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ABSORPTION OF PHOTOSYNTHETICALLY ACTIVE
RADIATION (PAR) IN CANOPY AND YIELD FORMATION
BY LEAFY AND SEMI-LEAFLESS MORPHOTYPES
OF THE PEA PLANT (*PISUM SATIVUM* L.)

ABSTRACT

An experiment aimed to review differences in the pattern of canopy forming, solar radiation penetration and its use efficiency (RUE) within the canopy of two contrasting pea morphotypes (leafy and semi-leafless) was conducted in the field. The differences in absorption of PAR were significant for both morphotypes in two consecutive years of different climatic conditions. The canopy architecture influenced absorption of PAR, penetration through the canopy and can result in different yield forming. For both morphotypes a common linear correlation between intercepted PAR and dry matter accumulation was found until the beginning of pod formation, but then this association was not linear. Differences in CGR and ULRC were significantly bigger in leafy pea morphotypes than in semi-leafless one and the higher values for both were observed at the beginning of pod formation.

Key words: biomass accumulation, canopy, radiation interception, pea, RUE.

INTRODUCTION

A gradient of radiation develops within a closed canopy stand in which individuals of species compete with each other to capture photons (Hirose 1995). The primary determinant of biological yield is the amount of light intercepted by the crop over the season, which depends on the integral of the leaf area index (LAI) over the growth period (Hay, Walker 1989; Beadle 1993). Plants do not accumulate biomass as a function of time, but rather as a function of the radiant energy (Arkebauer et. al. 1994). In many analyses the biomass accumulation is taken as the product of the amount of canopy-intercepted radiation and the radiation use efficiency (RUE) (Hamlyn 1992; Aufhammer 1998). Cumulated solar radiation intercepted or absorbed by a vegetation canopy during the vegetation is plotted against dry matter produced and

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the slope of the obtained curve is referred to as RUE. There are many models developed to estimate the RUE value for many species of crops (e. g. Heath, Hebblethwaite 1985; Wilson et al. 1985; Kiniry et al. 1989; Charles-Edwards et al. 1992; Jamieson et al. 1995; Gontarczyk 1998). For many species the values of RUE found by those authors ranged from 1.3 to 5.0. Leaves are the predominant plant organs responsible for harvesting the energy of photons and converting it into carbohydrates and other compounds during the growing season. Theoretical analysis of relations between foliage and its radiation interception resulted in a concept of "optimum leaf-area index" (Pietkiewicz 1985, Beadle 1993), where the value of crop growth rate (CGR) and unit leaf rate of canopy (ULRc) are the biggest. The arrangement of leaves has also been shown to exercise a great influence upon the radiation interception and dry-matter production of plant communities.

On the other hand some authors doubt whether the total amount of dry matter is always strictly correlated with the total amount of photosynthetically active radiation (PAR) intercepted or absorbed during the season (Monteith 1986; Demetriades-Shah et al. 1992; Czerednik, Nalborczyk 2000). It has been shown that RUE may also depend on other factors, either of exogenous or endogenous nature, and not always it is the only factor limiting growth of plant canopy.

The improvement of stand productivity is possible through the improvement of architecture of plants. The new morphotypes of pea give an example of marked differences to be found between plants growing in the stands. The major problem associated with the pea crop is lodging which drastically reduces the amount of seeds that can be harvested. Efforts to improve the growth habit of pea plant have centered on the use of leaf-mutant forms with genes *afaf* and *sfsf*. Crops composed of these mutant-leaf morphotypes have improved standing ability compared with the conventional leafy pea morphotypes and seem to be promising: reducing lodging, better penetration of PAR through the canopy and thus increasing the yield (Pyke, Hedley 1985; Murfet, Reid 1993).

