An evaluation of sunflower production strategies in a supplying area of an agricultural cooperative using the simulator COLLECTO

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ABSTRACT

- To improve the competitiveness of sunflower crop, yields and oil contents should be increased in average and the inter-annual fluctuations should be stabilized. A way to reach this goal consists in a better exploitation of the "genotype x environment x crop management" (GEM) interactions. These interactions are complex. The design and validation of crop practices exploiting them are difficult to carry out in a cooperative supplying area, considering the diversity of the production conditions. So the advisers need computer simulation tools allowing them to test production strategies at this scale in order to adjust their advices (variety and crop management) to the yield and grain quality targets and to the environmental constraints. The aim of this study was to evaluate different production strategies in a cooperative supplying basin which is fictive but representative of the cropping conditions in the South West of France. The strategies studied were : i) "R" strategy, close to the current practices (described from interviews of farmers), ii) "P" strategy, allowing to reach a mean yield close to the basin potential yield (recommended crop management and supplemental irrigation), iii) "V" strategy with an increase of the percentage of the basin area covered with a high oil variety and iv) "A" strategy with an improvement of the cropping practices in a part of the basin area.

- This evaluation was carried out with the software COLLECTO developed by CETIOM, INRA and INVIVO. This tool simulates the quantity and the quality (oil content) of the sunflower crop production and the economical results (for farmers and for the cooperative), at the supplying basin level, considering the diversity of the soil types, climatic conditions and cropping practices (including variety). COLLECTO is based on the sunflower crop model SUNFLO also developed by INRA and CETIOM whose characteristic is to take into account explicitly the characteristics of the varieties, in order to represent the GEM interactions. An aggregation module is used to figure the virtual basin as an assemblage of cultural situations. The effects of the limiting factors which are not considered by SUNFLO, but which might cause a significant crop damage (diseases, nutrient deficiencies…) are introduced with simple loss functions whose parameters are set by the users and which are applied on the values of yield and oil content calculated with SUNFLO.

- The results show that the difference between the yield permitted by current practices ("R" strategy) and the yield attainable after correction of the main limiting factors ("P" strategy) is about 0.6 $t.ha^{-1}$. The "V" strategy is more profitable than the "A" strategy, as well for the farmers (thanks to a better mean yield) than for the cooperative (mainly thanks to the higher oil content). The "A" strategy results in an intermediate yield between "R" and "V", but its profitability is the lowest both for farmers (increase of the costs which is not compensated by the increase of the yield) and for the cooperative (decrease of the oil content).

- This simulation exercise points out the potential interest of COLLECTO in evaluating production strategies in a complex system like a supplying area. Such an evaluation couldn't be performed with usual field experimental approaches.

- To our knowledge, no other example of tool able to simulate the production and the economical results at a supplying basin level, taking into account the complexity of the environment and crop management exists for sunflower. Cooperatives were closely associated to designing the specifications of COLLECTO. They imagine three mains applications for this simulator: assessment of production strategies, progressive yield forecast throughout the season and training of the farmers about the consequences of their decisions on production and economy of the sunflower crop.

Key words: COLLECTO, oil content, simulator, supplying area, SUNFLO, yield

INTRODUCTION

To improve the competitiveness of sunflower crop, yields and oil contents should be increased in average and the inter-annual fluctuations should be stabilized. Most of the time, the solution proposed by advisers is limited to the choice of varieties with high potential yield or oil content, without modifying the other elements of the crop management system (e. g. nitrogen, plant density, irrigation…) which can have also an important effect (Champolivier et al., 2005). It would be better to make a whole crop management advice, adapted to the variety and more generally to the targets of the farmers. A way to reach this goal consists in a better exploitation of the genetic potential of the varieties using the "genotype x environment x crop management" (GEM) interactions. But the design and validation of crop practices exploiting them are impossible to carry out with field trials at the level of cooperative supplying area because of the diversity of the production conditions. So the advisers need computer simulation tools allowing them to test different production strategies at this scale in order to fine-tune their advice (variety and crop management) to the yield and grain quality targets (both from farmers and cooperatives points of view) and to the environmental constraints (Champolivier et al., 2004 ; Debaeke et al., 2010). The supplying area is a relevant level to study the agronomical consequences of the choices made by the cooperatives concerning the advices to farmers for crop production (Le Bail, 2002).

