TESTING CROP MANAGEMENT SYSTEMS FOR SUNFLOWER IN SOUTH-WEST FRANCE

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Summary

Under rainfed conditions, the main limiting factor for sunflower growth in south-west France is water shortage, but a more recent limitation is due to the spread of phomopsis stem canker, a fungus which is responsible for dramatic yield losses. In both cases, avoidance (by sowing date or varietal choice), vegetative rationing (by plant density and N fertilization) and genotypic tolerance are possible management strategies to prevent the occurrence of the limiting factor or to reduce crop susceptibility.

Different crop management systems were designed for sunflower production and tested in a long-term experiment initiated in 1995 at INRA-Toulouse (SW France). The management systems were adapted to different levels of water availability for irrigation (rainfed vs. limited). A yield target was defined as a function of water availability. A management strategy, combining avoidance and (or) tolerance of limiting factors, and vegetative rationing was proposed and translated into sets of decision rules for varietal choice, sowing date, plant density, N fertilization rate and splitting, supplementary irrigation and fungicide protection. Every technical operation was triggered by an explicit rule (« if…then…, else… »), using a soil or plant indicator (either simulated or observed) on the basis of a decision threshold.

A general assessment was based on agronomical (yield, disease control, N management…), technical (working time…) and economical results (cost of inputs, gross margin under different assumptions). This evaluation is based on an original approach combining diagnostic at field scale (e.g. plant N status), test of single factors (e.g.yield response to plant density or fungicide protection, varietal comparisons) and main interactions in small plots (e.g variety x density), and crop simulation (e.g. effect of sowing date or genotypic earliness on yield).

The 5-yr results confirmed the value of low-input and cheap crop management systems for sunflower in the context of the current Common Agricultural Policy. Vegetative rationing and tolerant hybrids proved to be effective methods to prevent phomopsis damage and consequently, the use of fungicides. Under rainfed management, these practices were also compatible with the adaptation to water deficit. Avoidance strategy (early maturing cultivars) was effective for shallow soils while the use of late maturing cultivars sown early was the best solution on deep soils, whether irrigated or not. The approach applied to sunflower in contrasting water availability environments proved to be suitable to test the different decisions which constitute a crop management program.

Introduction

Under rainfed conditions, the main limiting factor for sunflower growth in south-west France is water shortage (high evaporative demand and low precipitation in summer) (Debaeke *et al.*, 1988). A more recent limitation occurred with the spread of phomopsis stem canker (*Diaporthe/Phomopsis helianthi* Munt.-Cvet. *et al.*), an ascomycete fungus which has been responsible for dramatic yield losses since 1985 (Delos and Moinard, 1995). The amount of spring precipitation, which is extremely variable from one year to another, explains the relative importance of the two limiting factors in a given year. In both cases, avoidance (by sowing date or varietal choice), vegetative rationing (by plant density and N fertilization) and genotypic tolerance are possible management strategies to prevent the occurrence of the limiting factor or to reduce crop susceptibility in those situations where the use of fungicides or supplementary irrigation is restricted for economical or environmental reasons.
Reau *et al.* (1998) reported the broad diversification of sunflower crop systems with the reform of the Common Agricultural Policy in 1992. Irrigation is now a marginal practice on sunflower, while the crop is grown mainly in drought-prone areas (shallow soils, southern regions). In the same way, low-input management is developing whereas disease problems are increasing because of short-term rotations (as sunflower-durum wheat). Therefore, in a context of year-to-year weather variability, there is a need for the development of crop management systems adapted to water availability but taking into account the risk of diseases.

Materials & Methods

A cropping system experiment was carried out in 1995 at INRA Agronomy Unit, in Toulouse-Auzeville, on a deep silty-clay to clay soil. Fixed and flexible crop rotations including sunflower were managed under 2 input levels (B & C), differing by variety, plant density, N fertilization, fungicide protection and irrigation. A generic approach was used to design and test the 2 crop management systems : 1) *definition of specifications for each system* : B = input and working time reduction in a context of limited irrigation; C = drastic input reduction under rainfed management, limited pesticide applications and limitation of time for crop monitoring; 2) *proposal of management strategies*, defined by explicit decision rules (**Table 1**): B = canopy rationing (through plant density and nitrogen) to limit input requirements ; C = avoidance of limiting factors (water, diseases) by varietal choice and sowing date, combined with crop rationing, to reduce the number of field operations ; 3) *application of decision rules* in big plots (1 ha), overall judgment (were the objectives reached and why ?), validation of specific decision rules.

