ACTA SOCIETATIS
BOTANICORUM POLONIAE
vol. XXXVIII — nr 2
1969

Photosynthetic production of some plant species in meadow ecosystem

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Ecophysiological investigations conducted in connection with the International Biological Programme tend to assay the global balance of plant production in definite natural and artificial plant associations. For this purpose a number of outset data are necessary, in the first place the rates of production and dissimilation, which may be only obtained from measurements of photosynthesis and respiration intensity. The intensity of these physiological processes is affected in a smaller or greater degree by a number of varying edaphic and microclimatic factors such as temperature, light and air humidity.

An adequate estimation of global photosynthetic production of leaves for some selected species of plants growing in natural ecosystems is difficult for methodical reasons in view of the diversity of factors and owing to the their wide variability and oscillation, not only during the vegetative season but even within 24 hrs (Koller, Samish 1964, Kuroiwa 1965, Šestak, Čatsky 1966; Czopek 1967a, b, Tooming 1967). It is therefore necessary to introduce certain methodical simplifications which would not only facilitate the measurements but also the calculations. The present paper utilizes the method for estimation of the photosynthetic production of leaves elaborated by Czopek and Starzecki (1967). It is based on measurements in the investigated ecosystem, laboratory measurements and productivity calculations.

In the investigated ecosystem the course of changes in the intensity of photosynthetically active radiation was studied together with thermic and humidity changes.

Photosynthesis and respiration intensity of leaves of some plant species from the investigated environment were measured in the laboratory in dependence on thermic and light conditions.

The productivity calculations were performed on the basis of the microclimatic data in the investigated ecosystem and of the laboratory measurements.

The present paper aimed at estimation of the global photosynthetic production, dissimilation and effective leaf production for some plant species in the meadow ecosystem during the vegetative season by means of the above described method.

MATERIAL AND METHODS

Three selected meadow plant species were used for the investigations: *Plantago lanceolata, Rumex acetosa* and *Dactylis glomerata.* The plants were collected in a meadow ecosystem from a patch of the *Arrhenatheretum elatioris* association situated in the Sąspówka valley in the Ojców National Park. The leaves of *Dactylis* were almost fully exposed to light, whereas those of *Rumex* and *Plantago* were partly shaded by grasses. The 3rd or 4th leaf from below was taken for investigation from barren shoots of *Dactylis glomerata* and the basal leaves of medium size from *Rumex acetosa.* The material was not uniform as regards age.

The photosynthetically active radiation (*PAR*) changes were recorded in the meadow ecosystem on an open area by means of an electronic integrator (Kubin nad Hladek 1963) with an automatic registrator of number of impulses (Czopek, Starzecki, Łagisz, Motyka 1967; Czopek 1968) in one-hour time intervals during the vegetative season. Thermic data were recorded by a diurnal thermograph and those concerning the investigated meadow ecosystem were taken from J. Klein's measurements (1966).

Laboratory measurements were performed at the beginning of every month during the vegetative season of 1966. Photosynthesis and respiratory intensities were measured by means of infrared gas analyzer (Infralyt, VEB, Junkalor, Dessau). The measurements were performed in a closed system and the time necessary for a change in CO_2 concentration within the range 300—400 ppm for respiration and 400—300 ppm for photosynthesis was recorded (Egle, Ernst 1949; Egle, Schenk 1951; Egle 1960, Koller, Samish 1964; Żelawski, Góral 1966).

The leaves for examination were placed in a special experimental chamber with temperature regulated by means of an ultrathermostat (Fig. 1). The leaf petiole was

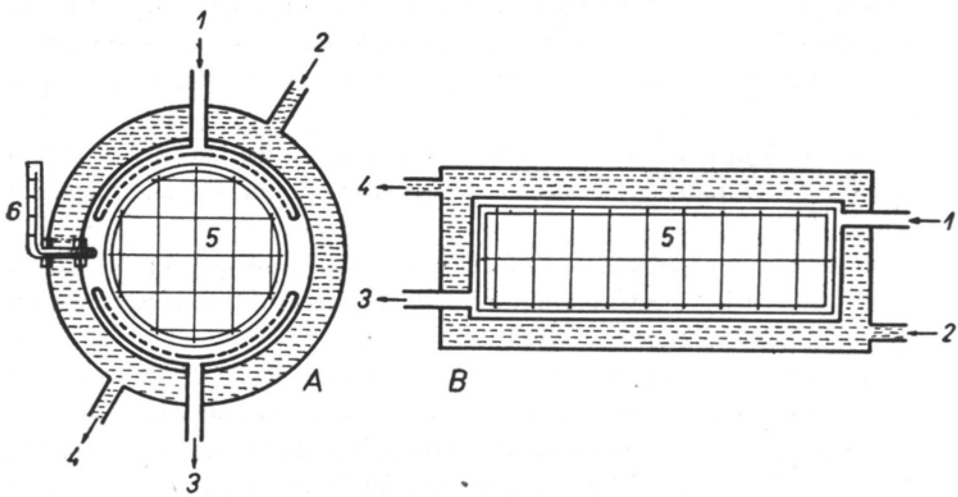

Fig. 1. Scheme of thermostated experimental chambers (*A, B*)

1 — air inlet, *2* — water inlet, *3* — air outlet, *4* — water outlet, *5* — system of transparent nylon threads, *6* — control thermometer immersed in a vessel with water and the leaf blade was smoothed out in a position vertical to the incident light by means of a loose network of transparent nylon threads.

A scheme of the closed measuring system with all its component elements is shown in Fig. 2. The thermostated experimental chamber with the leaf (*1*) is connected with two columns filled with anhydrous $CaCl_2$ (*2*) for removing water vapour from the air. Through the two three-way cocks (*3*) the air flows directly into the rotameter (*6*) or the scrubber with 20 percent KOH absorbing CO_2 (*4*), and further to the additional column (*5*) absorbing water vapour (anhydrous $CaCl_2$). The rotameter (*6*) regulating the rate of air flow at 3—35 l/h is connected through the measuring tube of the CO_2 analyzer (*7*) with the pump (*8*), the outlet of which reaches the experimental chamber (*1*). Outside the closed system there are in the infrared gas analyzer: a control tube (*9*) filled with pure nitrogen, an infrared radiation source (*10*), a radiation receiver with 10 percent CO_2 (*11*) and an appliance recording CO_2 concentration changes (*12*) in the closed system. The particular parts of the system are connected by standard ground joints. Owing to this it was easy to check quickly the tightness of the system as a whole or of its parts by means of a water manometer.

The value of one grade of the scale in the closed system depends on its capacity. The capacity of the measuring system used was 600 ml and was determined manometrically after Żelawski and Góral (1966).

The zero point was established by repeated passing of air through the additional circuit of the system with CO_2 and water vapour-absorbing columns (Fig. 2— n. *2* and *5*).