The aim of this study was to evaluate different production strategies in a fictive cooperative supplying basin using COLLECTO, a new software (developed by CETIOM, INRA and the French cooperative group INVIVO) based on the crop model SUNFLO (Casadebaig et al., 2011 ; Casadebaig and Debaeke, 2011) in order to illustrate the potential interest of such a tool.

This kind of approach using a software simulator at a supplying basin level is new and no other example of similar work was found in the sunflower literature.

MATERIALS AND METHODS

COLLECTO description

The evaluation of production strategies was carried out with the software COLLECTO. This tool simulates the sunflower crop production in quantity and quality (oil content) and the profitability (for farmers and cooperative) of different options, at a supplying basin level, considering the diversity of the soil types, climatic conditions and cropping practices (including variety). COLLECTO is based on the sunflower crop model SUNFLO developed by INRA and CETIOM. SUNFLO needs only a few input data (soil, weather…) which are relatively easy to supply. It runs at a daily time step on a homogeneous situation. It takes into account explicitly the characteristics of the varieties, and the constraints related to temperature, radiation, water and nitrogen supply and represents the GEM interactions (Casadebaig and Debaeke, 2011).

An aggregation module is used to figure the basin as an assemblage of many homogeneous cultural situations which have been described thanks to a more or less simplified typology of the basin. The typology of the climates, soil types, and crop management system has to be built before from data bases or/and the expertise of local advisers (Salvi et al., 2012). It is organized on the base of the input data requirement of SUNFLO. The relative surface of each situation of the typology has to be estimated. When COLLECTO runs, SUNFLO calculates the yield and the oil content for each situation. Then the weighted average values are calculated taking into account the area covered by each situation.

The effects of the limiting factors which are not considered by SUNFLO, but which might cause a significant crop damage (diseases, nutrient deficiencies…) are introduced with simple loss functions whose parameters (intensity and frequency) are set by the users (on the basis of literature or/and regional expertise) and which are applied on the values of yield and oil content calculated with SUNFLO (for example, 2 years out of ten, the boron deficiency induces a yield decrease of 0.3 $t.ha^{-1}$ and an oil content decrease of 0.5 point).

An optional economical module makes easy the calculation of simplified gross margins from the point of view of the farmers and of the cooperative, for each homogeneous situation and at the basin level.

The agronomical input data for COLLECTO concern i) genetic parameters (13 parameters: architecture, phenology, physiological water stress response, potential oil content and potential harvest index; the parameters of more than 20 current varieties are still available in COLLECTO), ii) soil description (for 2 layers -0.30 cm and below-: water content at pF 4.2 and pF 2.7, potential N mineralization rate, depth, bulk density, stoniness, initial water content and initial N mineral content), iii) climate (daily data :

minimum and maximum temperatures, evapotranspiration, rainfall, global radiation) and iv) crop management (sowing date, seedling density, amounts and timing of N fertilization and irrigation).
COLLECTO is a web service. It was built on the modular modelling platform RECORD that has been developed by INRA in Toulouse.

Basin and production strategies

The study was based on a fictive supplying basin corresponding to the extreme simplification of a real basin located in the South West of France. Thanks to an agronomical diagnosis study conducted from 2007 to 2009, the main production limiting factors were identified in this area. The main one was water availability. Another source of production limitation was that the farmers tended to simplify their crop management and to reduce the inputs compared to recommended practices: lower seed density, later sowing date, no fungicide protection and no boron fertilization…

The simulated basin consisted in two types of soils: i) shallow soil, representing 60% of the basin surface (depth = 60 cm ; maximum available water = 85 mm) and deep soil representing 40 % of the basin surface (depth = 110 cm ; maximum available water = 160 mm). The meteorological data were those registered by the station of En Crambade (France, Haute-Garonne, about 30 km south east from Toulouse) from 2001 to 2010.