The agronomic evaluation was based on 3 methods:
• *the use of diagnostic curves* (e.g. the “nitrogen dilution law” and the time-course of yield formation) which enable an observed variable to be related to a reference point;
• *the carrying out of subsidiary analytical trials* which may confirm the adequation of technical decisions and suggest interactions between techniques. Thus, 3 factors were tested in small plots (10 m²) in both B and C systems to study management interactions: 1) **genotypic earliness** (Early, Semi-Early, Semi-Late): 5-10 commercial varieties were compared for each earliness group in a randomized block design with 4 replicates; 2) **plant population**: 3 levels (D1 = 3.7 pl/m²; D2 = 6.2 pl/m²; D3 = 8.9 pl/m²) were compared for 3 varieties expressing the range of earliness (cvs. Albena, Asturia and Santiago in 1995 and 1996, cvs. Albena, Melody, and Labrador in 1997, 1998 and 1999) in a randomized block design with 2-3 replicates; 3) **fungicide treatment** (sprayed vs unsprayed), applied to the 3 densities and the 3 cultivars.
• *the simulation of crop management*. The EPIC-Phase model (Cabelguenne *et al.*, 1999) was used: a) to estimate the potential yields each year for each system, b) to explore the effects of management systems in more drastic conditions, such as on shallow soils, and to study the conditions for their extrapolation (on a 50 yr weather database).

On each experimental plot, 6-12 areas of 100 m^2 were monitored regularly from sowing to harvest. The main observations were : the number of plants emerged (on 16 m²), the vegetative biomass and cumulative N absorbed at 3 stages (flower bud, anthesis and maturity) from a sample of 5 plants, the fraction of radiation intercepted (ε_i) using a mobile PAR sensor (Picq, 1988) 3 times during the growing season, the main yield components and the grain yield (on 6 m^2). The frequency of stems bearing a spot of phomopsis (or phoma) and the severity of symptoms were assessed in early August on 20-30 plants per station. A similar diagnostic was performed on the analytical plots.

Table 1. Summary of major decision rules

		B management	C management
Sowing date	Target *Realized*	as soon as D > 10 April *2/05 (95), 10/04 (96), 8/04 (97)* *9/04 (98), 8/04 (99)*	a.s.a D > 25 April *2/05 (95), 15/05 (96), 8/04 (97)* *10/04 (98), 8/04 (99)*
Genotype Earliness Productivity Phomopsis	 Target *Realized*	 Semi-Late (SL) Good under B moderately (MT), very tolerant (VT) *95-96 : Santiago (SE) (VT)* *97-99 : Melody (SL) (MT)*	 SL if SD < 15/05 else E to SE good under C (hardy type) very tolerant (VT), resistant (R) *95 : Asturia (SL) (R)* *96 : Albena (E) (MT)* *97-99 : Labrador (SL) (VT)*
Plant density	Target *Realized*	6.5 pl/m² 6.6 – 7.0	5.0 pl/m² 5.7 – 6.5
N fertilization Yield (q ha^{-1}) N requirement N splitting N amount (kg ha^{-1})	 Target *Realized*	According to N balance sheet method (BILN) 33 5.0 kg N/q 2 applications 110 (55-125)	 25 4.5 kg N/q at sowing 45 (0-60)
Irrigation Mean amount (mm)	 *Realized*	According to water balance (BILH) and thresholds 110 (80-130) : 2-3 irrig from E5 to F4	 0
Fungicide(s)	Target *Realized*	Advices from SRPV 1 application (Punch CS 0.8 l ha^{-1})	0 0