The value of one grading in the scale was determined by introducing into the system a specified CO_2 volume evolved from a titrated Na_2CO_3 solution under the action of H_2SO_4 (Żelawski and Góral 1966). It was established by calibration

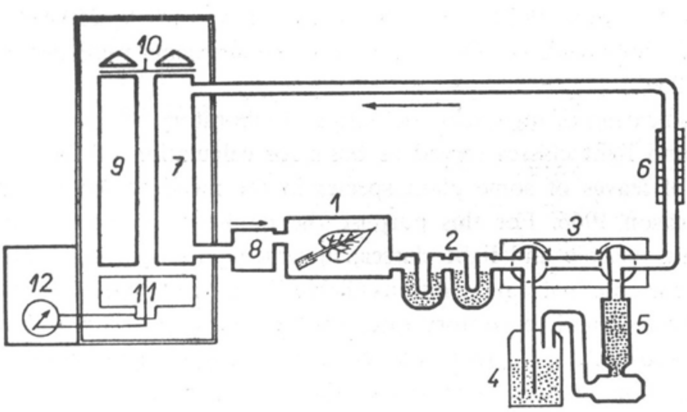

Fig. 2. Simplified scheme of closed system of infrared gas analyzer

1 — chamber with the leaf; *2* — two columns with anhydrous $CaCl_2$; *3* — two three-way cocks; *4* — scrubber with 20% KOH; *5* — the column with anhydrous $CaCl_2$; *6* — the rotameter; *7* — the measuring tube of the CO_2 analyzer; *8* — the air pump; *9* — a control tube; *10* — a infrared radiation source; *11* — a radiation receiver; *12* — an appliance recording CO_2 concentration changes that the value of one scale grading (20 ppm within the range 300—400 ppm) is in dependence on temperature:

at 10°C — 0.0228 mg CO_2
15°C — 0.0224 „ „
20°C — 0.0220 „ „
25°C — 0.0216 „ „

The photosynthesis, respectively the respiration rate is calculated from the formula:

$$I = \frac{d \cdot n \cdot 3600}{t \cdot l}$$

where:

I — photosynthesis (or respiration) intensity in milligrams of CO_2 $dm^{-2}h^{-1}$,
d — value of one scale grading in milligrams CO_2 for the given temperature,
n — number of gradings shifted on the scale during measurement,
3600 — number of seconds in 1 hour,
t — time of measurement (seconds),
l — leaf area (dm^2).

For calculating production or dissimilation (in milligrams of hexose) the number of milligrams of CO_2 $dm^{-2}h^{-1}$ should be multiplied by the coefficient 0.68 (since 1 mg of CO_2 assimilated corresponds to 0.68 mg of hexose).

The dependence between photosynthesis rate and light was investigated for the following intensities: 4 900, 18 400, 38 000 and 73 500 erg $cm^{-2}s^{-1}$ within the range of *PAR* and found to be 0.007, 0.026, 0.054 and 0.105 cal $cm^{-2}min^{-1}$, respectively. These values were obtained from measurements performed with a Kipp and Zonen thermopile and a Kipp type A-70 (Delft, Holland) galvanometer with WG-1 and RG-8 filters (Czopek 1967c, 1968). A mercury lamp (220 V, 250 W) was used as light source. Photosynthesis and respiration measurements were performed at 10, 15, 20 and 25°C.

The classification of microclimatic data and laboratory measurements according to thermic and light classes served as basis for calculation of the photosynthetic production of leaves of some plant species in the meadow ecosystem during the vegetative season 1966. For this purpose the monthly number of hours in the corresponding thermic and light classes, in which photosynthetic and respiratory processes occurred in natural conditions (Table 1) were multiplied by the corresponding photosynthesis and respiratory rates (in mg hexose $dm^{-2}h^{-1}$) obtained in the laboratory (Tables 2, 3, 4). In this way we get the photosynthetic production for the individual combination of classes in the particular months. Then we sum up production and dissimilation rates separately. The difference between the global photosynthetic production and global dissimilation gives the effective photosynthetic production of leaves during the month or the vegetative season (Tables 5, 6, 7) for the particular plant species.

Table 1

Number of hours for particular thermic (*T*) and light (*L*) classes during which the photosynthetic process occurs in vegetative season on the basis measurements in the investigated meadow ecosystem

The symbol *r* determines the duration (hours) of respiratory process, *cp* — number of hours for compensation point

Months	T_{25}					T_{20}					T_{15}					T_{10}					*cp*
	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*	
V	6	—	—	—	6	38	—	—	—	38	158	10	2	—	174	139	52	60	—	464	62
VI	37	—	—	—	37	99	—	—	—	99	166	—	—	10	194	118	—	—	50	330	60
VII	13	—	—	—	13	94	—	—	—	94	175	7	7	3	202	121	34	24	55	373	62
VIII	49	—	—	—	49	122	1	—	—	123	172	18	26	24	283	60	12	36	38	227	62
IX	14	—	—	—	14	70	1	—	—	71	127	20	10	11	188	119	39	20	49	387	60
X	—	—	—	—	—	11	—	—	—	11	104	1	—	—	105	195	30	62	31	566	62
XI	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	240	60	60	30	660	60
Total	119	—	—	—	119	434	2	—	—	436	902	56	45	48	1146	992	217	262	253	3007	428

Table 2

Photosynthesis and respiration rates in mg of hexose dm^{-2} h^{-1} *Plantago lanceolata* leaves during the vegetative season for various thermic (*T*) and light (*L*) classes on the basis of laboratory measurements

Months	T_{25}					T_{20}					T_{15}					T_{10}				
	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*
V	4,2	4,1	3,9	2,7	1,2	3,9	3,7	3,5	2,5	0,8	2,7	2,5	2,3	1,7	0,5	1,5	1,3	1,2	1,0	0,3
VI	4,5	4,2	4,1	2,9	0,8	3,6	3,5	3,3	3,2	0,6	2,7	2,6	2,4	1,8	0,5	1,5	1,4	1,3	1,1	0,3
VII	4,7	4,3	3,9	2,2	0,7	4,3	3,9	3,6	2,1	0,6	4,0	3,7	3,3	1,9	0,3	2,4	2,3	2,0	1,2	0,2
VIII	3,4	3,2	2,2	1,6	0,5	3,2	3,0	1,9	1,0	0,4	2,0	1,9	1,8	1,2	0,3	1,2	1,1	1,0	0,7	0,2
IX	4,5	4,2	3,5	2,2	1,2	4,0	3,7	3,3	2,2	1,1	3,3	3,2	3,0	2,0	0,7	2,0	1,9	1,8	1,2	0,4
X	3,2	3,0	2,8	1,9	0,9	3,1	2,8	2,6	1,7	0,6	2,7	2,3	2,0	1,4	0,4	1,5	1,3	1,2	0,9	0,2
XI	1.2	1,2	1,2	0,8	0,6	1,0	1,0	1,0	0,7	0,5	0,8	0,8	0,8	0,6	0,3	0,6	0,5	0,5	0,4	0,2

