RESPONSES OF SUNFLOWER TO STAND STRUCTURE AND CROP POPULATION DENSITY: EFFECTS ON LEAF AREA AND YIELD

Mónica López Pereira, Cátedra de Cultivos Industriales, Facultad de Agronomía. Universidad de Buenos As. Argentina
E-mail: pereiram@mail.agro.uba.ar

Nora Trápani, **Gervasio Piñeiro,** and **Antonio J. Hall,** IFEVA/CONICET and Departamentos de Biología Aplicada y Alimentos and Ecología, Facultad de Agronomía. Universidad de Buenos Aires. Avda. San Martín 4453 (1417) Bs. As. Argentina
E-mail: trapani@ifeva.edu.ar
E-mail: hall@ifeva.edu.ar

Abstract

Responses of crop leaf area at anthesis and yield to crop population density (CPD) and stand structure were explored. Treatments were variations in CPD (1–14.3 pl m sq.) combined with variations in interplant spacing within the target row and in neighbouring rows. Row spacing was 0.70 cm. In one of the three years, two hybrids of putatively contrasting potential grain number per head were compared, under the assumption that more florets (grains) per head might prove advantageous for maintaining yield in low-density, heterogenous stands. Crops were irrigated and protected from lodging and disease. Land area per plant (AP) was calculated using Thiessen polygons and CPD was derived from AP. Plant and crop leaf area at anthesis, grain yield and harvest index were determined. No advantage accrued, under low-density conditions, to the hybrid with greater potential grain (floret) number. Two other important results were: i) crop yield per unit area increased up to plant population densities well above that of the commercially accepted value; and ii) in two out of three experiments crop yield responses to population density were significantly ($P>0.05$) greater in crops with interrow spacings of 1.40 m than in crops of equivalent density grown at 0.70 m between rows. We conclude that the physiological capacity of the plant to set and fill grain does not limit crop tolerance to high CPD, and that these limits must be sought elsewhere (e.g., lodging and/or disease tolerance). In addition, yield responses to interrow spacing require further study.

Introduction

Non-homogeneous distribution of plants in the crop is a rather common feature in sunflower crops, even those grown by good farmers. Although many of these crops reach full cover at anthesis, crop yield can be impaired (AACREA, 1998). Non-homogeneity in stand structure affects localized crop population density, and is characterized by patches of higher or lower densities than the target population density (Trápani et al., 2000). Understanding of overall crop yield responses to patchy plant distribution requires an understanding of plant responses to localized variations in resource availability.

In sunflower, the phenological windows for the establishment of floret number and leaf area per plant overlap only partially. While leaf area per plant can adjust to variations in resource availability right up to anthesis, floret initiation is completed and the number of florets per plant is fixed 18-20 days before anthesis (Cantagallo et al., 1997). Sunflower cultivars exhibit variability for the potential number of flowers or grains per head. Cultivars with a greater potential number of florets per head might be able to better adjust to resource availability than those in which smaller inflorescences restrict potential grain number per plant (Villalobos et al., 1994).

The aims of this work were to evaluate and compare the responses of plant leaf area and grain number and size to variable resource availability imposed by variations in plant population density in the target row and in neighbouring rows. Two hybrids of putatively different potential head size were used, in one year, for this purpose. The experimental layout also allowed us to explore crop yield responses in stands protected from disease and lodging, two factors often assumed to impair plant performance in high population density crops and, by extension, in equivalent localized patches.

Materials and Methods

Three experiments were conducted at the experimental field of the Facultad de Agronomía, Universidad de Buenos Aires (34º 35´ S.) during 1998-1999 (Experiment 1), 1999-2000 (Experiment 2) and 2002-2003 (Experiment 3) seasons. In Experiment 1 crops of Aguará (AG) and Contiflor 9 (C9), two hybrids of putative contrasting plasticity of capitulum size, were used; in Experiments 2 and 3 only C9 was sown. The experimental area covered 0.1 ha and the crop rows were oriented north-south. The plots were fertilized (60 kg N/ha) and irrigated. Diseases, insects and lodging were controlled.

