Utilisation of total solar radiation energy in the photosynthetic production of radish, red beet and bean

WIESŁAW NOWAKOWSKI

Department of Environment Protection, Faculty of Horticulture, Warsaw
Agricultural University — SGGW-AR, Nowoursynowska 166, 02-766 Warszawa,
Poland

(Received: February 21, 1983. Revision accepted: April 27, 1983)

Abstract

Utilisation of total solar radiation energy in the photosynthetic production of radish, red beet and bean is expressed as per cent of solar radiation accumulated in the carbon of the dry mass per 1 cm² of the assimilation surface area. Utilisation of this energy ranges from 2.6 to 8.4 per cent in radish, from 1.7 to 7.5 per cent in beet and from 1.9 to 4.9 per cent in bean.

Key words: *photosynthetic production, solar radiation energy, radish, red beet, bean.*

INTRODUCTION

The amount of solar radiation energy utilised in photosynthesis depends on such climatic agrotechnical factors as light and thermal conditions, amount of precipitation, length of vegetation period, patch structure, age of plant and genus and species of plant (Strebeyko et al. 1963, Nicziporowicz 1968, Listowski 1979). According to Wassink (1968) and Dajoz (1975) plants utilise about 1 per cent of total solar radiation energy during the whole vegetation period. Investigations on the utilisation of solar radiation energy in photosynthetic production on 20 varieties of *Triticum durum* demonstrated that the amount of total solar radiation accumulated in the carbon of the dry mass of plants per 1 cm² of assimilation area of the above ground parts reaches on the average values of 2.23 to 3.80 per cent (Nowakowski et al. 1975).

Detailed analysis of accumulation of this energy was performed in various periods of growth of three vegetable species in order to determine the degree of solar radiation energy utilisation in their photosynthetic production. An accurate knowledge of the amount of accumulated energy in the biomass of crop plants is particularly important in the programme of increase of plant production. The functioning of agrocenoses is above all dependent on the flow and storage of solar radiation energy (Duvigneaud 1974).

MATERIAL AND METHODS

Radish — Szkarłatna z Białym Końcem, red beet — Okrągły Ciemnoczerwony and the bean — Wyborowa Biała were cultivated on an experimental field of the Agricultural University in Wolica in the years 1976-1977. The vegetables were grown on plots with a $2\text{ m} \times 2\text{ m}$ surface in four replications. The soil type was light loamy sand, $\text{pH}_{\text{H}_2\text{O}}$ 6.6. For determining the dry mass increment of the plants and their assimilation surface, a mean of 15-30 plants was taken at each date of harvest. The cultivation conditions and methods of laboratory analysis are described in detail in an earlier paper (Nowakowski 1982).

Utilisation of solar radiation energy in photosynthetic production was calculated in reference to total solar radiation which reached the surface of the plants. The values of solar total radiation intensity (daily sums in $\text{cal} \cdot \text{cm}^{-2}$, were supplied by the Hydrometeorological Institute in Warsaw, where they were recorded by means of a Molla-Gorczyński solarimetre with a Kipp integrator (Nowakowski 1972, Promieniowanie... 1981). Total solar radiation intensities in Warsaw refer to point φ N $52^\circ 16'$ and λ E $20^\circ 29'$ (Promieniowanie... 1981).

The calculations of total solar radiation utilisation in photosynthetic production of plants were done after Strebeyko (1971), that is, if reduction and assimilation of one mol CO_2 requires 12 quanta of red light of 40 Kcal each, a total of 480 Kcal is necessary per 1 mol of CO_2 or 40 Kcal for 1 g of assimilated carbon (Strebeyko 1971, Costes 1975). Moreover, it was assumed in the calculations that 50 per cent of dry plant mass consists of carbon the assimilation of 1 g of which by plants requires 40 Kcal (Strebeyko 1971). Further computations of the percentual utilisation of solar radiation energy in photosynthetic production of vegetables were done by the method described by Nowakowski et al. (1975).

The results were subjected to statistical analysis which included standard deviations and correlation coefficients (r).

RESULTS AND DISCUSSION

As seen in Tables 1 and 2, among the three vegetable species tested the dry weight increment is highest in bean amounting to 0.392 to 8.164 g per plant in 1976 and from 0.330 to 8.400 g per plant in 1977. The mean assimilation surface area of the shoot is also largest in the bean (Tables 1 and 2). The more this surface increases in size in the vegetation period, the more intensive is the dry mass increment. The correlation coefficient (r) for the dry mass increment of the plants and their mean assimilation surface for the three tested vegetables is 0.898 and it is significant at $p = 0.05$ (Table 1).