Table 3

Photosynthesis and respiration rates in mg of hexose $dm^{-2} h^{-1}$ *Rumex acetosa* leaves during the vegetative season for various thermic (T) and light (L) classes on the basis of laboratory measurements

Months	T_{25}					T_{20}					T_{15}					T_{10}				
	L_{100}	L_{75}	L_{50}	L_{25}	r	L_{100}	L_{75}	L_{50}	L_{25}	r	L_{100}	L_{75}	L_{50}	L_{25}	r	L_{100}	L_{75}	L_{50}	L_{25}	r
V	4,6	4,5	4,3	2,8	1,4	4,5	4,2	4,0	2,3	0,8	4,4	4,0	3,7	2,2	0,7	2,6	2,4	2,2	1,3	0,4
VI	3,2	2,9	2,4	1,7	1,0	2,9	2,7	2,6	1,9	0,7	2,7	2,5	2,2	1,5	0,4	1,5	1,4	1,2	1,0	0,2
VII	4,8	4,4	3,9	2,3	1,1	3,7	3,3	2,8	2,0	0,5	3,0	2,8	2,5	1,7	0,4	1,8	1,6	1,4	1,1	0,2
VIII	4,2	4,0	3,7	2,9	1,0	3,9	3,8	3,7	2,6	0,7	3,5	3,4	3,3	2,5	0,5	2,1	2,0	1,9	1,5	0,3
IX	4,2	4,0	3,8	2,8	0,8	4,0	3,8	3,6	2,5	0,6	3,7	3,6	3,4	2,4	0,4	2,2	2,1	2,0	1,4	0,2
X	3,6	3,5	2,9	2,6	0,7	2,9	2,8	2,7	2,0	0,5	2,8	2,7	2,5	1,8	0,3	1,6	1,5	1,3	1,1	0,2
XI	2,6	2,4	2,2	1,4	0,4	1,6	1,5	1,2	0,8	0,3	1,2	1,1	1,0	0,7	0,2	0,7	0,6	0,5	0,4	0,1

Table 4

Photosynthesis and respiration rates in mg of hexose $dm^{-2} h^{-1}$ *Dactylis glomerata* leaves during the vegetative season for various thermic (T) and light (L) classes on the basis of laboratory measurements

Months	T_{25}					T_{20}					T_{15}					T_{10}				
	L_{100}	L_{75}	L_{50}	L_{25}	r	L_{100}	L_{75}	L_{50}	L_{25}	r	L_{100}	L_{75}	L_{50}	L_{25}	r	L_{100}	L_{75}	L_{50}	L_{25}	r
V	0,7	0,7	0,7	0,6	0,6	0,5	0,5	0,5	0,4	0,4	0,3	0,3	0,3	0,2	0,2	0,2	0,2	0,2	0,1	0,1
VI	1,8	1,7	1,6	1,0	0,6	1.7	1.6	1,5	0,9	0,5	1,4	1,3	1,2	0,8	0,3	0,8	0,7	0,6	0,4	0,2
VII	3,1	2,8	2,6	1,7	0,9	3,0	2,7	2,4	1,5	0,7	1,7	1,6	1,4	1,1	0,6	1,0	0,9	0,8	0,7	0,4
VIII	4,0	3,8	3,5	-2,7	1,1	3,3	3,2	3,1	2,3	0,8	2,7	2,6	2,5	1,6	0,6	1,6	1,5	1,4	1,0	0,4
IX	3,3	3,2	3,0	2,1	1,2	2,9	2,8	2,6	1,8	1,0	2,6	2,5	2,2	1,6	0,8	1,5	1,4	1,2	1,0	0,5
X	2,9	2,6	2,3	1,5	1,1	2,3	2,2	2,1	1,4	0,8	2,1	2,0	1,9	1,2	0,6	1,2	1,1	1,0	0,7	0,4
XI	1,7	1,6	1,4	0,8	0,7	1,5	1,4	1,3	0,7	0,5	1,4	1,3	1,2	0,6	0,4	0,8	0,7	0,6	0,4	0,2

Table 5

Photosynthetic production and dissimilation in mg of hexose dm^{-2} $month^{-1}$ *Plantago lanceolata* leaves during the vegetative season for various combinations of thermic and light classes. *Pg* — global photosynthetic production, *Dg* — global dissimilation, *EP* — effective photosynthetic production

Months	T_{25}					T_{20}					T_{15}					T_{10}					*Pg*	*Dg*	*EP*
	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*			
V	25,2	—	—	—	7,2	148,2	—	—	—	30,4	426,6	25,0	4,6	—	87,0	208,5	67,6	72,0	—	139,2	977,7	263,8	713,9
VI	166,5	—	—	—	29,6	356,4	—	—	—	59,4	448,2	—	—	18,0	97,0	177,0	—	—	55,0	99,0	1221,1	285,0	936,1
VII	61,1	—	—	—	9,1	404,2	—	—	—	56,4	700,0	25,9	23,1	5,7	60,6	290,4	55,2	48,0	66,0	74,6	1679,6	200,7	1478,9
VIII	166,6	—	—	—	24,5	390,4	3,0	—	—	49,2	344,0	34,2	46,4	28,8	84,9	72,0	13,2	36,0	26,6	45,4	1161,2	204,0	957,2
IX	63,0	—	—	—	16,8	280,0	3,7	—	—	78,1	419,1	64,0	30,0	22,0	131,6	238,0	74,1	36,0	58,8	154,8	1288,7	381,3	907,4
X	—	—	—	—	—	34,1	—	—	—	6,6	280,8	2,3	—	—	42,0	292,5	39,0	74,4	27,9	113,2	751,0	161,8	589,2
XI	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	144,0	30,0	30,0	12,0	132,0	216,0	132,0	84,0
																				Total	7295,3	1628,6	5666,7

Table 6

Photosynthetic production and dissimilation in mg of hexose dm^{-2} $month^{-1}$ *Rumex acetosa* leaves during the vegetative season for various combinations of thermic and light classes. For explanations see Table 5