Results

General assessment. The application of the decision rules resulted in very different sets of techniques between the 2 systems and the 5 years (**Table 1**). Calculating irrigation requirements using a water balance model resulted in different irrigation amounts and schedules between years and different values of the relative crop transpiration (T_a/T_0) with physiological phases and management (**Table 2**). In the rainfed system, the simulated T_a/T_0 expressed climatic conditions undergone by the sunflower: water stress at flowering (phase 2) in 1996, 1998 and 1999, and during grain filling (phase 3) in 1995, 1998 and 1999. The reduction of plant population and N fertilization in C-system resulted in a decrease of potential transpiration by 14-19 % with year. The consequences of crop rationing in C were a reduction of IPAR, mostly during the early growth of flower bud, and a N deficiency measured at anthesis by NNI (**Table 2**). This strategy was efficient enough to prevent the harmful symptoms of phomopsis on stems – except in 1997 - without spraying, the economic threshold for fungicide application being 15 % of harmful symptoms (Pinochet, 1995).

The C system provided the opportunity to reduce the working time (8-11 hours/ha vs 13-16 hours/ha in B) and the use of fungicides and other pesticides (**Table 2**). A yield reduction of 5.8 (1995), 1.2 (1996), 10.3 (1997) and 3.5 q/ha (1999) was observed when compared to B results, but in 1998, there was no difference between the two management systems at a high level of yield (40.7 q/ha). In addition, the between-year yield variability was greater in the C system. The residual N at sunflower harvest was lower for C, and less N was left in the vegetative residue. The two systems did not differ at harvest time, having the same genotypic earliness and sowing dates except in 1996, but earliness compensated the late sowing date in this case. Differences in harvest time were better explained by the genotype and the sowing date, which varied between years, than by the irrigation management.

The profitability of system C is clear 4 years out of 5 (+16 % of direct margin – including cost of machinary - in 1995, +59 % in 1996, +50 % in 1998, +46 % in 1999). In 1997, the profitability was similar in the two systems, as a result of the yield advantage for B. In deep soils, where high yields were obtained under C management, the profitability of B could be improved more by a specific subsidy for irrigated crops (as for grain sorghum) than by a decrease of irrigation costs. In shallow soils, where the yield difference between irrigated and rainfed management is expected to be greater, the interest of supplementary irrigation is probably better. Under a price assumption of 120 FF/q of grain, a difference of 10-12 q/ha is necessary between B and C to get a similar net return in the 2 systems.

Table 2 - Global evaluation of sunflower management systems (* = simulations)

	1995		1996		1997		1998		1999	
	B	C	B	C	B	C	B	C	B	C
Yield (q ha^{-1}, 9 % hum)	37.3	31.5	34.2	33.0	36.1	25.8	40.7	40.7	39.0	35.5
Harvest date	26/09	27/09	16/09		9/09	4/09	9/09	8/09	8/09	
*T_a/T_0 sowing to F1 F1 to M0 M0 to M4	0.94 0.95 **0.67**	0.96 0.84 **0.48**	0.91 0.88 0.93	0.81 **0.76** 0.81	0.92 0.91 0.86	0.94 0.85 **0.71**	0.83 0.83 **0.76**	0.87 **0.72** **0.48**	0.85 0.83 0.85	0.85 **0.56** **0.59**
IPAR (or ε_i) at F1 (%)	87	85	84	83	90	86	91	89	84	82
N Nutrition Index (at F1)	1.11	0.77	0.78	0.67	0.89	0.83	1.08	0.64	0.57	0.50
Straw N conc. (%)	0.67	0.48	0.95	0.66	0.63	0.53	0.78	0.55	0.83	0.59
*Soil N at harvest (kg ha^{-1})	13	9	23	9	67	23	38	19	28	7
Phomopsis on stems (%)	6.3	1.5	8.7	1.9	4.1	29.0	0.8	5.0	0.6	5.6
Number of pesticides	3	1	3	1	2	1	3	2	3	2
Working time(h ha^{-1})	15.9	11.4	15.4	7.8	15.1	10.8	12.7	8.0	13.2	7.6
Inputs (kFF ha^{-1})	2.2	1.0	2.5	0.7	2.5	1.4	2.8	1.5	2.4	1.4
Direct margin (kFF ha^{-1}) H1	4.4	5.1	3.4	5.4	3.0	3.0	3.8	5.7	2.8	4.1
Direct margin (kFF ha^{-1}) H2	**5.4**	-	4.4	-	**4.0**	-	4.8	-	3.8	-
Direct margin (kFF ha^{-1}) H3	**5.6**	-	4.7	-	**4.2**	-	5.1	-	4.1	-