In all three experiments, a large range of crop population densities and stand structures were tested, using a basic row separation of 0.70 m (the commercial norm in Argentina). Treatments consisted in stands with widely spaced, normal (i.e., commercial crop array) and crowded plants in the target row (i.e., the central row of a three-row stand), combined with a range of between-plant spacings (from 14 cm to infinite) in the two border rows (Table 1). Experiments were laid out in a split plot (Experiment 1) or randomized complete block designs (Experiment 2 and 3) with three (Experiment 1 and 2) or six replicates (Experiment 3). Only the central portion of each target row within a plot was used for measurements, and two guard rows bordered the experimental area. Crops were oversown and desired crop structures were established by removing plants from the oversown stand at the two-leaf stage. Land area available to each plant (AP) in the target row was estimated using Thiessen polygons (Hühn, 2000), which are based on the distance from each plant to all immediate neighbouring plants. This technique signifies, for example, that the land area of a plant grown in a plot with an intra-plant spacing in the target row of 14 cm and empty neighbouring rows is assigned a land area of 0.14 m x 1.4 m =0.197 m sq. Crop population densities were calculated using AP. Crop developmental stages were recorded and anthesis leaf area per plant in the target row was estimated from the measurements of leaf width (Pereyra et al., 1982). At physiological maturity, yield per plant and harvest index were determined. Oil yield was calculated using grain oil concentration (% dry matter) which was measured by nuclear magnetic resonance (Oxford 4000, Oxford Analytical Instruments).

Analysis of variance and regression analysis were used to establish significance ($P < 0.05$) of differences among treatments and associations between variables. Fitting of functions to data and logarithmic transformations were performed using SAS (2002) and regression models were compared using a dummy variable.

Table 1. Treatments, area per plant, crop population density and description of crop structure of Experiments 1, 2 and 3.

Experiment	Treatment *	Area per plant (m^{-2}) (AP)	Resulting 3-row crop density (plant m^2)	Crop row structure
1 to 3	**28/28**	0.196	**5.1**	**Target=Neighbour (Control)**
1 to 3	**14/14**	0.098	10.2	Target=Neighbour
1 and 2	**56/56**	0.392	2.6	Target=Neighbour
2 and 3	**70/70**	0.490	2.0	Target=Neighbour
3	**10/10**	0.07	14.3	Target=Neighbour
3	**21/21**	0.147	6.8	Target=Neighbour
3	**40/40**	0.280	3.6	Target=Neighbour
2	10/28	0.071	14.1	Target ≠Neighbour
1 and 2	14/28	0.099	10.1	Target ≠Neighbour
2	40/28	0.276	3.6	Target≠Neighbour
1 and 2	56/28	0.376	2.7	Target≠ Neighbour
2	70/28	0.456	2.2	Target≠ Neighbour
1 and 2	14/56	0.103	9.7	Target≠ Neighbour
2	28/14	0.194	5.2	Target≠ Neighbour
2	28/56	0.204	4.9	Target≠ Neighbour
2	40/14	0.273	3.7	Target≠ Neighbour
2	40/56	0.287	3.5	Target ≠Neighbour
1 and 2	56/14	0.372	2.7	Target≠ Neighbour
2	70/14	0.451	2.2	Target≠ Neighbour
2	70/56	0.475	2.1	Target ≠Neighbour
3	21/0	0.295	3.4	Empty neighbour
2 and 3	10/0	0.141	7.1	Empty neighbour
1 to 3	14/0	0.197	5.1	Empty neighbour
1 to 3	28/0	0.392	2.6	Empty neighbour
2 and 3	40/0	0.558	1.8	Empty neighbour
1	56/0	0.774	1.3	Empty neighbour
2 and 3	70/0	0.963	1.0	Empty neighbour

* The first number in each pair describing treatments indicates distance (cm) between plants in the target row; the second number, distance (cm) between plants in the two adjacent rows. In treatments labelled -- /0, target rows had empty immediate neighbouring rows. Treatments with bold numbers are "perfect" crops, and treatment 28/28 represents the commercial norm in Argentina (crop population density 5.1 plant m sq.). Row separation was 0.70 m.