Months	T_{25}					T_{20}					T_{15}					T_{10}					*Pg*	*Dg*	*EP*
	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*	L_{100}	L_{75}	L_{50}	L_{25}	*r*			
V	27,6	—	—	—	8,4	171,0	—	—	—	30,4	695,2	40,0	7,4	—	121,8	361,4	124,8	132,0	—	185,6	1599,4	346,2	1253,2
VI	118,4	—	—	—	37,0	287,1	—	—	—	69,3	448,2	—	—	15,0	77,6	177,0	—	—	50,0	66,0	1095,7	249,9	845,8
VII	62,4	—	—	—	14,3	347,8	—	—	—	47,0	525,0	19,6	17,5	5,1	80,8	217,8	38,4	33,6	60,5	74,6	1327,7	216,7	1111,0
VIII	205,8	—	—	—	4,9	475,8	3,8	—	—	86,1	602,0	61,2	85,8	60,0	141,5	126,0	24,0	68,4	57,0	68,1	1769,8	300,6	1469,2
IX	58,8	—	—	—	11,2	280,0	3,8	—	—	42,6	469,9	72,0	34,0	26,4	75,2	261,8	81,9	40,0	68,6	77,4	1397,2	206,4	1190,8
X	—	—	—	—	—	31,9	—	—	—	5,5	291,2	2,7	—	—	31,5	312,0	45,0	80,6	34,1	113,2	797,5	150,2	647,3
XI	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	168,0	36,0	30,0	12,0	66,0	246,0	66,0	180,0
																				Total	8233,3	1536,0	6697,3

Table 7

Photosynthetic production and dissimilation in mg of hexose dm^{-2} $month^{-1}$ *Dactylis glomerata* leaves during the vegetative season for various combinations of thermic and light classes. For explanations see Table 5

Months	T_{25}					T_{20}					T_{15}					T_{10}					Pg	Dg	EP
	L_{100}	L_{75}	L_{50}	L_{25}	r	L_{100}	L_{75}	L_{50}	L_{25}	r	L_{100}	L_{75}	L_{50}	L_{25}	r	L_{100}	L_{75}	L_{50}	L_{25}	r			
V	4,2	—	—	—	3,6	19,0	—	—	—	15,2	47,4	3,0	0,6	—	34,8	27,8	10,4	12,0	—	46,4	124,4	100,0	24,4
VI	66,6	—	—	—	22,2	168,3	—	—	—	49,5	232,4	—	—	8,0	58,2	94,4	—	—	20,0	66,0	589,7	195,9	393,9
VII	40,3	—	—	—	11,7	28,2	—	—	—	65,8	297,5	11,2	9,8	3,3	121,2	121,0	21,6	19,2	38,5	149,2	590,6	347,9	242,7
VIII	19,6	—	—	—	53,9	402,6	3,2	—	—	98,4	464,4	46,8	65,0	38,4	169,8	96,0	18,0	50,4	38,0	90,8	1242,4	412,9	829,5
IX	46,2	—	—	—	16,8	203,0	2,8	—	—	71,0	330,2	50,0	22,0	17,6	150,4	178,5	54,6	24,0	49,0	193,5	977,9	431,7	546,2
X	—	—	—	—	—	25,3	—	—	—	8,8	218,4	2,0	—	—	63,0	234,0	33,0	62,0	21,7	226,4	596,4	298,2	298,2
XI	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	192,0	42,0	36,0	12,0	132,0	282,0	132,0	150,0
																				Total	4403,4	1918,6	2484,8

RESULTS

1. Measurements in the investigated ecosystem

In the investigated meadow ecosystem the three most important ecological factors: light, temperature and humidity were registrated continuously.

The intensity of photosynthetically active radiation changes in the course of the day in dependence of the angle of incidence of the sun rays and the conditions of sky overcast (Fig. 3). Maximum irradiation falls as a rule to midday hours. With a cloudless sky in summer months between 5 a.m. and 6 p.m. the *PAR* energy exceeds the light saturation point of photosynthesis (0,1 cal $cm^{-2}min^{-1}$). When the sky is overcast, the number of hours exceeding the light saturation point lies within the

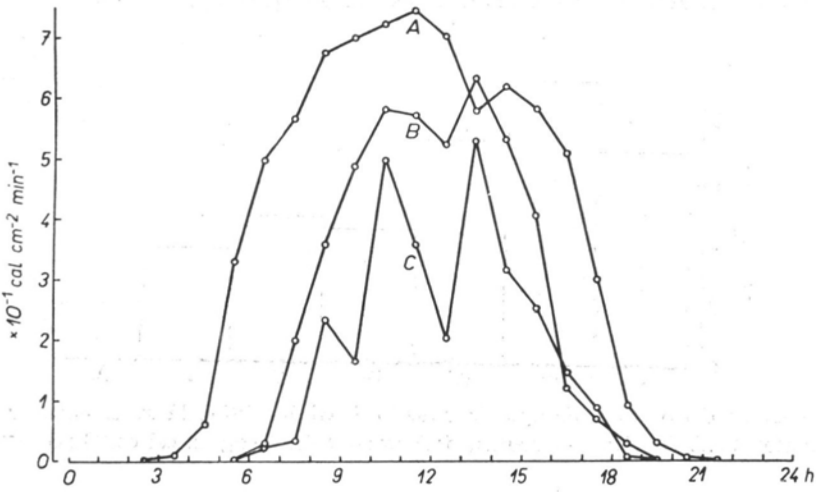

Fig 3. Course of changes in intensity of photosynthetically active radiation in Ojców National Park during several days and various weather conditions. *A* — 17. June 1966, *B* — 15. Sept. 1966. *C* — 16. Sept. 1966. Abscissae — hours, ordinates — *PAR* energy in cal cm^{-2} min^{-1}.

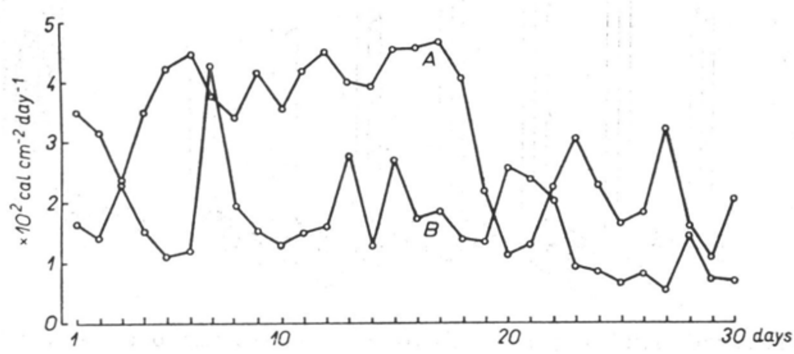

Fig. 4. Course of changes in intensity of photosynthetically active radiation in Ojców National Park in June (*A*) and September (B) 1966. Abscissae — days, ordinates — *PAR* energy in cal cm^{-2} min^{-1}.

limits of 6—8. Maximum light intensity occurs in June attained ca. 400 cal cm^{-2}day^{-1} (Fig. 4). The lowest photosynthetically active radiation during a vegetative season falls in November (ca. 60 cal cm^{-2}day^{-1}, Fig. 5). During the vegetative season the number of hours exceeding the light saturation point of photosynthesis is 65 percent of the total number of hours of light. The remainder consists of hours falling to other light classes (23.6 %) and the compensation point (11.4 %, Fig. 6).