Three types of crop management (excepted variety) inspired by the results of the agronomical diagnosis and differing in sowing density, sowing date, irrigation, nitrogen and boron fertilization and fungicide protection were described (Table 1) : i) "advice-dry" : close to the recommended management, without irrigation, ii) "advice-irr" : close to the recommended management and irrigated around anthesis and iii) "cheap" : lower sowing density, later sowing date, no nitrogen and boron fertilization, no fungicide protection.

Table 1: Description of the types of crop management

	Sowing date (dd/mm)	Seedling rate (seed/ha)	Irrigation rate & date (l/m² (date))	N fertilization (kgN/ha (date))	Fongicide & boron application	Other losses	
						Yield	Oil content
Advice-dry	15/04	65000	0	80 (15/05)	yes	0.4 t/ha, 1 year/10	1 point, 1 year/10
Advice-irr			40 (05/07) 40 (25/07)		yes		
Cheap	15/05	45000	0	0	no	0.4 t/ha, 3 years/10	1 point, 3 years/10

Two varieties were used: i) "H" with high potential oil content: 50.3 % of the weight of commercial standard seeds (water content = 9% and impurity = 2%), ii) "M" with a lower potential oil content (48.1 %) and a higher potential yield (about + 0.3 $t.ha^{-1}$).

Four strategies were simulated (Table 2): i) "R" strategy, close to the current practices, ii) "P" strategy, allowing to reach a mean yield close to the basin potential yield (recommended crop management and supplemental irrigation), iii) "V" strategy with an increase of the percentage of the basin area covered with high oil varieties and iv) "A" strategy with an improvement of the cropping practices in a part of the basin area.

Table 2: Description of the types of strategies (soil x crop management x variety combinations) and percentage of the basin surface covered by each of them

	Strategy	R		P		V		A	
Crop management	Soil type	superf.	deep	superf.	deep	superf.	deep	superf.	deep
	Variety								
Advice-irr	M	1.5	1.0	30.0	20.0	0.3	0.2	1.5	1.0
	H	1.5	1.0	30.0	20.0	2.7	1.8	1.5	1.0
Advice-dry	M	7.5	5.0	0.0	0.0	1.5	1.0	15.0	10.0
	H	7.5	5.0	0.0	0.0	13.5	9.0	15.0	10.0
Cheap	M	21.0	14.0	0.0	0.0	4.2	2.8	13.5	9.0
	H	21.0	14.0	0.0	0.0	37.8	25.2	13.5	9.0

At the economical level, the main hypothesis were as follows: i) the price at which the cooperative buys the harvested seeds to farmers doesn't depend on the oil content which is the most common case in France for sunflower seeds, ii) the price at which the crushing industry pays the seeds to the cooperative increases with oil content level (price increased/decreased by 1.5 % per point of oil content above/below 44 %) in accordance with the French interprofessional agreement.

RESULTS AND DISCUSSION

Multi-year comparison of homogeneous situations: yield example (Figure 1)

For the "M" variety, the highest yields are reached with the "advice-irr" crop management on the deep soil. They fluctuate from 3.3 to 4.2 t.ha^{-1} depending on the year. The lowest yields are most often reached with the "cheap" crop management on the shallow soil (from 1.5 to 2.6 t.ha^{-1}). In each case, the lowest yields are related to the years with the driest climatic conditions (2003, 2004 and 2005) and the highest ones are related to the wettest climatic conditions (2007 and 2008). For each type of crop management, the yields obtained are always higher on the deep soil than on the shallow one (mean difference: 1.0 t.ha^{-1} with the "advice-irr" and 1.2 t.ha^{-1} with the two other types of crop management ; amplitude: from 0.7 t.ha^{-1} to 1.8 t.ha^{-1}). The yields of the "advice-irr" management are always higher than those of the "advice-dry" one: the average increase allowed by irrigation (80 l/m²) is about 0.4 t.ha^{-1} on deep soil and 0.6 t.ha^{-1} on shallow soil. Most often, the yield of the "advice-dry" crop management is slightly better than the yield of the "cheap" one. But some years, they are almost equal. The mean difference is about 0.1 to 0.2 t.ha^{-1}.