Results

Duration of the pre-anthesis phase in C9 was 52 (Experiment 1), 50 (Experiment 2) and 55 (Experiment 3) days from emergence, and took a week longer in AG (Experiment 1). The post–anthesis phase was completed in 45 days in all experiments and cultivars. Plant anthesis leaf area and yield data for the control (commercial structure) crops are shown in Table 2.

Responses at the Plant Level. Consistent with the expected relative performance of the hybrids used in Experiment 1, grain number varied by 86% (C9) and 138% (Aguara) between extreme crop densities (14.3-2.6 pl m sq.). However, contrary to expectations, relative (to commercial structure [control] crops) responses of both AG and C9 anthesis plant leaf area and yield to AP in Experiment 1 were indistinguishable (data not shown), negating (in this comparison) the hypothesis that greater potential head size might provide a basis for better adjustment to high resource availability. Consequently, only C9 was used for Experiments 2 and 3, which included a number of treatments that allowed us to explore a larger range of crop structures and densities (see Table 1). In what follows, only data for C9 is dealt with.

Table 2. Leaf area at anthesis and yield of sunflower plants of treatment 28/28 (standard commercial (control) crop at 5.1 plants per m sq.) during three seasons. Means ± standard error (n=3 for Experiments 1 and 2; n=6 for Experiment 3).

Variables	Aguará Experiment 1	Contiflor 9 Experiment 1	Contiflor 9 Experiment 2	Contiflor 9 Experiment 3
Leaf area at anthesis (cm^2 $plant^{-1}$)	5639 ± 435.2	6680 ± 596.8	5318 ± 457.6	6725 ± 742.6
Grain yield (g $plant^{-1}$)	63.8 ± 1.53	84.4 ± 3.07	69.3 ± 10.04	81.8 ± 12.70

Leaf area at anthesis and grain yield per plant showed curvilinear responses to AP over the full range of AP explored by the experiments (Figure 1). Relative (to the control stands [28/28]) responses of both these variables to AP were very similar across the three experiments (Figure 2), indicating similar plasticities for vegetative and reproductive responses. However, it is notable that data points for plants growing in target rows with empty neighbouring rows were above the general regression at the lower end of the AP range (Figure 2).

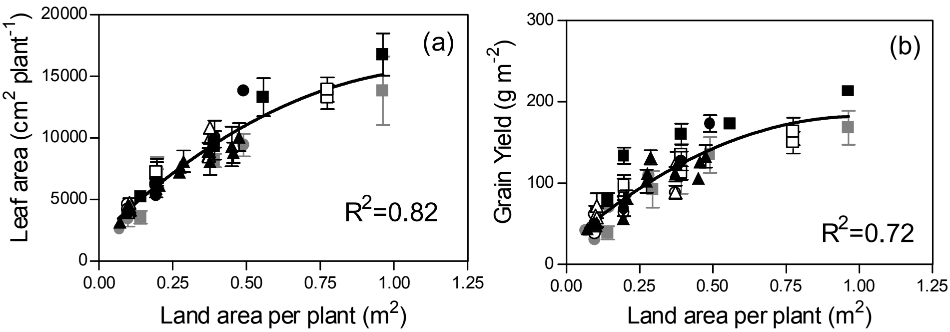

Figure 1. Sunflower leaf area per plant at anthesis (a) and grain yield per plant (b) as a function of land area per plant for Experiment 1 (open symbols), Experiment 2 (closed symbols), and Experiment 3 (closed grey symbols). Plants were grown in three-row stands of differing crop structure: uniform stands (circles), nonuniform stands (i.e., different inter-plant spacings in target and neighbouring rows) (triangles), and stands with empty border rows (squares). Bars are ± one standard error of the mean, n=3. Regression lines: Leaf area per plant: 1993+22960X - 9656X2 ; R2=0.82; Grain yield per plant: 24.98+313X – 155.9X2 ; R2=0.72