MATERIAL AND METHODS

Experiments aimed to review differences between morphotypes of pea in the pattern of canopy forming, dynamic of crop growth, solar radiation penetration and its use efficiency within the canopy were conducted during two consecutive years of different climatic conditions. The structure of stands of two different morphotypes of spring pea: cv. Ramir (semi-leafless form) and strain RAH 594 (conventional leafy form) was studied. The seeds were sown in micro-plots 10 m² at density of about 75 plants × m⁻² with row spacing 0.33 m in north-south row orientation. Total aboveground dry matter was determined at the regular time intervals during growth (4 times in 1995 and 6 times in 1996), and seed

yields as well the harvest index (HI) were determined at maturity. During the vegetation period at different growth phases the measurements of solar radiation above the canopy and its penetration through of plant canopy together with LAI determination were taken. The leaf area duration (LAD) as the integrate of LAI over the whole vegetation period was calculated. The data concerning total solar radiation that reached the canopy during period of vegetation were received from the Institute of Meteorology and Water Management in Warsaw and amount of PAR was calculated according to Szeicz (1974) as 50% of total above-ground solar radiation. On the basis of the equation $Q = 1 - I/I_0$ [where Q - the radiation absorbed by plants, I - radiation penetrates into the canopy, I_0 - PAR radiation above the canopy], the RUE was calculated as a slope line of a function of total dry matter and PAR radiation absorbed (Charles-Edwards et al. 1992).

On the basis of obtained data the crop growth rate (CGR) expressed as terms of dry weight per unit area and time, and unit leaf rate of canopy (ULRc) measured as the net gain in dry weight of the plant per unit leaf area and per unit of time were calculated (Beadle 1993). The investigation of solar radiation absorption and pea canopy architecture was made with the use of Li-Cor equipment (Lincoln, Nebraska, USA): Li-191 SA Quantum Line Meter connected with Dataloger Li-1000 and LAI-2000 Plant Canopy Analyser respectively.

Obtained data were elaborated using one-way analysis of variance ANOVA in SAS statistical paquet. Significance of differences at confidence level of 0.05 and 0.01 was tested.

RESULTS AND DISCUSSION

Experiments were conducted during two consecutive years. Due to the big difference in climatic conditions time courses of developmental phases of investigated morphotypes during period spring-summer were quite different (Fig.1). In year 1996 with warm spring the flowering of investigated pea morphotypes began earlier than in year 1995 of cold spring, netherless whole period of vegetation was comparable for both forms - 103 days in 1995 and 101 days in 1996.

The relationship between accumulated biomass and the radiation energy intercepted is shown in Fig.2. When water and nutrients are not limiting factors, it is commonly accepted that the biomass and intercepted PAR are linearly associated (Kiniry et al. 1989; Czerednik, Nalborczyk 2000). Despite of differences in leaf area either in years of experiments or between morphotypes the radiation use efficiency changed for conventional morphotype and traditional one. One to the essential differences in climatic conditions in years of experiments was that, RUE of both morphotypes was lower in 1996 than in 1995. These differences could be result of better absorption of PAR by the canopy

