PHYSIOLOGICAL CHARACTERISTICS OF THE SUNFLOWER CROP (*HELIANTHUS ANNUUS* L.) AS AFFECTED BY PLANTING GEOMETRY

WULF DIEPENBROCK*, Institute of Agronomy & Crop Science, Martin-Luther-University Halle-Wittenberg, Ludwig-Wucherer-Str. 2, D-06099 Halle, Germany
Fax: +49-345-5527119; e-mail: diepenbrock@landw.uni-halle.de
*Corresponding author

MU-HUA LONG and BOY FEIL, Institute of Plant Sciences, ETH Zurich, Universitätstrasse 2, CH-8092 Zürich, Switzerland
Fax: +41-1-6321143; e-mail: muhua.long@ipw.agrl.ethz.ch, boy.feil@ipw.agrl.ethz.ch

Summary: The effects of planting geometry on oil yield, above-ground biomass, leaf area index (LAI), and rates of intercepted (RIR) and reflected radiation (RR) were assessed for the sunflower crop. Field trials were carried out for three years (1996, 1997, and 1998) on a Haplic Chernozem in the Hercynian dry region of central Germany. The treatments included two row orientations (east-west; north-south), three row spacings (50, 75, and 100 cm), and three plant densities (4, 8, and 12 plants m^{-2}). Sunflower plants in the east-west rows yielded on average 12 % more oil than plants in the north-south rows. High latitude (51°24‘ N) and relatively low intensity of radiation may account for this effect. Oil yield was always higher when rows were 75 cm apart than when they were 50 cm apart, while increasing the distance to 100 cm did not have a consistent positive effect on yield. With the exception of 1996, oil yield was higher at 4 and 8 plants m^{-2} than at 12 plants m^{-2}. The effects of planting geometry on above-ground biomass, LAI, RIR, and RR were inconsistent at the various developmental stages and over the years.

1. INTRODUCTION

One of the most important factors in crop production is the utilization of radiation, which is influenced by the structure of canopy. The canopy structure can be modified in several ways, by breeding and changes in planting geometry, i.e., by changing the density of the plants, row spacing, and/or row orientation (Palmer and Kilen, 1987). Increasing the plant density can increase the amount of radiation captured by the canopy. However, the efficiency with which intercepted radiation is inverted to grain yield decreases with increasing plant density because of mutual shading of plants (Buren et al., 1974). Sunflower (*Helianthus annuus* L.) responds inconsistently to increasing plant density; the optimum plant density for oil yield depends on the environment and the cultivar (Prunty, 1981; Blamey et al., 1997). Wade and Foreman (1988) found that the oil yield increased to a maximum with increasing plant density and remained constant at even higher plant densities under favourable environmental conditions. Under less favourable conditions, however, the oil yield started to decline at very high plant density. Row spacing may affect the utilization of light (Flénet et al., 1996), water, and nutrients (Gubbels et al., 1988) and, thus, sunflower growth and oil yield. Metz et al. (1984) suggested that the optimum oil yield is obtained when intra- and inter-row spacings are about the same at any given plant density. Information on the effect of row orientation on yield is still meager. Robinson (1975), Robinson et al. (1982), Schmidt (1995), and Myers and Minor (1993) reported that row orientation had no or only a slight effect on oil yield.

The objective of this research was to determine the effects of row orientation, row spacing, and plant density on oil yield and physiological characteristics (above-ground biomass, leaf area index, rates of intercepted and reflected radiation) of the sunflower crop.

2. MATERIALS AND METHODS

Field experiments were conducted at Bad Lauchstädt (51°24' N, 11°53' E, 113 m asl) in central Germany on a Haplic Chernozem in 1996, 1997, and 1998. This site is a border area for sunflower production. Eurosol, a short season cultivar, was grown. Plots (9 by 6 m) were arranged in a split-plot design with four replications. Row spacing (50, 75, and 100 cm) was the main plot and plant density (4, 8, and 12 plants m^{-2}) the subplot. This experimental unit was established for two row orientations, east-west (EW) and north-south (NS).

The phenology of the sunflower crop was recorded according to the method of Schneiter and Miller (1981). To determine biomass production, plant samples were taken at V12 (the 12th leaf stage), R1 (head visible), and R9 (physiological maturity) from an area of 3 m^2 in the center of each plot and dried at 60 °C to constant weight. The leaf area index (LAI) was measured with an LAI-2000 Plant Canopy Analyzer (LI-COR, Inc. Lincoln, NE, USA) under cloudy conditions. The incoming radiation was measured with a 190 SA point quantum sensor (LI-COR Inc., Lincoln, NE, USA), and the transmitted and reflected radiation was measured with a 191 SA line quantum sensor (LI-COR Inc., Lincoln, NE, USA). The rates of intercepted and reflected radiation were calculated from these data.