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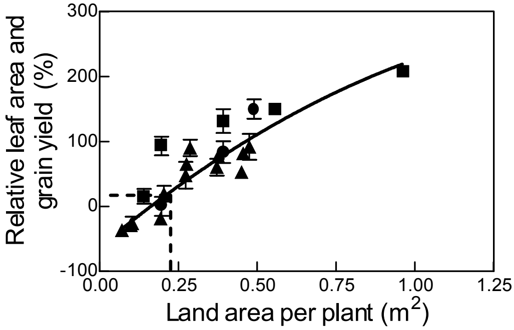

Figure 2: Variation of relative (to values of the control plants, Treatment 28/28, see Table 1) plant grain yield (symbols) and leaf area (line) as a function of land area per plant of sunflower crops of the hybrid Contiflor 9 (Experiment 2) with different structures: uniform (closed circles); nonuniform (i.e., different interplant spacings in target and neighbouring rows, closed triangles) and with empty border rows (closed squares). Bars are ± one standard error of the mean, n = 6. Dotted lines indicate ordinate and abscissae values for control plants.

Responses at the Crop Level. Leaf area index at anthesis showed a curvilinear response to crop population density with little evidence of any effect of crop structure on this response (Figure 3). Crop grain yield increased with crop population density well beyond the usual commercial value of 5.1 plants per square meter (Figure 4 a). When data from "perfect" (i.e., equal intrarow plant spacing in target and neighbour rows) crops were considered separately, grain yield increased linearly over the 2 to 16 plant m sq.) range, contrasting with the notional response to density found in crops unprotected against disease and lodging (Figure 4b). In Experiments 1 and 2 the slope of the "Yield (g m sq.) vs. ln [Density (plant m sq.)]" relationship describing the responses of plots with empty neighbouring rows was significantly (P<0.05) higher than the one for plots with neighbouring rows (of equal or different spacings to the target row), while the Y intercepts did not differ (P >0.05) (Figure 4a). By contrast, in Experiment 3, grain yields were similar between the different crop (with/without neighbouring rows) structures at equivalent crop population densities. (Figure 4a).

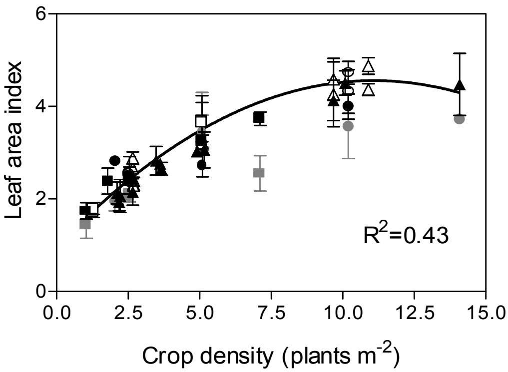

Figure 3: Leaf area index (LAI) at anthesis as a function of crop population density for Experiment 1 (open symbols), Experiment 2 (closed symbols), and Experiment 3 (closed grey symbols) for three-row plots of differing crop structure: uniform stands (circles); nonuniform stands (i.e., different interplant spacings in target and neighbouring rows, triangles) and stands with empty border rows (squares). See Table 1 for crop structure details. Bars are ± one standard error of the mean, n=3. Regression line: Leaf area index: 0.96+0.65X – 0.029X2 ; R2=0.43

Harvest index (HI) did not differ (P>0.05) among treatments and cultivars either when oil or grain HI were considered. Mean values from the three experiments were 0.36 ± 0.012 and 0.17 ± 0.012 for grain and oil HI, respectively. This result indicates that the effects of different crop structures and densities on biomass and yield were proportional, i.e., no significant changes in partitioning of aerial biomass were detected for the two hybrids tested in Experiment 1 nor for cultivar C9 used in Experiments 2 and 3.

