | Small bean | | | | | | Pea | | | | | | White lupine | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | seeds | | | straw | | | seeds | | | straw | | | seeds | | | straw | | |
| Irrigation | NPK (kg/ha) | 1995 | 1996 | mean | 1995 | 1996 | mean | 1995 | 1996 | mean | 1995 | 1996 | mean | 1995 | 1996 | mean | 1995 | 1996 | mean |
| Not irrigated | 0 | 2.00 | 2.35 | 2.18 | 2.50 | 3.85 | 3.18 | 2.29 | 3.55 | 2.92 | 2.82 | 3.93 | 3.38 | 2.42 | 2.51 | 2.47 | 2.80 | 3.25 | 3.03 |
| | 120 | 2.54 | 3.00 | 2.77 | 2.75 | 4.45 | 3.60 | 3.25 | 3.60 | 3.43 | 3.45 | 4.47 | 3.96 | 3.49 | 4.10 | 3.80 | 3.51 | 5.40 | 4.46 |
| | 240 | 3.11 | 4.00 | 3.56 | 3.20 | 5.01 | 4.11 | 3.65 | 5.60 | 4.63 | 4.21 | 6.66 | 5.44 | 3.67 | 4.61 | 4.14 | 3.71 | 5.67 | 4.69 |
| | 360 | 2.90 | 4.37 | 3.64 | 2.92 | 5.04 | 3.98 | 3.50 | 5.65 | 4.58 | 4.57 | 6.95 | 5.76 | 3.61 | 4.60 | 4.11 | 3.68 | 5.82 | 4.75 |
| Mean | | 2.64 | 3.43 | 3.03 | 2.84 | 4.59 | 3.72 | 3.17 | 4.60 | 3.89 | 3.76 | 5.50 | 4.63 | 3.30 | 3.96 | 3.63 | 3.43 | 5.04 | 4.23 |
| Irrigated | 0 | 2.68 | 2.47 | 2.58 | 2.90 | 4.45 | 3.68 | 3.02 | 4.17 | 3.60 | 4.05 | 4.78 | 4.42 | 3.10 | 2.70 | 2.90 | 3.54 | 3.34 | 3.44 |
| | 120 | 3.83 | 4.57 | 4.2 | 3.68 | 5.27 | 4.48 | 4.63 | 5.00 | 4.82 | 5.25 | 6.75 | 6.00 | 4.19 | 4.34 | 4.27 | 4.53 | 5.48 | 5.01 |
| | 240 | 4.65 | 5.11 | 4.88 | 4.50 | 6.01 | 5.26 | 5.27 | 5.83 | 5.55 | 5.59 | 7.29 | 6.44 | 4.75 | 4.85 | 4.80 | 4.94 | 5.75 | 5.35 |
| | 360 | 5.00 | 5.28 | 5.14 | 4.75 | 6.08 | 5.42 | 5.55 | 5.67 | 5.61 | 5.67 | 7.33 | 6.50 | 4.88 | 5.12 | 5.00 | 4.98 | 6.14 | 5.56 |
| Mean | | 4.04 | 4.36 | 4.20 | 3.96 | 5.45 | 4.71 | 4.62 | 5.17 | 4.89 | 5.14 | 6.54 | 5.84 | 4.23 | 4.25 | 4.24 | 4.50 | 5.18 | 4.84 |
| Effect of fertilization | 0 | 2.34 | 2.41 | 2.38 | 2.70 | 4.15 | 3.43 | 2.66 | 3.86 | 3.26 | 3.44 | 4.36 | 3.90 | 2.76 | 2.61 | 2.68 | 3.17 | 3.30 | 3.23 |
| | 120 | 3.19 | 3.79 | 3.49 | 3.22 | 4.86 | 4.04 | 3.94 | 4.30 | 4.12 | 4.35 | 5.61 | 4.98 | 3.84 | 4.22 | 4.03 | 4.02 | 5.44 | 4.73 |
| | 240 | 3.88 | 4.56 | 4.22 | 3.85 | 5.51 | 4.68 | 4.46 | 5.72 | 5.09 | 4.90 | 6.98 | 5.94 | 4.21 | 4.73 | 4.47 | 4.33 | 5.71 | 5.02 |
| | 360 | 3.95 | 4.83 | 4.39 | 3.84 | 5.56 | 4.70 | 4.53 | 5.66 | 5.09 | 5.12 | 7.14 | 6.13 | 4.25 | 4.86 | 4.55 | 4.33 | 5.98 | 5.16 |
| Mean | | 3.34 | 3.89 | 3.62 | 3.40 | 5.02 | 4.21 | 3.90 | 4.88 | 4.38 | 4.45 | 6.02 | 5.24 | 3.76 | 4.10 | 3.93 | 3.96 | 5.11 | 4.53 |
| $LSD_{0,05}$ for: | | | | | | | | | | | | | | | | | | | |
| irrigation | | 0.25 | 0.09 | 0.17 | 0.11 | 0.11 | 0.11 | 0.12 | 0.09 | 0.11 | 0.17 | 0.07 | 0.12 | 0.24 | 0.17 | 0.21 | 0.29 | 0.10 | 0.20 |
| fertilization | | 0.18 | 0.07 | 0.13 | 0.26 | 0.08 | 0.17 | 0.08 | 0.11 | 0.10 | 0.13 | 0.12 | 0.13 | 0.18 | 0.19 | 0.19 | 0.14 | 0.13 | 0.14 |
| interaction | | 0.33 | 0.12 | 0.23 | 0.37 | 0.13 | 0.25 | 0.15 | 0.16 | 0.16 | 0.23 | 0.16 | 0.20 | 0.32 | 0.28 | 0.30 | 0.33 | 0.18 | 0.26 |