The means of the treatments were compared using the least significant difference (LSD) test at the P = 0.05 level. LSD values are not shown when the differences between the measurements are not significant at P = 0.05 according to the F-test.

2. RESULTS AND DISCUSSION

3.1. Weather Conditions

The experimental years can be characterized as follows: 1996 was relatively dry and cool, and 1998 was comparatively wet and warm. The precipitation in July was much higher than the long-term average, indicating that water supply was relatively high during the phase of rapid growth. Solar radiation was relatively high throughout the growing season in all the experimental years and especially in 1997 (Table 1).

Table 1. Precipitation, solar radiation, and air temperature during the growing seasons of three experimental years and long-term (1896 to 1995) means.

Year	April	May	June	July	Aug.	Total/mean
			Precipitation (mm)			
Long-term	37	51	61	64	57	270
1996	13	67	20	97	34	231
1997	23	40	53	187	50	353
1998	36	26	89	96	48	295
			Solar radiation (MJ m^{-2})			
Long-term	357	489	512	508	431	2297
1996	427	447	564	561	478	2477
1997	431	609	620	538	553	2751
1998	402	602	577	534	500	2615
			Air temperature (°C)			
Long-term	8.1	13.0	16.2	17.9	17.2	14.5
1996	8.7	11.5	15.7	16.1	17.8	14.0

1997	6.7	13.4	16.1	17.9	20.6	14.9
1998	9.9	14.4	17.2	17.4	18.8	15.5

3.2. Effects of planting geometry on oil yield and physiological characteristics

The effects of planting geometry on oil yield, above-ground biomass, LAI, RIR, and RR are summarized in Tables 2-4. There were some statistically significant interactions, but the effects of these interactions were inconsistent across the years; thus, detailed analyses of the interactions are not included in this study.

3.2.1. Oil Yield and Above-ground Biomass

Averaged across the plant densities and the row spacings, the EW rows consistently produced higher oil yields than the NS rows; the average yield advantage was about 12 % (Table 2). This finding is not line with that of previous studies (Robinson, 1975; Robinson et al., 1982; Schmidt, 1995; Myers and Minor, 1993). Conflicting results may be due to differences in the angle and the intensity of incoming radiation. These parameters are determined by the latitude and local weather conditions. In all three years, the lowest oil yield was observed when the distance between the rows was 50 cm, whereas the effect of plant density was different in each year. At V12, the above-ground biomass was consistently higher in the NS rows than in the EW rows; the effect of row orientation was significant (P = 0.01) only in 1997 and 1998. The differences in above-ground biomass, depending on row spacing, were large at this stage. The greatest amount of biomass was produced when rows were 75 cm apart, both in 1996 and 1998. In 1997, however, the greatest amount of biomass was found in rows spaced 50 cm apart. The above-ground biomass increased with increasing plant density in all three years. In 1997 and 1998, the NS row orientation at R1 still resulted in the greatest amount of biomass, but this was not the case in 1996. The above-ground biomass was lowest for the 100 cm row spacing and highest for the 75 cm row spacing. The effects of row spacing on biomass were significant at P = 0.05 in 1996 and 1998 and at P = 0.10 in 1997. The above-ground biomass increased with increasing plant density in all three years (Table 2). At physiological maturity (R9), the EW rows produced more biomass than the NS rows in all years (Table 2). In 1996 and 1998, the above-ground biomass increased significantly with increasing distance between the rows. In 1997, however, the differences between the row spacings were generally small. The above-ground biomass increased with increasing plant density in 1996 and 1998, but the lowest biomass production was found at 4 plants m^{-2} in 1997.

Table 2. Oil yield and above-ground biomass (Mg ha^{-1}) at various developmental stages as affected by row orientation, row spacing, and plant density in various years.