The "H" variety reaches a lower yield than the "M" variety on the deep soil, in accordance with the respective potential yields. But on the shallow soil, the yields of the "H" variety becomes higher than those of the "M" variety. For example, the mean yield with the "advice-irr" management is about 3.8 t.ha^{-1} for the "M" variety and 3.6 t.ha^{-1} for the "H" variety on the deep soil, and about respectively 2.8 t.ha^{-1} and 3.0 t.ha^{-1} on the shallow soil. So, the drought tolerance of the "H" variety seems to be better. The ranking of the types of crop management is the same for the two varieties.

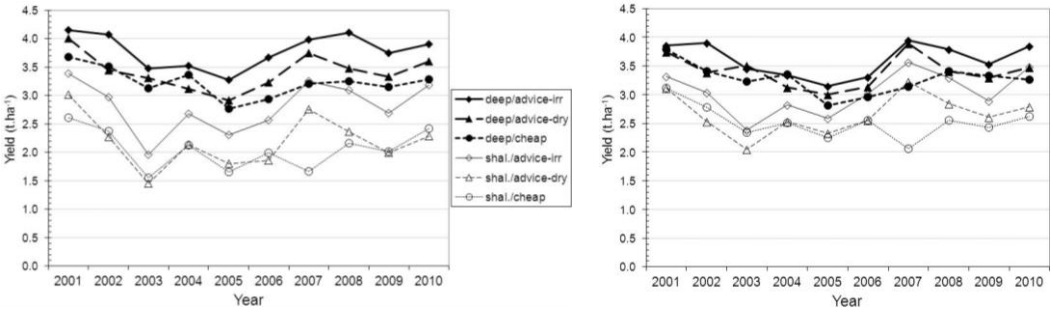

Fig. 1: Yields calculated for each year, crop management, and soil (left: "M" variety; right: "H" variety) (legend : soil type / crop management)

Comparison of situations for multi-year average values of oil content and gross margins (Figure 2)

Averaged over the ten years, the oil contents of the three types of crop management are ranked as follows by decreasing order: "cheap" management, "advice-irr" management and finally "advice-dry". There is a mean difference of about 2.4 points between the "cheap" and the "advice-irr" managements (from 1.8 points for the "M" variety on the deep soil to 2.5 points in the other situations) and of about 2.3 points between the "advice-irr" and the "advice-dry" managements (from 1.7 points with the "M" variety on the shallow soil to 2.9 points with the "H" variety on the deep soil). The best oil contents obtained with the "cheap" crop management are probably due to the lower amount of nitrogen fertilizer they received.

The gross margins for farmers are mainly positively related to the yields. This is because we assumed that the price at which the cooperative buys the harvested seeds to farmers doesn't depend on the oil content. However, decreasing the production costs with the "cheap" crop management allows to compensate for the slight yield decrease between the "cheap" and the "advice-dry" management.

The fluctuation of the cooperative gross margin mainly depends on the oil content. It is due to the assumption that the price at which the crushing industry pays the seeds to the cooperative increases when

the oil content increases. So for a cooperative the oil content can be more profitable than the quantity of seeds produced. For example, the gross margin reached with the "H" variety is better than with the "M" variety (whose oil content is lower) even on the deep soil where the yield of the latter is better.

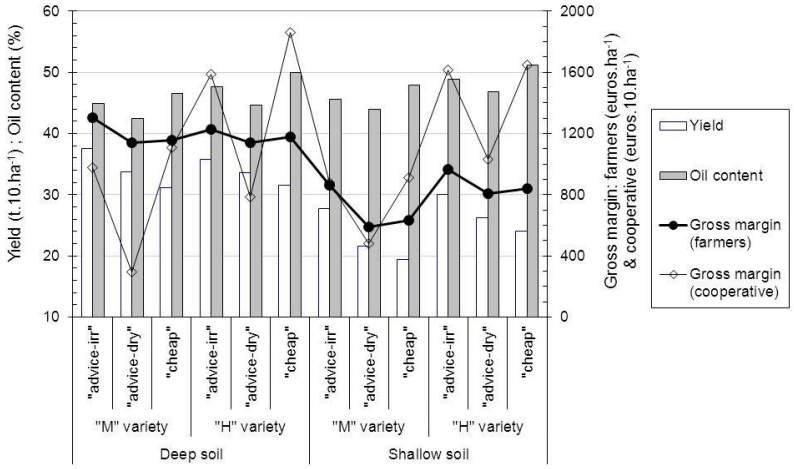

Fig. 2: Average yields, oil contents and gross margins for the farmers and for the cooperative calculated for each type of crop management, and soil