H1 : no irrigation subsidy, irrigation cost (5 FF/mm for water, 4 FF /mm for material)
H2 : irrigation subsidy (+ 1000 FF/ha) as for sorghum, high water cost (5 FF/mm)
H3 : irrigation subsidy (+ 1000 FF/ha) as for sorghum + low water cost (2.5 FF/mm)

Evaluation of the varietal choice for each management system. The objective of the varietal choice is to find the best combination of precocity, tolerance to phomopsis, oil concentration and potential yield for each management system. In the South-West, the tolerance to phomopsis and mildew are the main criteria when choosing a variety.

• ***Simulation***. EPIC-Phase was used to simulate the effect of genotypic earliness (growing degree-days from sowing to maturity) on sunflower yield as a function of water availability. The choice of a late maturing genotype was the most suitable for system B while no marked effect of the cycle length was observed under C management **(Table 3)**. The value of early varieties is greater when water is scarcer; thus the yield difference between very early and semi-late varieties diminishes with water availability: -7.5 q/ha with full irrigation, compared with –0.6 q/ha on a shallow soil without irrigation. This is due to the greater number of stress days before grain-filling period for the L variety in unirrigated shallow soil, while the VE variety manages to escape the water stress to some extent.

Table 3 - Simulation of the genotypic effect on sunflower water use and distribution of water stress periods for 3 soil and water conditions (sowing date : 10 April) – 50 years (Toulouse)

	Very Early Genotype				Semi-Late Genotype			
	Yield (q/ha)	T_a (mm)	Stress.days cycle	gr.filling	Yield (q/ha)	T_a (mm)	Stress.days cycle	gr.filling
Deep soil (1.60 m), (B Management, irrigated a.s.a $T_a / T_0 < 0.95$)	28.8	420	5.2	3.5	36.3	495	10.6	7.6
Deep soil (1.60 m), (B Management, irrigated a.s.a $T_a/T_0 < 0.70$)	25.7	381	12.7	10.0	31.4	446	20.4	14.5
Deep soil (1.60 m), (C Management, rainfed)	23.8	351	15.8	12.8	25.5	396	28.0	22.6
Shallow soil (0.8 m), (C management, rainfed)	16.6	286	32.7	25.0	17.2	315	46.6	31.8

• ***Analytical trials***. In 1995, the initial varietal choice was not contested: cv.Santiago yielded more than cv.Asturia (+ 4.4 q/ha) in B under moderate plant density (D2 = 6.2 pl/m²) and was one of the most productive genotypes tested in B (+ 4.2 q/ha above the average yield). This short cultivar did not respond positively to a strong rationing by plant density (-9.2 q/ha for D1 = 3.7 pl/m²) or to a lack of fungicidal protection (-7 q/ha in B unsprayed plots). Conversely, cv.Asturia, which is tall and resistant to phomopsis, did not respond significantly to any increase of water supply, N fertilization, plant density or fungicidal protection (+1.4 q/ha with fungicide in B). In C (unsprayed), the choice of cv.Asturia was preferable to cv.Santiago (+2.5 q/ha for Asturia) but this was not true when fungicide was applied (-2.5 q/ha). Late maturing genotypes (SL types) yielded more than early ones (SE types) under C management with fungicide (+2.4 q/ha). On the other hand, in system B (sprayed), early types such as cv.Santafe (VE) and cv.Albena (E) yielded more (+ 4.0 q/ha) than later ones such as cv.Santiago (SE) and cv.Euroflor (SL). This result was explained by the severe water shortage in August during grain filling **(Table 2)**, which affected late maturing cultivars more than early ones because irrigation was not adjusted on the former.The choice of SL varieties sown in early May was responsible for the late harvest date (26/09) in 1995. The risk of increasing grain losses and of harvesting under poor soil conditions increases rapidly from 15-20/09.