The thermic data of the meadow ecosystem from the microclimatic investigations of J. Klein (1966) were utilized. The humidity conditions could be considered as optimal.

Confrontation of the thermic and light data in Table 1 indicates that the highest number of hours falls to light intensity exceeding the saturation point of photosynthesis and it increases with the decrease of temperature. The number of hours

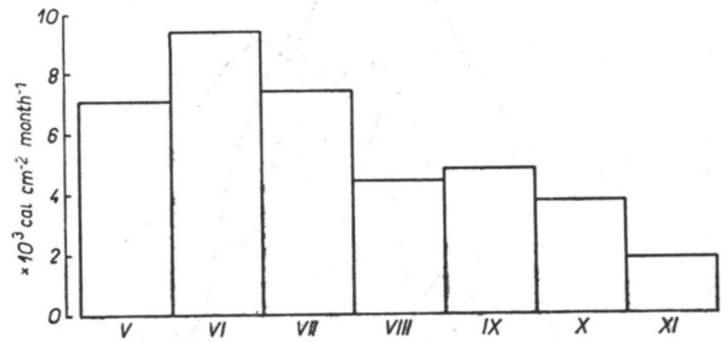

Fig. 5. Intensity of photosyn'hetically active radiation in Ojców National Park during the vegetative season 1966. Abscissae — months, ordinates — *PAR* energy in cal cm^{-2} month^{-1}.

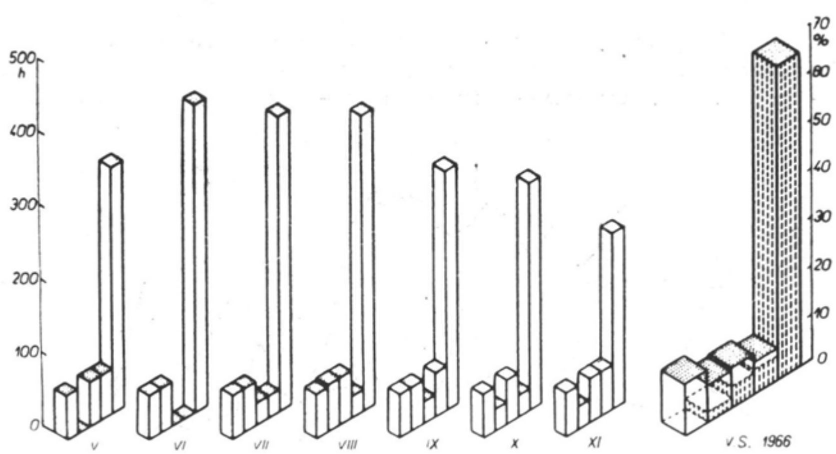

Fig. 6. Number of hours in lihgt classes (left ordinate) and percentage of light energy utilization (right ordinate) for photosynthetic production during the vegetative season. First bar refers to the compensation point, the second denotes the light class L_{25}, the third — L_{50}, the fourth — L_{75}, the fifth — L_{100}.

in which respiration occurs diminishes with temperature rise. Two hours daily were assumed as falling to the compensation point.

2. Laboratory measurements

Measurements of photosynthesis and respiration intensities show differences in the photosynthetic activity in dependence on the plant species during the vegetative season. The range of the changes in the dependence of photosynthesis on light

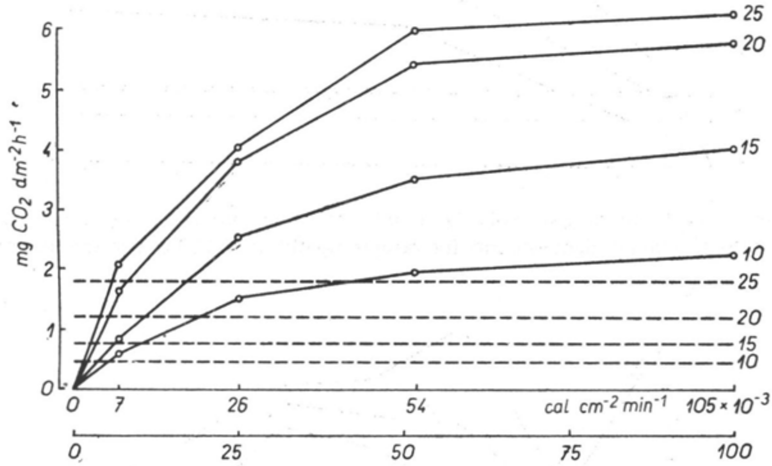

Fig. 7. Intensity of photosynthesis (solid line) and respiration (broken line) in leaves of *Plantago lanceolata* in May 1966 as the function of light intensity for various temperatures. Abscissae — light energy in cal cm^{-2} min^{-1}, ordinates — intensity of photosynthesis and respiration in mg CO_2 dm^{-2} h^{-1}. The figures on the curves denote temperatures. Below the axis of abscissae is the line with light classes (*L*).

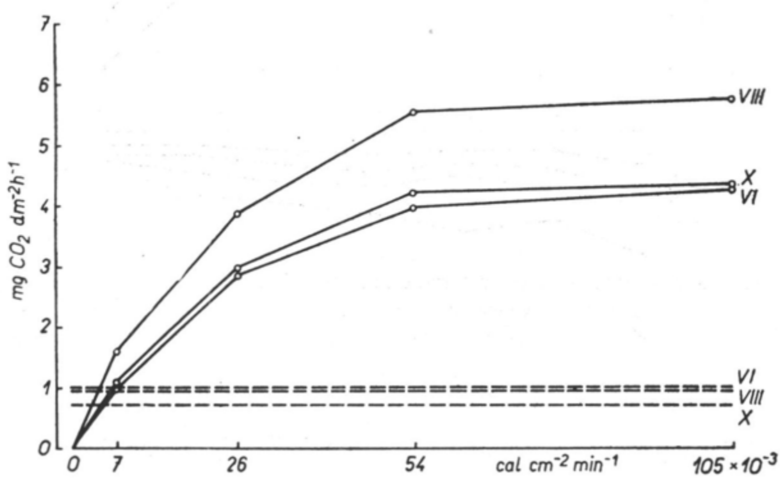

Fig. 8. Intensity of photosynthesis (solid line) and respiration (broken line) in leaves of *Rumex acetosa* as the function of light intensity for various months at 20°C. Abscissae — light energy in cal cm^{-2} min^{-1}, ordinates — intensity of photosynthesis and respiration in mg CO_2 dm^{-2} h^{-1}. The figures on the curves denote months.