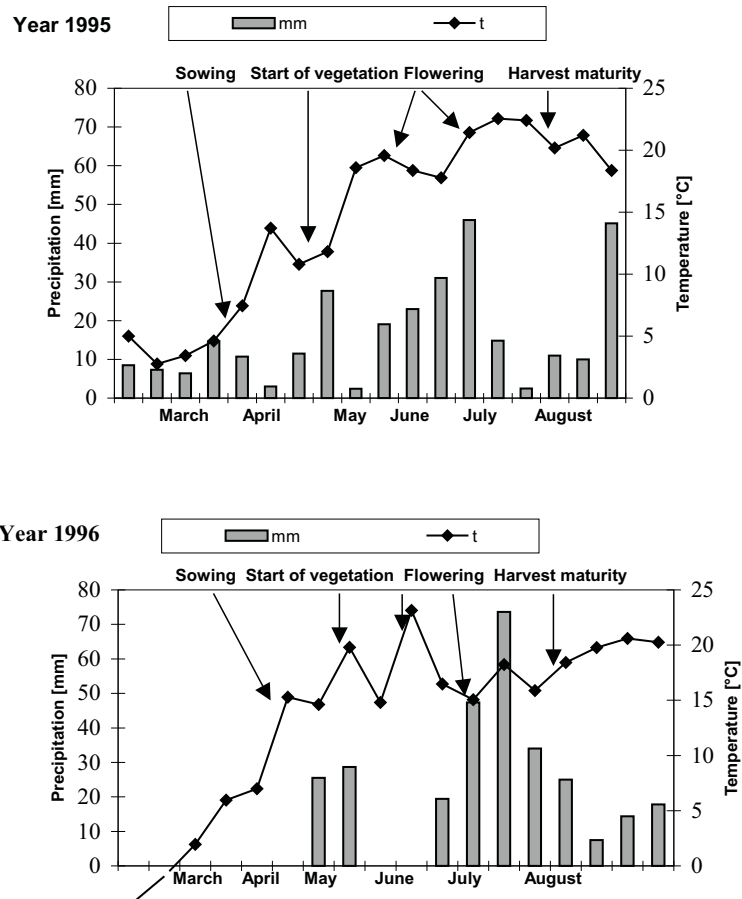


Fig.1 Climate factors influencing growth and vegetation of investigated pea morphotypes in two years of vegetation

of traditional pea plants and its better use in biomass production as is reflected in higher intensity of photosynthesis.

A common linear correlation between absorbed PAR and accumulated biomass was observed for both morphotypes until the beginning of pod formation. Then, this association was not linear, probably because of differences in distribution of assimilates accumulated in previous growth phases. This values of RUE are comparable with data 1.46- 2.36 obtained by other authors (Heath, Hebblethwaite 1985; Wilson et al. 1985).

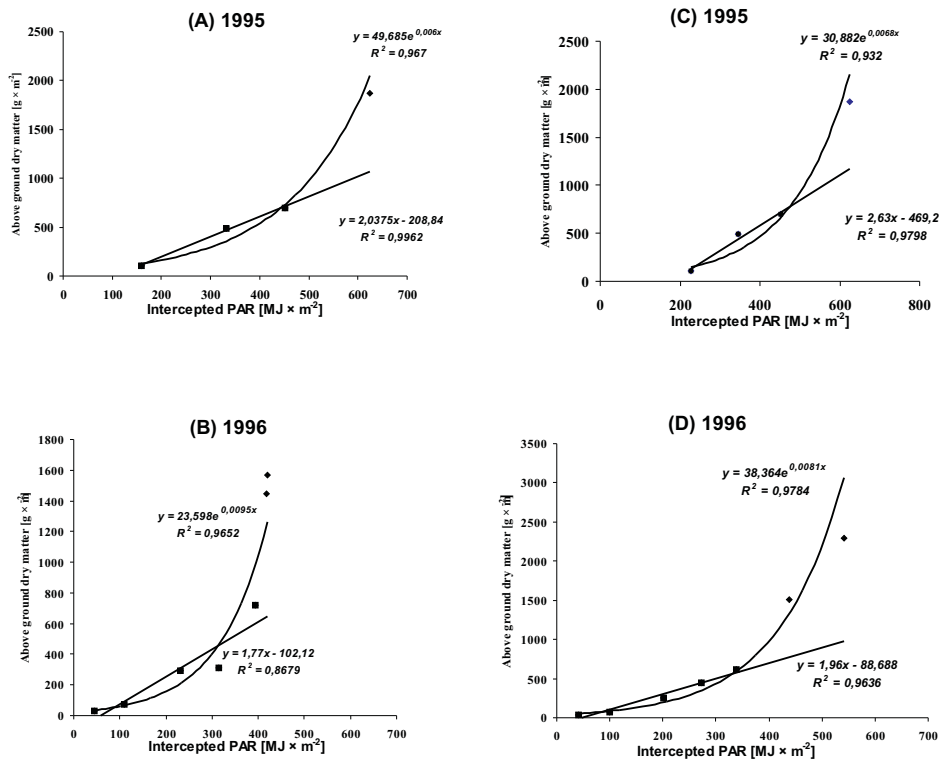


Fig. 2. Relationship between accumulated areal dry matter and intercepted photosynthetically active radiation (PAR), for leafless Ramir morphotypes (A,B) and conventional RAH 594 (C,D) one in years 1995 and 1996