Traits	Oil yield			Above-ground biomass								
					V12			R1			R9	
Year	1996	1997	1998	1996	1997	1998	1996	1997	1998	1996	1997	1998
Row orientation (RO)												
East-West	1.47	1.65	1.59	1.10	0.83	1.45	4.70	5.92	6.29	12.27	10.68	12.50
North-South	1.31	1.59	1.31	1.15	0.98	1.77	4.57	6.46	6.69	11.72	10.65	11.84
LSD$_{0.05}$	0.08	-	0.27	-	0.08	0.23	-	0.45	-	1.17	-	-
Row spacing (RS)												
50 cm	1.29	1.59	1.42	1.13	1.02	1.65	4.58	6.31	6.67	11.25	10.47	11.58
75 cm	1.41	1.65	1.51	1.27	0.89	1.74	4.93	6.33	6.69	11.78	10.86	12.20
100 cm	1.46	1.62	1.43	0.98	0.81	1.43	4.40	5.93	6.12	12.94	10.66	12.72
LSD$_{0.05}$	0.07	-	-	0.12	0.06	0.16	0.40	-	0.65	1.30	-	0.57
Plant density (PD)												
4 plants m^{-2}	1.33	1.66	1.65	0.73	0.62	1.08	3.98	5.42	5.55	10.81	11.34	11.59
8 plants m^{-2}	1.42	1.60	1.45	1.17	0.92	1.70	4.62	6.37	6.73	12.14	9.85	12.15
12 plants m^{-2}	1.41	1.60	1.26	1.48	1.18	2.05	5.34	6.77	7.19	13.03	10.80	12.77
LSD$_{0.05}$	0.07	-	-	0.10	0.06	0.14	0.38	0.29	0.61	1.04	0.65	0.67
F-test												
RO	**	ns	*	ns	**	**	ns	*	ns	*	ns	+

RS	**	ns	+	***	***	**	*	+	*	***	ns	**
PD	*	ns	+	***	***	***	***	***	***	***	**	***
RO × RS	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns
RO × PD	ns	ns	*	ns	ns	ns	ns	+	ns	ns	ns	+
RS × PD	+	*	ns	ns	ns	+	ns	ns	*	*	ns	ns
RO × RS × PD	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns

+, *, **, *** significant at P = 0.10, 0.05, 0.01, and 0.001, respectively; ns not significant.

3.2.2. Leaf area index

Leaf area is considered to be one of the key physiological parameters that determine oil yield (Sadras and Trápani, 1999). During the vegetative stage (V12), the LAI was consistently higher for the NS row orientation than for the EW row orientation (Table 3). The effect of row orientation was significant only in 1997 and 1998. The LAI increased with decreasing row spacing and increasing plant density. At R1, the effect of row orientation on LAI was inconsistent. Significant (P = 0.01) differences in LAI occurred only in 1997 when the NS orientation had a higher LAI than the EW orientation. The effects of row spacing and plant density on LAI were still significant in all three years; as at V12, the LAI decreased with increasing row spacing and decreasing plant density. At the end of flowering (R6), row orientation had a significant but inconsistent effect on LAI in the various years. In 1996 and 1998, the NS orientation resulted in a higher LAI than did the EW orientation. In contrast, LAI was lower in the NS rows in 1997. The LAI decreased consistently with increasing row spacing. In 1996, the LAI tended to increase with increasing plant density, while it increased significantly with decreasing plant density in 1997 (P = 0.01) and 1998 (P = 0.001). The differences were in part statistically significant but always relatively small, especially after flowering. It has to be kept in mind that the LAI does not provide information about the structure of the canopy, which may be different for the various planting patterns.

Table 3. Leaf area index at various developmental stages as affected by row orientation, row spacing, and plant density in various years.

Traits	Leaf area index								
	V12			R1			R6		
Year	1996	1997	1998	1996	1997	1998	1996	1997	1998
Row orientation (RO)									
East-West	1.41	1.73	2.03	4.48	4.64	6.13	5.04	5.11	5.67
North-South	1.48	2.12	2.37	4.36	5.52	6.18	4.52	5.41	5.22
$LSD_{0.05}$	-	0.09	0.13	-	0.27	-	0.37	0.34	0.24
Row spacing (RS)									
50 cm	1.68	2.30	2.79	4.75	5.55	6.56	4.97	5.44	5.58
75 cm	1.55	1.84	2.14	4.55	5.12	6.26	4.75	5.29	5.40
100 cm	1.12	1.63	1.64	3.97	4.56	5.65	4.62	5.04	5.36
$LSD_{0.05}$	0.08	0.13	0.15	0.21	0.27	0.18	0.23	0.22	-
Plant density (PD)									
4 plants m^{-2}	1.13	1.58	1.68	4.19	4.99	5.83	4.69	5.43	5.67
8 plants m^{-2}	1.49	2.00	2.25	4.40	5.03	6.24	4.79	5.19	5.40
12 plants m^{-2}	1.72	2.20	2.64	4.67	5.21	6.40	4.86	5.15	5.26
$LSD_{0.05}$	0.14	0.08	0.24	0.18	0.20	0.15	-	0.17	0.14
F-test									
RO	ns	***	***	ns	**	ns	**	*	***
RS	***	***	***	***	***	***	*	**	+
PD	***	***	***	***	**	***	ns	**	***
RO × RS	ns	ns	ns	ns	ns	ns	ns	ns	ns
RO × PD	ns	ns	ns	ns	ns	ns	ns	**	**
RS × PD	***	ns	***	ns	**	+	ns	ns	ns
RO × RS × PD	ns	ns	ns	ns	ns	ns	ns	ns	ns

+, *, **, *** significant at P = 0.10, 0.05, 0.01, and 0.001, respectively; ns not significant.