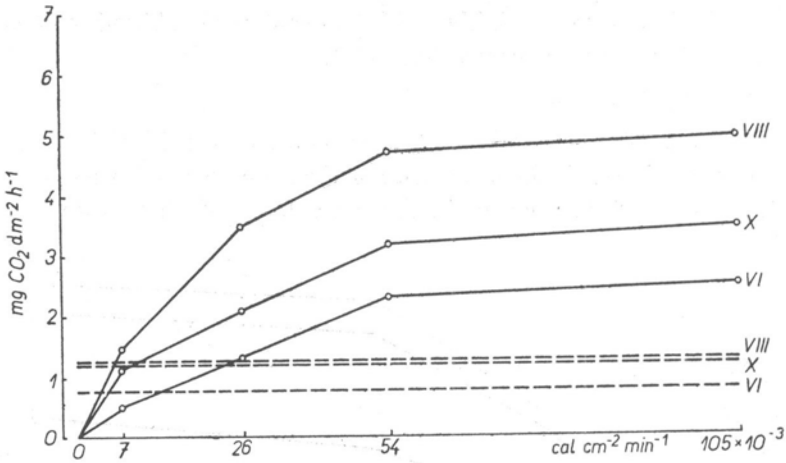

Fig. 9. Intensity of photosynthesis (solid line) and respiration (broken line) in leaves of *Dactylis glomerata* as the function of light intensity for various months at 20°C. For explanations see Fig. 8.

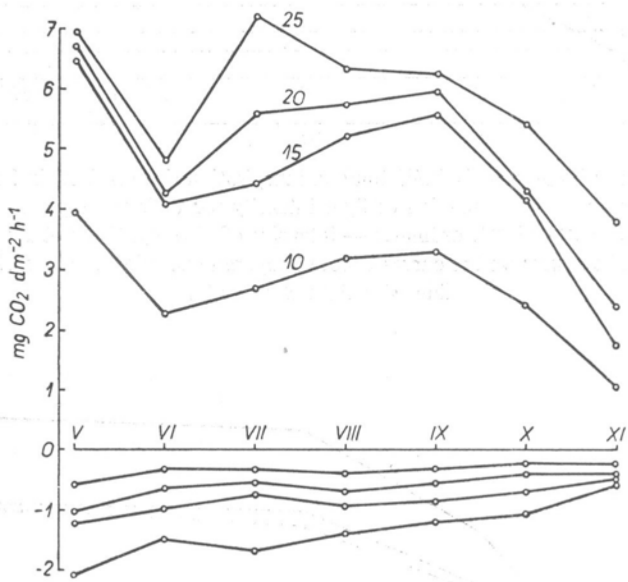

Fig. 10. Course of photosynthesis and respiration intensity in leaves of *Plantago lanceolata* during the vegetative season for various temperatures at the light saturation point. Abscissae — months, ordinates — intensity of photosynthesis and respiration in mg CO_2 dm^{-1} h^{-2}. The figures on the curves denote temperatures.

intensity and temperature is presented as example in Fig. 7. On the basis of such curves it was established that the compensation point in the investigated plant species lies below 0,007 cal $cm^{-2}min^{-1}$, and the light saturation point does not as a rule exceed 0.06 cal $cm^{-2}min^{-1}$ only for *Plantago lanceolata* it may attains 0.1 cal cm^{-2} min^{-1} (Figs 8, 9).

Graphs 10, 11, and 12 present the maximum of photosynthesis intensities lying above the light saturation point for various temperatures in the particular months of the vegetation season. As seen from these graphs there are distinct differences

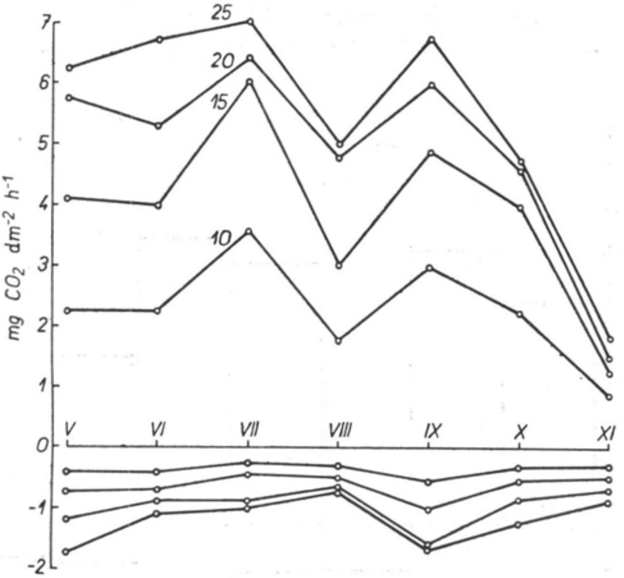

Fig. 11. Course of photosynthesis and respiration intensity in leaves of *Rumex acetosa* during the vegetative season for various temperatures at the light saturation point. For explanations see fig. 10.

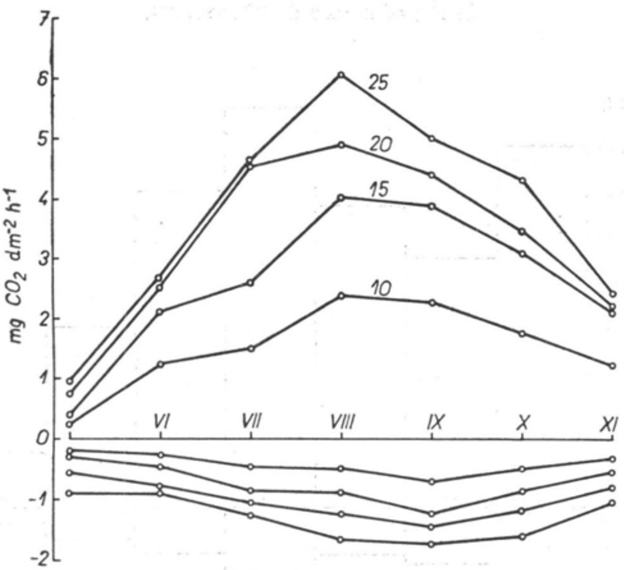

Fig. 12. Course of photosynthesis and respiration intensity in leaves of *Dactylis glomerata* during the vegetative season for various temperatures at the light saturation point. For explanations see fig. 10.

in the course of these curves between the particular plant species. For instance for the leaves of *Plantago lanceolata* and *Rumex acetosa* high photosynthesis intensities were noted in May. For these plant species two maxima occur registrated in July and September, the differences for *Plantago* beeing more pronounced than for *Rumex*. For the latter species measurements at 25°C showed a maximum in August, whereas in September it was noted at 10, 15 and 20°C. In contradistinction to these