The straw yield was less affected by irrigation, but there is no doubt that the study on the response of various plant species to supplemental irrigation and fertilizer doses is purposeful. The influence of agrotechnical measures on the plant's physiological processes should also be considered since it determines the yield.

## CONCLUSIONS

1. Supplemental irrigation and high doses of mineral fertilizer caused significant increases of the content of chlorophyll and carotenoides in small bean, pea and white lupine leaves, and also modified the activity of red-ox enzymes. High NPK doses increased the activity of nitrate reductase in all tested plants, and that of peroxydase in pea stipule. Irrigation decreased the activity of nitrate reductase, but slightly increased the acid phosphatase activity.
2. The applied agrotechnical measures enhanced the carbon dioxide assimilation and transpiration, and decreased the concentration of CO2 in the substomatal cells. An increased stomatal conductance was also found, particularly in the pea stipule.
3. As effect of the increased activity of the plant physiological processes caused by the applied agrotechnique, an increased yield of seeds and straw was obtained. The yield of small bean from irrigated plots was by 40% higher, that of pea by 26%, of white lupine by 17%. High doses of mineral fertilizer increased the crops by 84, 56, 70%, respectively. The combined effect of both measures always exceeded 90%.

## REFERENCES

1. Borówczak F., 1997, Effects of sprinkling irrigation of seed crops in Poland. Proceedings of Polish-Israeli Conference on Plant Irrigation. Tel Aviv, vol. II: 149-156.
2. Devlin R. M., Barker A. V., 1971, Photosynthesis. Van Nostrand Reinhold Co. New York.
3. Dzieżyc J. (red.)., 1989, Water demand of cultivated plants. PWN, Warszawa. [In Polish].
4. Dzieżyc J., Nowak L., Panek K. 1987, A method for irrigation control, considering the plant demand. Probl. Post. Nauk Rol. 314: 137-148. [In Polish].
5. Grabarczyk S., Dudek S., Peszek J., Rzekanowski Cz., Żarski J., 1995. Regional differentiation of anticipated irrigation effects of plants cultivated on very poor soils. Zesz. Nauk. AR Wroc. 267: 45-4. [In Polish].
6. Karczmarczyk S., 1979, Effect of irrigation and mineral fertilization of small bean, winter wheat and spring barley cultivated in crop rotation and on some porperties of a sandy soil. AR Szczec. Rozpr. 60. [In Polish].
7. Karczmarczyk S., Kaczmarek G., Kowalski W., Friedrich S., 1990, Yield and growth and development of some oat cultivars depending on irrigation and mineral fertilization. Part III. Some plant features and pigment content and enzyme activity. Szczec. Rocz. Nauk. 5 (2): 27-43. [In Polish].
8. Karczmarczyk S., Koszański Z., Podsiadło C., 1993, Some physiological processes and yield of winter wheat and triticale affected by irrigation and nitrogen fertilization. Part I. Chlorophyl and carotenoides content in some organs of wheat and triticale. Acta Agrob. 46 (1): 15-30. [In Polish].
9. Karczmarczyk S., Koszańska E., Ściążko D., Roy M., 1993a, Some physiological processes and yield of winter wheat and triticale affected by irrigation and nitrogen fertilization. Part II. Enzyme activity and yield of winter wheat and triticale. Acta Agrob. 46 (1): 31-38. [In Polish].
10. Panek K., 1983. Variability of yield and yield features of small bean as effect of moisture conditions. Zesz. Nauk. AR Wroc. 142 (24): 127-132. [In Polish].
11. Sestak Z., Catsky J., 1962, Intensity of photosynthesis and chlorophyll content as related to leaf age in Nicotiana Sanderae. Hart. Biol. Plantar. 4: 131.