LAI of both investigated morphotypes were different in two years of experiments and for traditional morphotype changed more than in semi-leafless one (Fig. 3 a, b). The maximum LAI as well the LAD was substantially higher for semi-leafless pea plants because of more steadily leaf drying in a canopy. The maximum LAI of both morphotypes reached at the end of flowering occurred later than it was observed in experiments of Armstrong and Pate (1994). Also leaf area duration changed between seasons. LAD of traditional morphotypes in 1996 reached value of 208 over the whole vegetation season and was twice as bigger than in 1995. In the semi-leafless form of pea the differences in LAD were more linked to changes in whole area of canopy leafage - 157 and 235 in 1995 and in 1996 respectively. In our experiments the RUE of semi-leafless pea was lower than that of traditional one. Nevertheless the total amount of PAR absorbed by the semi-leafless pea canopy in both years of experiments was bigger than that of traditional pea plants (Table 1). It could be a result of longer leaf area duration (LADc) in a canopy

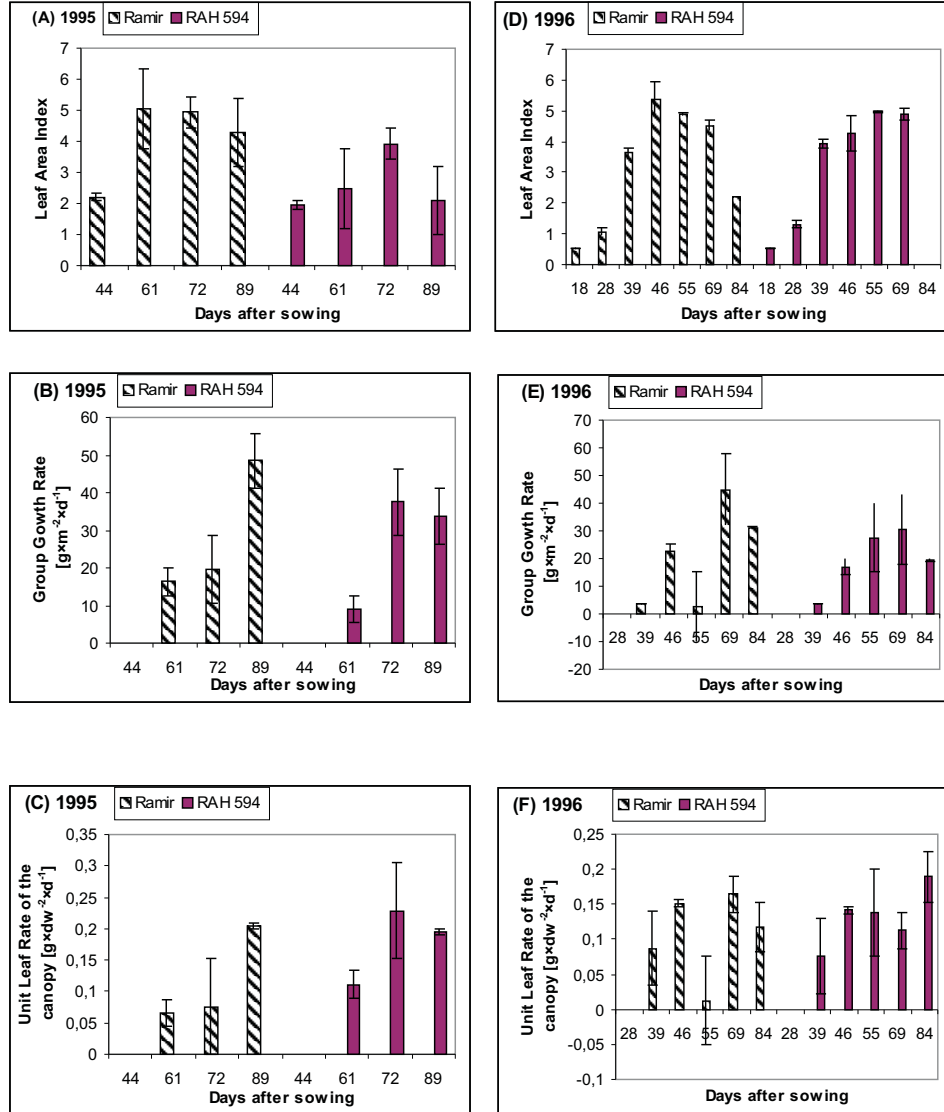


Fig.3 The differences in growth analysis indices LAI (a,d), CGR (b,e), ULRC (c,f), between investigated morphotypes of pea plants in two years of experiments. LSd ($P < 0.05$)

of semi-leafless pea as well as the better penetration of radiation through the canopy.