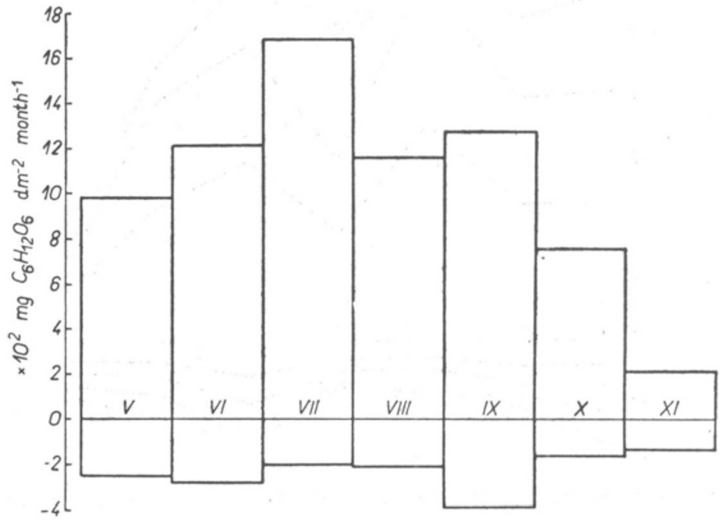

Fig. 13. Course of photosynthetic production and dissimilation during the vegetative season in leaves of *Plantago lanceolata*. Abscissae — months, ordinates — production or dissimilation in mg of hexose dm^{-2} $month^{-1}$.

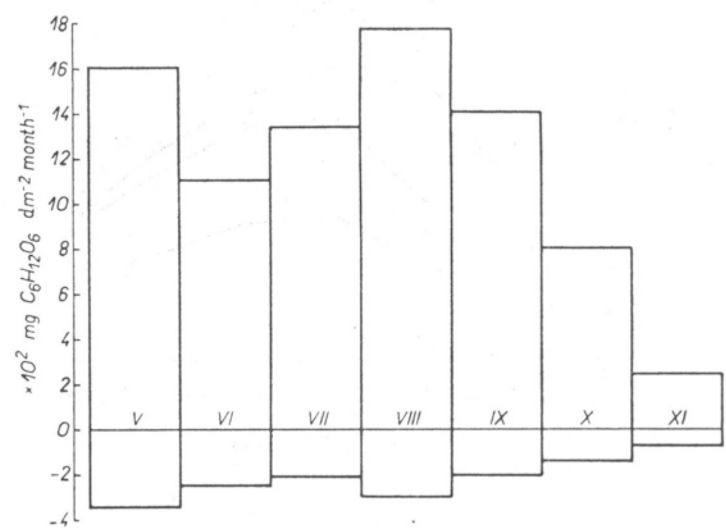

Fig. 14. Course of photosynthetic production and dissimilation during the vegetative season in leaves of *Rumex acetosa*. For explanations see Fig. 13.

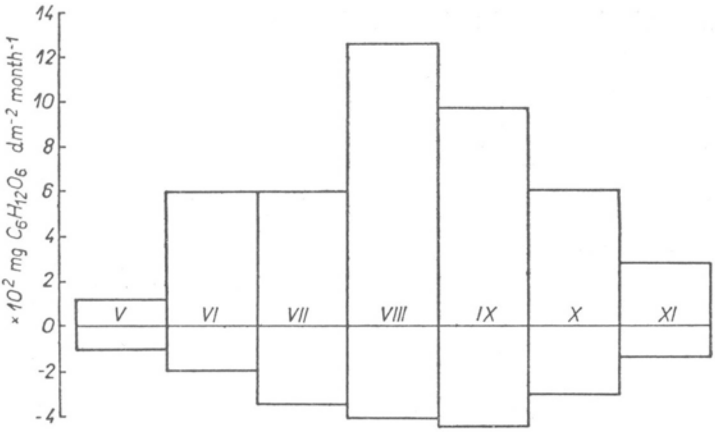

Fig. 15. Course of photosynthetic production and dissimilation during the vegetative season in leaves of *Dactylis glomerata*. For explanations see Fig. 13.

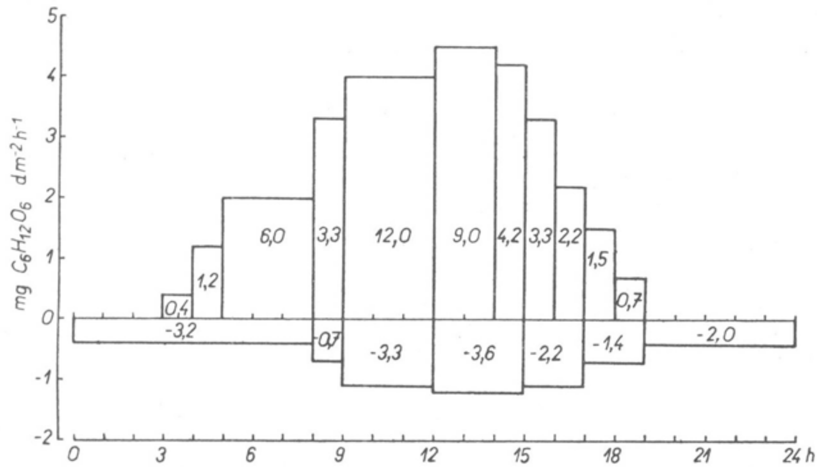

Fig. 16. Daily photosynthetic production and dissimilation (13. Sept. 1966) in leaves of *Plantago lanceolata*. Abscissae — hours, ordinates — production or dissimilation in mg of hexose $dm^{-2} h^{-1}$. The figures denote the production or dissimilation rates for the particular combinations of thermic and light classes. The effective photosynthetic production in this day attained 27.4 mg hexose $dm^{-2} day^{-1}$.

species, in *Dactylis glomerata*, the intensity of photosynthesis is relatively very low in May and a one-peak maximum appears in August.

The curves showing the respiration rate during the vegetative season for the species discussed are also given in Figs 10, 11 and 12. It may be concluded from their course that in *Plantago* and *Dactylis* the respiratory intensity is highest in September, whereas in *Rumex* the respiration rates show a decreasing tendency during the vegetative season.

On the basis of the thermic and light curves of the photosynthesis intensity and in view of the respiration-temperature relations, absolute numerical rates for these processes were obtained for definite thermic and light classes (Czopek, Starzecki 1967). The rates were expressed in milligrams of hexose $dm^{-2}h^{-1}$ and collected in Tables 2, 3, 4.

3. Calculation of photosynthetic productivity

As described above effective photosynthetic production of the leaves of some plant species is calculated on the basis of microclimatic (Table 1) and laboratory data (Tables 2, 3, 4).