Table 1

Dry mass increment of radish, red beet and bean and their assimilation surface in the course of vegetation in 1976

Plant	Vegetation period	Dry mass increment, g $\cdot$ plant $^{-1}$	Mean assimilation surface, cm 2 $\cdot$ plant $^{-1}$	Sum of solar radiation, cal $\cdot$ cm $^{-2}$
Radish (shoot + roots)	27.04-20.05	0.127 $\pm$ 0.008	11.0 $\pm$ 0.9	8927
	20.05-27.05	0.247 $\pm$ 0.023	41.0 $\pm$ 1.2	2828
	27.05- 3.06	0.376 $\pm$ 0.027	77.6 $\pm$ 3.4	1295
Red beet (shoot + roots)	16.06- 1.07	0.180 $\pm$ 0.013	26.5 $\pm$ 2.1	7345
	1.07-14.07	0.770 $\pm$ 0.062	65.0 $\pm$ 4.2	6708
	14.07-29.07	0.750 $\pm$ 0.064	139.5 $\pm$ 8.5	6402
	29.07-11.08	3.000 $\pm$ 0.094	159.0 $\pm$ 8.7	4942
Bean (shoot)	10.06-23.06	0.392 $\pm$ 0.031	61.8 $\pm$ 4.3	4809
	23.06- 8.07	1.439 $\pm$ 0.082	168.8 $\pm$ 8.4	9053
	8.07-21.07	4.721 $\pm$ 0.124	470.9 $\pm$ 9.5	5980
	21.07- 4.08	8.164 $\pm$ 0.245	1116.3 $\pm$ 18.6	5390

Correlation coefficient (r) for Tables 1 and 2: a) plant dry mass $\times$ mean assimilation surface = 0.898, signif. at $p = 0.05$; b) plant dry mass $\times$ sum of solar radiation = 0.208, not significant.

Utilisation of total solar radiation energy in photosynthetic production expressed as the per cent of solar radiation accumulated in the carbon of the dry weight per 1 cm 2 of assimilation surface attained for radish a value of 2.6 to 7.5 per cent in 1976 and from 6.9 to 8.4 per cent in 1977. The corresponding values for red beet were 1.7 to 4.7 in 1976 and 4.9 to 7.5 per cent in 1977. The same values for bean were 1.9 to 3.4 and 3.1 to 4.9 per cent in 1976 and 1977, respectively (Fig. 1). The highest utilisation of total solar radiation in terms of carbon accumulation in dry mass was noted in radish and the lowest in bean (Fig. 1). The coefficient of correlation was not found to be significant amounting to 0.208 (Table 1) for dry mass increment and the sum of total solar radiation intensity.

Table 2

Dry mass increment of radish, red beet and bean and their assimilation surface in the course of vegetation in 1977

Plant	Vegetation period	Dry mass increment, g · plant ⁻¹	Mean assimilation surface, cm ² · plant ⁻¹	Sum of solar radiation, cal · cm ⁻²
Radish (shoot + roots)	30.05- 7.06	0.190±0.011	29.2± 0.9	1826
	7.06-15.06	0.377±0.028	52.6± 2.4	1712
	15.06-21.06	0.424±0.031	83.4± 4.8	1462
Red beet (shoot + roots)	25.05-15.06	0.236±0.018	21.9± 1.9	4414
	15.06- 5.07	1.040±0.084	80.0± 3.6	4258
	5.07-25.07	1.130±0.089	125.5± 8.2	4063
	25.07-16.08	5.690±0.152	253.5± 9.4	4045
Bean (shoot)	15.06-21.06	0.330±0.024	101.5± 7.4	1462
	21.06- 5.07	0.960±0.082	219.5± 8.6	2796
	5.07- 3.08	6.090±0.104	456.0± 9.7	5729
	3.08- 7.09	8.400±0.165	638.5±10.2	5404

Correlation coefficient (r) — see Table 1.