In 1996, the replacement of cv.Asturia by cv.Albena was justified in C, because of the late sowing date imposed by the spring rain (**Table 1**). In C (unsprayed), the low density D1 was favourable to cv.Albena, which is moderately tolerant to phomopsis. As in 1995, late maturing genotypes responded better than early ones in C. In B (sprayed), the highest yields were observed with high plant density (D3 - D1 = +11.3 q/ha), as in 1995. Low plant density is the main factor limiting yield in cv.Santiago, a short cultivar. The use of a late genotype is more justified in B than in C, as was confirmed by the variety trial in 1996 (yield difference between SL and E = +4.0 q/ha in B and +1.4 q/ha in C). But, as cv.Asturia (a late type) responded only slightly to plant density, unlike cv.Santiago, the tall genotype was more suitable for system C than for B. The resistance to phomopsis combined with impressive vegetative development makes this variety a good candidate for low-input management.

In 1997, two late maturing cultivars were selected, cv.Melody for B and cv.Labrador for C, because of their good performance in 1995 and 1996 (+4.5 q/ha in 1995 and +5.0 q/ha in 1996 for Labrador in C) and the earlier sowing date. These genotypes have average vegetative development compared to the opposite behaviour of cv.Santiago and cv.Asturia. In addition, cv.Melody is resistant to the new races of mildew, now present in France. In 1997, their performance was confirmed in analytical trials (+5.1 q/ha for Melody in B, +3.6 q/ha for Labrador in C). In C management, early maturing genotypes (E) were more productive than later ones, i.e SE (+2.1 q/ha): this was related to water shortage at flowering in July **(Table 2).** In B, late maturing genotypes (SL) gave the best yields (+2.9 q/ha). The varietal choice was reproduced in 1998 and 1999: the good performance of the 2 genotypes for early sowings, already suggested in small plots, confirmed the soundness of the varietal decision (1998 : +2.4 q/ha for Labrador-C, +2.1 q/ha for Melody-B ; 1999 : +5.8 q/ha for Labrador-C, and Melody-B). Late maturing genotypes yielded more than early ones in 1999 (SL-E = +4.9 q/ha) but the differences were not significant in 1998.
The optimal population density was higher under B management (7.4 p/m² vs 6.3 p/m² for C), especially for Santiago and Melody (**Table 4**). The optima were the lowest for unsprayed conditions, tall (as Asturia) and moderately phomopsis tolerant genotypes (as Albena).

Table 4. Optimal population density as a function of variety and management

	1995		1996		1997			1998			1999		
	Ast	San	Ast	San	Alb	Lab	Mel	Alb	Lab	Mel	Alb	Lab	Mel
B (+fungicide)	5.4	8.4	7.0	7.3	6.2	7.2	8.5	6.3	7.3	8.8	7.2	8.0	9.0
B (unsprayed)	-	-	-	-	-	-	-	4.3	6.5	6.7	-	-	6.5
C (unsprayed)	6.1	6.2	6.0	4.7	5.9	7.0	6.8	4.8	7.7	6.6	6.2	5.7	8.5

Alb:Albena (MT), Ast:Asturia (R), Lab:Labrador (VT), Mel:Melody (MT), San:Santiago (VT)

Conclusions

The 5-yr results confirmed the value of low-input and cheap crop management systems for sunflower in the context of the current Common Agricultural Policy. Vegetative rationing and tolerant hybrids proved to be effective methods to prevent phomopsis damage and consequently, the use of fungicides. Under rainfed management, these practices were also compatible with the adaptation to water deficit. Avoidance strategy (early maturing cultivars) was effective for shallow soils while the use of late maturing cultivars sown early was the best solution on deep soils, whether irrigated or not. The plant population decision should take into account cultivar, irrigation, nitrogen and fungicide protection. The approach applied to sunflower in contrasting water availability environments proved to be suitable to test the different decisions which constitute a crop management program.

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