Of the three plant species of the meadow ecosystem which were investigated, the leaves of *Plantago lanceolata* show the highest seasonal production (Table 5), next comes *Rumex acetosa* (Table 6), whereas the production of *Dactylis glomerata* leaves is lowest (Table 7). On the other hand, the course of photosynthetic production and dissimilation processes during the vegetative season shows wide differences in the individual plant species. In the leaves of *Plantago lanceolata* (Fig. 13) the highest photosynthetic production occurs in July and the lowest in November, whereas in *Rumex acetosa* (Fig. 14) two production peaks were observed in May and in August. The lowest production, and at the same time the highest dissimilation as compared to the other plant species was exhibited by the leaves of *Dactylis glomerata* (Fig. 15).

Analysis of the results of calculation of daily productivity proves that diurnal thermic changes are a modifying factor as regards photosynthetic production, whereas light is nearly always present in excess in natural conditions. Only in the early morning and late evening hours light energy supply may be a factor limiting photosynthesis (of course under the assumption that CO_2 concentration and humidity conditions are optimal). In the midday hours the intensity of respiration increases with the rise of temperature, only in the night it remains on a low steady level (Fig. 16).

DISCUSSION

The estimation of the photosynthetic productivity of natural ecosystems is extremely difficult from the methodical point of view. Measurements made even directly in the field by means of a infrared gas analyzer and special experimental chambers in which gas exchange of the meadow plant community can be investigated, give only some random data burdened moreover with a considerable error. This is caused by the lack of data concerning the respiration of the underground parts of plant and the changes in the microclimatic conditions in the experimental chambers in relation to the environment. At the present stage of ecophysiological investigations it is only possible to perform photosynthetic productivity measurements in the leaves of some selected plants characteristic for the investigated ecosystem. For this purpose Czopek and Starzecki (1967) elaborated a method for estimation of the photosynthetic production of leaves on the basis of laboratory and microclimatic measurements. As all methods it has its advantages and drawbacks. Among the latter the following may be enumerated:

1. it cannot be applied for a plant association as a whole;

2. it only deals with the photosynthetic production of leaves, without reference to the other plant parts (intensity of root and shoot respiration and photosynthesis in other green parts);

3. it does not take into account the period of depressed assimilation which may occur in the midday hours;

4. it does not take into consideration the changes in intensity of respiration of the assimilatory organs in dependence on the light intensity.

As far as photosynthetic production of leaves as the main assimilatory organ, is concerned, the above mentioned method has also some advantages:

1. it allows to measure the photosynthetic and respiratory rates in unimpaired leaves collected in the field, in dependence on controlled thermic, light and humidity conditions;

2. it is based on continuous registrating of the changes in intensity of photosynthetically active radiation on an open area (corresponding to the meadow ecosystem), and on the thermic and humidity changes at the level of the leaves collected for testing;

3. it gives the possibility of an easy and relatively simple calculation of the productivity based on the thermic and light classes for the whole vegetative season. For this reason this method was applied in the estimation of the photosynthetic productivity of leaves of some plant species from the meadow ecosystem of the Ojców National Park.

Measurements of photosynthesis and respiration rates in the leaves of *Plantago lanceolata*, *Rumex acetosa* and *Dactylis glomerata* were also performed in the preceding vegetative season (1965) by the microrespirometric method (Czopek 1967a). The results of these measurements, however were burdened with a certain error since disks were cut out from the leaves. Neither were the microclimatic measurements continuous, they were performed only three times daily. Thus the calculations of photosynthetic productivity of leaves for that vegetative season could be only considered as orientational (Czopek 1967a). Notwithstanding the above mentioned errors of the method some conclusions may be drawn from the comparison of the data for both these vegetative season concerning the same species.

The level of the compensation point was only slightly higher at the beginning of the vegetative season 1965, whereas in the further months it remained at about the same level (ca. 0.007 cal cm^{-2} min^{-1}). The light saturation point in particular months of 1965 was lower than in 1966.

The course of the respiratory intensity in both the vegetative season and for the individual plant species was closely similar (in spite of difference in the absolute rates). On the other hand, there were major differences in the course intensity of photosynthesis. They were more pronounced in measurements at higher temperatures (20 and 25°C). These differences may be due to: (1) the application of a different method of photosynthesis and respiratory intensities measurement (microrespirometer and infrared gas analyzer), (2) a change of the microclimatic conditions in the meadow ecosystem and differences in their recording in the particular seasons and (3) the application of a different method for photosynthetic productivity calculations.

The investigations demonstrated that the highest photosynthetic production of the leaves falls in the some plant species of meadow ecosystem to the summer months. The course of production depends on the changes in the environmental conditions as a whole and on the physiological state of the plants during the vegetative season.

SUMMARY

The present paper describes the possibility for estimation of effective photosynthetic production of leaves of some plant species in meadow ecosystem during the vegetative season on the basis of the following data;

1. continuous registration of the intensity of photosynthetically active radiation and of the thermic changes in the investigated ecosystem;

2. laboratory measurements of intensities of photosynthesis and respiration in dependence on the thermic and light conditions.

The microclimatic and laboratory data are collected to appropriate thermal and light classes and used for calculation of the photosynthetic productivity and dissimilation in three plant species of the meadow ecosystem (*Plantago lanceolata*, *Rumex acetosa* and *Dactylis glomerata*). The changes in intensity of photosynthetically active radiation during the vegetative season 1966 in the Ojców National Park are also presented.

The author is indebted to Professor dr. F. Górski, Professor dr. J. Zurzycki and Docent dr. W. Starzecki for their critical remarks and to J. Klein M. Sc. for making available to him the microclimatic data for the Ojców National Park.

The investigations were carried out together with ecological studies conducted in the Ojców National Park by the Nature Conservation Research Centre of the Polish Academy of Sciences in Cracow. They were partly supported by a grant from the Polish Committee of the International Biological Programme.

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(Entered: September 27, 1968)

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Produkcja fotosyntetyczna wybranych gatunków roślin ekosystemu łąkowego

Streszczenie

W niniejszej pracy wskazano na możliwość wyszacowania efektywnej produkcji fotosyntetycznej liści dla wybranych gatunków roślin ekosystemu łąkowego podczas sezonu wegetacyjnego na podstawie:

1) ciągłej rejestracji natężenia światła fotosyntetycznie czynnego i zmian termicznych w badanym ekosystemie,

2) laboratoryjnych pomiarów natężenia fotosyntezy i oddychania w zależności od warunków termicznych i świetlnych.

Dane mikroklimatyczne i laboratoryjne zestawiono w odpowiednie klasy termiczne i świetlne i wykorzystano do obliczeń produktywności fotosyntetycznej i dysymilacji u trzech wybranych gatunków roślin ekosystemu łąkowego (*Plantago lanceolata*, *Rumex acetosa* i *Dactylis glomerata*). Przedstawiono również zmiany w natężeniu światła fotosyntetycznie czynnego w ciągu sezonu wegetacyjnego 1966 r. w Ojcowskim Parku Narodowym.