3.2.3. Rates of intercepted (RIR) and reflected radiation (RR)

Table 4. Rates of intercepted and reflected radiation (%) at various developmental stages as affected by row orientation, row spacing, and plant density in various years.

Traits	Rate of intercepted radiation						Rate of reflected radiation					
	R1			R5			R1			R5		
Year	1996	1997	1998	1996	1997	1998	1996	1997	1998	1996	1997	1998
Row orientation (RO)												
East-West	90.9	95.5	94.7	97.7	96.8	98.2	4.4	5.5	4.5	5.7	8.2	7.1
North-South	88.1	95.9	95.3	96.5	97.3	98.0	4.3	5.7	4.8	5.8	6.6	5.5
$LSD_{0.05}$	-	-	-	0.9	-	-	-	-	0.2	-	1.2	0.5
Row spacing (RS)												
50 cm	93.8	98.0	97.7	97.5	97.4	98.1	4.4	5.7	4.7	5.8	7.5	6.8
75 cm	92.2	96.5	96.1	97.0	97.6	98.2	4.4	5.8	4.7	5.8	7.3	6.2
100 cm	82.5	92.5	91.3	96.8	96.3	98.0	4.2	5.3	4.6	5.7	7.4	5.9
$LSD_{0.05}$	4.3	3.6	2.3	-	1.1	-	-	-	-	-	-	0.4
Plant density (PD)												
4 plants m^{-2}	87.1	94.5	92.1	96.8	96.8	97.9	4.2	5.3	4.4	5.3	7.6	5.6
8 plants m^{-2}	89.2	96.3	95.4	97.3	97.5	98.2	4.2	5.7	4.8	5.9	7.3	6.6
12 plants m^{-2}	92.2	96.3	97.6	97.3	96.9	98.2	4.6	5.9	4.8	6.1	7.3	6.8
$LSD_{0.05}$	3.5	2.4	2.3	-	-	-	0.2	0.3	0.2	0.2	-	0.3
F-test												
RO	+	ns	ns	**	ns	ns	ns	ns	*	ns	*	***
RS	***	***	***	ns	**	ns	ns	ns	ns	ns	ns	***
PD	***	*	***	ns	ns	ns	***	***	***	***	ns	***
RO × RS	ns	ns	ns	ns	*	ns	ns	*	+	ns	ns	*
RO × PD	ns	ns	ns	ns	ns	ns	+	ns	ns	ns	+	ns
RS × PD	**	**	**	ns	ns	ns	+	ns	ns	+	**	ns
RO × RS × PD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	+	ns

+, *, **, *** significant at P = 0.10, 0.05, 0.01, and 0.001, respectively; ns not significant.

Andrade and Ferreiro (1996) reported that radiation may affect the oil yield of sunflower to a large extent. Radiation during the early reproductive stages is considered to be very important for oil yield (Schneiter et al., 1987). Two parameters, RIR and RR, will be considered here. At

R1, the effect of row orientation on RIR was relatively small and inconsistent over the years (Table 4). The responses of RIR to row spacing were significant (P = 0.001) and consistent; the RIR decreased markedly with increasing row spacing. RIR increased with increasing plant density. At the beginning of flowering (R5), the effects of planting geometry on RIR were small and inconsistent across the years.

At R1, the effect of row orientation on RR was significant (P = 0.05) in 1998 only (Table 4). In this year, more radiation was reflected at NS rows compared to the EW rows. A similar trend was found in 1997, whereas the opposite was true in 1996. The effect of row spacing on RR was always non-significant. The RR increased consistently with increasing plant density. At R5, a significantly higher RR was found for the EW orientation than for the NS orientation in 1997 and 1998. In 1996, however, the opposite was true. Thus, the effect of row orientation was inconsistent over the years (Table 4). The RR tended to decrease with increasing row spacing, but this effect was significant in 1998 only. The RR increased with increasing plant density in 1996 and 1998 but tended to decrease with increasing plant density in 1997.

4. CONCLUSIONS

Planting geometry may affect above-ground biomass, LAI, and rates of intercepted and reflected radiation, but there is no simple link between these physiological parameters and the oil yield. Row orientation may have marked effects on oil yield. Since this contrasts with the findings of previous studies, further research seems justified. Conflicting results concerning the effect of row orientation on yield may be due to differences in latitude and in the transparency of the atmosphere. To clarify this point, growth simulation models must be developed which take into account the various portions of direct and diffuse light that are brought about by differences in latitude and cloudiness.

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