Fig. 1. Utilisation of total solar radiation energy in photosynthetic production of radish, red beet and bean in various vegetation periods in the years 1976-1977 (see Tables 1, 2)

Radish with a short vegetation period accumulates most intensively solar radiation energy in photosynthetic production, whereas red beet and bean with a long vegetation period show a lower accumulation. This seems in agreement with the remark of Listowski (1979) that under

equal climatic and soil conditions the length of the vegetation period is decisive for the amount of utilised solar radiation energy.

According to Loomis et al. (quoted after Listowski 1979), conversion of the absorbed photosynthetically active radiation in various regions and in various plants varies within the limits of 4.6 to 9.8 per cent.

The results of the present experiment confirmed that utilisation of solar radiation energy in photosynthetic production depends on the differences between the plant species and on the period and year of vegetation. The highest utilisation of total solar radiation in photosynthetic production was noted in radish, amounting on the average to 6.1 for the vegetation periods of the two years, next came the red beet with a value of 5.6 and the bean showed the lowest value 3.4 per cent.

REFERENCES

- Costes C., 1975. Processus photochimiques et conversion énergétique de la lumière dans la feuille. In: Photosynthèse et production végétale. C. Costes (ed.), Gauthier-Villars, Paris. pp. 33-72.
- Dajoz R., 1975. Les méthodes de mesure de la productivité primaire. In: Précis d'écologie. Dunon, Paris. pp. 380-384.
- Duvigneaud P., 1974. Flux d'énergie et productivité des écosystèmes. In: La synthèse écologique. Doin, Paris. pp. 55-77.
- Listowski A., 1979. Wykorzystanie promieniowania słonecznego w fotosyntezie. In: Agrofizjologiczne podstawy produktywności roślin. PWN, Warszawa. pp. 52-60.
- Nicziporowicz A. A., 1968. Evaluation of productivity by study of photosynthesis as a function of illumination. UNESCO, Rech. Ress. Nat. 5: 261-270.
- Nowakowski W., 1972. Natężenie promieniowania słonecznego w 1970 r. mierzone solarymetrem Kippa w Zakładzie Biofizyki Roślin Uprawnych IHAR Radzików. Wiad. Bot. 16: 115-120.
- Nowakowski W., 1982. Wpływ emisji przemysłu rafinerujo-petrochemicznego na wzrost roślin warzywnych oraz ich skład chemiczny. Rozprawy Naukowe SGGW-AR, Warszawa. pp. 1-108.
- Nowakowski W., Konopko E., Lubańska G., 1975. Utilisation de l'énergie solaire dans la productivité photosynthétique au cours de quatre phases végétatives de différentes variétés du *Triticum durum*. Acta Agrobot 28: 197-204.
- Promieniowanie słoneczne. 1981. Instytut Meteorologii i Gospodarki Wodnej. Wyd. Kom. Łącz., Warszawa.
- Strebeiko P., 1971. Fotosynteza w aspekcie biofizycznym. In: Fotobiologia. PWN, Warszawa. pp. 105-109.
- Strebeiko P., Krzywacka T., Madej L., 1963. Szybkość fotosyntezy i wzrostu pszenicy jarej (*Triticum aestivum* L. ssp. *vulgare* MacKey). Hod. Roślin Aklim. Nasien. 7: 475-479.
- Wassink E. C., 1968. Light energy conversion in photosynthesis and growth of plants. UNESCO, Rech. Ress. Nat. 5: 53-66.

*Wykorzystanie energii promieniowania słonecznego całkowitego
w produkcji fotosyntetycznej rzodkiewki, buraka ćwikłowego i fasoli*

Streszczenie

W latach 1976-1977 określono wykorzystanie promieniowania słonecznego w produkcji fotosyntetycznej, wyrażone w procentowej ilości promieniowania słonecznego całkowitego zakumulowanego w węglu suchej masy na cm^2 powierzchni asymilacyjnej pędu rzodkiewki, buraka ćwikłowego i fasoli. Wykorzystanie energii promieniowania słonecznego w produkcji fotosyntetycznej wynosi od 2,6% do 8,4% u rzodkiewki, od 1,7% do 7,5% u buraka ćwikłowego oraz od 1,9% do 4,9% u fasoli. Współczynnik korelacji (r) dla przyrostów suchej masy i średniej powierzchni asymilacyjnej pędu wynosi 0,898 i jest istotny przy $p = 0,05$. Natomiast nie stwierdzono istotności współczynnika korelacji dla przyrostów suchej masy i natężenia promieniowania słonecznego całkowitego.