The differences in CGR were significant for both morphotypes (Fig 3, a, b). The biggest values of this parameter were reached by both morphotypes after flowering. The highest values of ULRC were observed at the beginning of pod formation. In experiments of Dzierżyńska (1990) the highest value of

Table 1
Amount of incident and absorbed PAR of two different pea morphotypes (cv. Ramir and select RAH 594) during vegetation

Period of observations	cv. Ramir			Period of observations	Strain RAH 594		
	Total amount of incident PAR	Amount of absorbed PAR			Total amount of incident PAR	Amount of absorbed PAR	
	[MJ × m ⁻²]	[MJ × m ⁻²]	%		[MJ × m ⁻²]	[MJ × m ⁻²]	%
1995 r							
06.05 - 05.06	270.34	131.76	49	06.05 - 05.06	270.34	122.87	46
06.06 - 23.06	187.85	141.71	75	06.06 - 23.06	187.85	123.29	66
24.06 - 04.07	117.51	98.70	84	02.06 - 10.07	199.95	142.04	71
05.07 - 20.07	186.99	146.73	79				
Σ	762.68	518.90	68	Σ	658.14	388.20	59
1996 r							
29.04 - 17.05	145.98	37.77	26	29.04 - 17.05	145.98	40.41	28
18.05 - 27.05	93.75	55.85	60	18.05 - 27.05	93.75	59.76	64
28.05 - 07.06	122.54	102.57	84	28.05 - 07.06	122.54	101.96	83
08.06 - 14.06	93.16	71.38	77	08.06 - 14.06	93.16	70.18	75
15.06 - 24.06	81.80	66.63	82	15.06 - 27.06	116.03	89.02	77
25.06 - 10.07	128.07	86.65	68				
Σ	665.00	420.85	63	Σ	571.46	361.33	77

LSD¹⁹⁹⁵ for total amount of PAR between morphotypes = 65.35, LSD¹⁹⁹⁶ for total amount of PAR for morphotypes = 30.26

Table 2
Elements of seed yield of two pea morphotypes

Year	Morphotype	Seeds/Pod	Seeds yield [kg/plot]	HI
1995	Ramir	4.5	6.67 (a)	0.47
	RAH 594	5.0 NS	4.96 (b)	0.43 NS
1996	Ramir	4.6	5.40 (c)	0.55
	RAH 594	5.3 NS	7.91 (d)	0.55 NS

LSD_(0.05) for (a) and (b) = 0,86; LSD_(0.05) for (c) and (d) = 1,26
NS - not significant between morphotypes as well between years

ULRc in pea crops also occurred at the beginning of pod formation. The higher amount of PAR was absorbed at the time when LAI of cv. Ramir canopy reached its bigger value. But the highest CGR was observed when LAI was between 4.9 - 4.5. It seems that this value of LAI is optimum for the investigated morphotype. For RAH 594 the biggest amount of PAR was absorbed during the flowering. It does not correspond with the maximum LAI for this morphotype.

In case of pea strain RAH 594 the bigger yield (Table 2) in 1996 was reached as a result of substantial increase in leaf area and time of its duration, as well as harvest index.

CONCLUSIONS

It can be supposed that differences between two forms of pea in absorption of PAR by canopy and its utilization for biomass production result the differences of canopy architecture.

The traditional morphotype of pea close the canopy earlier and the radiation conditions are less appropriate for photosynthesis in plant parts.

Plants of semi-leafless pea morphotype of cv. Ramir have fewer leaves, so tendrils take role of leaves. In such stand the radiation penetrates through the canopy much better. Tendrils and stipules can develop even bigger area than leaves and stipules of traditional pea morphotypes, due to cylindrical shape not only allowed the radiation penetrate better through the canopy.

The different architecture of canopy of semi-leafless pea allows for much more plants per the same area and as a consequence to reach the higher yield of seeds.

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