Comparison of production strategies at the supplying basin level (Figure 3)

The results of the comparison of the four production strategies at the supplying area level show that the "P" strategy for which the main limiting factors are at least partially corrected (particularly drought stress) reaches the best average yield over 10 years (about 3.2 t.ha^{-1}). This result gives an idea of the potential yield of the basin with the soils, the climate and a recommended crop management. This "P" strategy results in an average oil content of 46.8 % which is close to the lowest results among the four tested strategy. This is probably the consequence of the high nitrogen availability (N mineral fertilization of 80 kg N.ha^{-1} systematically applied). Due to the high yield level of this strategy, the gross margin for farmers is the best out of the four strategies. As the contrary, the cooperative gross margin is among the lowest because of the low oil content.

The "R" strategy, close to the current practices, leads to the lowest mean yield (2.6 t.ha^{-1}) and to a high oil content equal to 47.7 %. The gross margin obtained is the lowest because the oil content is not valued at the level of farmers.

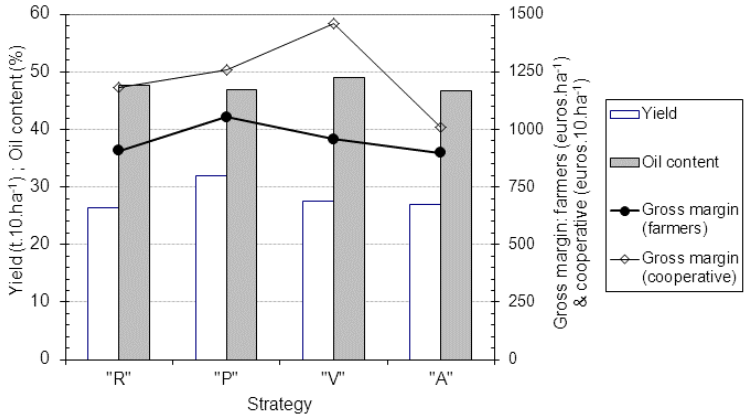

Fig. 3: Yield, oil content and gross margins calculated for each production strategy at basin level

Increasing the percentage of the basin area covered with the "H" variety ("V" strategy) leads to a slight higher average yield (about 2.8 t.ha^{-1}) than the "V" strategy although the yield potential of the "M"

variety is higher. This is because the "H" variety is more tolerant to drought stress and to crop management simplification, so its yields on the shallow soil (the most represented in the basin) are higher than those of the "M" variety. The oil content is the highest out of the four strategies tested (48.9 %) because the potential oil content of the "H" variety is higher than the "M" variety one. Therefore, the gross margins both for farmers and for the cooperative are improved.

Improving the crop management ("A" strategy) leads to a slight increase of the yield and a decrease of the oil content probably due to the negative effect of the N fertilization. The economical results of this strategy are the lowest out of the four strategies tested.

This simulation exercise points out the potential interest of COLLECTO in evaluating production strategies in a complex system like a supplying area. Such an evaluation couldn't be performed with usual field experimental approaches. For example, our results suggest that it could be more profitable both for farmers and the cooperative to grow varieties which do not reach the highest yield potential on deep soils but which are well adapted to the cropping conditions.

COLLECTO is an original computer tool using a crop model in order to simulate the production and the economical results (both for farmers and cooperative) of a crop at this complex level of organisation (supplying area) taking into account the environmental and crop management diversity. We have not found any other example of this kind of tool in the sunflower literature.

COLLECTO was designed and built by scientists and advisers together. A particular attention was paid to the effective possibility of use by the advisers with cooperatives. The latter were closely associated to designing the specifications of COLLECTO. They imagine three mains applications for this simulator: the assessment of production strategies, the progressive yield forecast throughout the season and the training of the farmers about the consequences of their decisions on production and economy of the sunflower crop.

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