Discussion

These results provide no support for our initial notion that cultivar-determined greater potential grain (floret) number per head might prove advantageous in low density heterogeneous crops. Rather, sunflower reproductive plasticity is similar to the well established leaf area per plant plasticity (Figure 2).

Two important and rather unexpected results of this work are that: i) currently accepted crop population densities in Argentine farming practice are below that which allows expression of crop yield potential under protection from lodging and disease (Figure 4b); and ii) at crop population densities of 5 to 7 plants per square meter the yield of plots with empty neighbouring rows was higher than or similar to the homogeneous stands (Figure 4a).

Because the limitations to higher crop densities in commercial practice do not seem to lie with plant capacity to set and fill grain, future work should focus on the effects of crop density on lodging and disease tolerance, the more likely remaining candidate causes for limits to crop yield under high density conditions. On the other hand, our results also call for research into the causes of the increased or maintained yield potential per unit land area of crops structured with wider than usual interrow spacings.

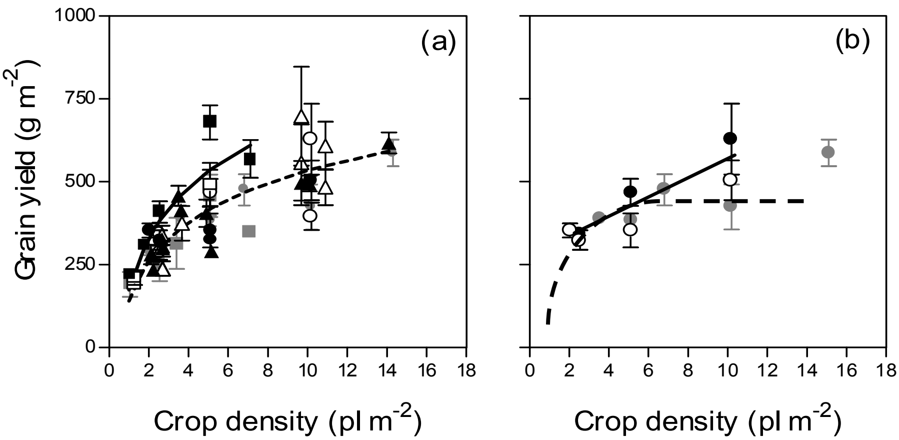

Figure 4. (a) Grain yield as a function of crop population density for Experiment 1 (open symbols), Experiment 2 (closed symbols), and Experiment 3 (closed grey symbols) for three-row plots of differing crop structure: uniform stands (circles); nonuniform stands (i.e., different interplant spacings in target and neighbouring rows)(triangles) and stands without border rows (squares). See Table 1 for crop structure details. Bars are ± one standard error of the mean, n=3. Regression lines: Yield (g m sq.) = 221.9 ln (X, plants m sq.) + 174.38; R2 = 0.87, $p<0.001$ for stands without border rows (line); Yield (g m sq.) = 170.54 ln (X, plants m sq.) + 140.47; R2 = 0.68, $p<0.001$ for stands with border rows (dotted line) Experiments 1 and 2. (b) Grain yield as a function of crop population density for sunflower homogeneous stands. Experiment 1 (open circles), 2 (closed circles), and 3 (open triangles). Bars on symbols represent ± standard errors of the mean, n=3. Dotted line indicates the expected response of commercial crops to population density. Regression line: Yield (g m sq.) = 265.7+31.58X; R2 =0.84, $p<0.0002$ for uniform stands Experiments 1 and 2.

Acknowledgments

This work was supported by a grant from UBACyT TG24, and ASAGIR 2002/03.

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