12. Stock H., El Sayed, El-Naggar, 1981. Studies on optimal methods of small bean irrigation. Prz. Nauk. Lit. Rol. Leś. 28 (3-4): 346. [In Polish].
13. Wojcieska U., 1994c, The effect of nitrogen nutrition of soybean on plant growth and $CO_2$ exchange parameters. Acta Physiol. Plant. 16: 262-268. [In Polish].
14. Wojcieska-Wyskupajtys U., 1996, Effect of nitrogen nutrition on yield and some physiological parameters in rye plants. Acta Physiol. Plant. 18 (1): 19-24. [In Polish].
15. Wojcieska U., Mroczkowski W., Podleśna A., Kocoń A., 1994b, Effect of amonium nitrate of nitrogenase activity in pea varieties Ramir and Koral. Biulletin of the Polish Academy of Sci. Biol. Sci. 42 (2): 189-193. [In Polish].
16. Wojcieska U., Wolska E., Podleśna A., Kocoń A., 1994a, The activity of nitrate reductase in organs of pea plants. Bulletin of the Polish Academy of Sci., Biol. Sci. 42 (2): 183-187. [In Polish].
17. Wojcieska U., Szczypa E., 1971, Growth and productivity of photosynthesis of winter wheats. Part II. Photosynthesis activity and productivity in the course of plant aging. Pam. Puł. 44: 49-70. [In Polish].
18. Wojcieska U., Wolska E., Giza A., 1991, Effect of N-nutrition on the yield of spring wheat and nitrate activity as an index of the plant nutrition status. Pam. Puł. 98: 22-38. [In Polish].
19. Wojcieska U., Wolska E., Samiec H., 1983, Comparison of photosynthesis productivity of chosen strains of triticale and rye cv. Dańkowskie złote. Hod. Rośl. Aklim. 27: 69-84. [In Polish].
20. Zbieć J., Karczmarczyk S., Kaczmarek G., 1988, Growth and yield of corn subjected to water and nutrient stress. Part I. Intensity of photosynthesis and activity of some enzymes in leaves and corn yield. Zesz. Nauk. AR Szczec. 135 (46): 257-272. [In Polish].

Translated by: Irena Zbieć, PhD DSc Prof

## STRESZCZENIE

Celem przeprowadzonych badań było określenie wpływu uzupełniającego deszczowania oraz wysokiego nawożenia mineralnego na zawartość barwników, aktywność enzymów oksydacyjno-redukcyjnych oraz intensywność fotosyntezy i plony bobiku, grochu i łubinu białego uprawianych na glebie lekkiej.

Stwierdzono, że deszczowanie oraz wysokie dawki nawozów mineralnych spowodowały istotny wzrost ilości barwników w liściach testowanych roślin oraz modyfikowały aktywność enzymów oksydacyjnych. Wzrosła też pod ich wpływem intensywność fotosyntezy i transpiracji oraz przewodność dyfuzyjna liści.

W efekcie wzrostu aktywności procesów fizjologicznych pod wpływem zastosowanych zabiegów agrotechnicznych uzyskano istotne przyrosty plonów nasion i słomy.

Received: July 1998