# Describing and quantifying crop management systems in order to spatialize a sunflower crop model

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**Abstract**

- Crop simulation models are generally developed at field scale. But numerous applications are concerned by simulations at farm or regional scale. The aim of this work was to propose a spatialization process in order to achieve this upscaling with SUNFLO crop model developed for sunflower.

- Cooperative supplying areas were our spatial scale. We focused on two regions from different cooperatives in Southwestern France. The upscaling method we used consisted in choosing few representative types for each area and quantifying them. Then, simulations were applied to each type. The model outputs will be averaged to figure out our regions.
  To do so, we used crop management schemes and farm features.
  Crop management data were collected from over more than two hundred fields (2007 and 2008) by direct surveys and farmers' interviews. Data collected concerned: soil tillage, sowing dates and densities, fertilizers, crop protection and irrigation. We also measured canopy indicators and final performances like grain yields and oil contents.
  Farm characteristics were collected on about 210 farms, corresponding to almost 6 500 ha of sunflower and of about 25 000 ha of total agricultural area. We had only few data available concerning farm structures such as farm size, production orientation, cropping areas, irrigation.

- Using multivariate methods, cluster analysis and also some expertise, farm and management typologies were produced and significant relations between farm structures and crop management methods were identified.
  Seven crop management types were identified. They differed mainly on two aspects: the soil preparation (ploughed or not) and the level of intensification for crop protection and fertilization.
  Farm typology was based on the farmer's technical skill, the farm size, irrigation facilities and his investment on sunflower crop. The diversity of situations was gathered in seven farm types.
  Mixing farm characteristics and crop management methods allowed us to highlight relevant relationships between farm structures and crop management types. Only largest and non-specialized farms presented specific crop managements due to labor reduction necessity.

- So the contribution of the different crop managements in a given production basin could be predicted from statistical data on farm structures available in the cooperatives collecting sunflower. With this study, we proved that simple but numerous data were sufficient to determine and quantify the main sunflower crop management in two harvest basins.

- This method could be used and generalized in other areas, thus offering new perspectives for aggregating management data as model inputs of a decision-support model applied at a micro-regional level.

**Keywords:** classification method - crop management - crop model - spatialization - sunflower - typology

**Introduction**

According to several authors (Sebillote, 2006; Doré, 2006), agronomic research has to evolve from field level to regional and global levels. This evolution is needed to answer to current questions such as, nitrate water contamination in hydrographic basins, management of harvest quality within supplying areas (S.A.), labor management due to farm extension and integrated pest management at landscape scale. Agronomy raises more and more complex and diversified questions, which cannot be solved only at field scale.

Consequently, tools used for diagnosis, prediction or decision-making have to change their working scales. This is especially true for crop simulation models which have to be upscaled at territorial level.

But, model upscaling is not a trivial question. Bierkens *et al.* (2000) proposed a method to choose the most appropriate way to do it. The choice depends on the structure and characteristics of the model but also on the final precision required. Our study case was to propose a decision-making tool, based on a crop model SUNFLO, to manage sunflower crop and improve its quantity and its quality at a S.A. level (Champolivier *et al.*, 2012). The best way to upscale our model SUNFLO was to define representative production situations and the corresponding model inputs. Then, one simulation was run for each production situation. Results were aggregated as a function of their contribution to total basin area or farm number. The proposed approach is described in figure 1.

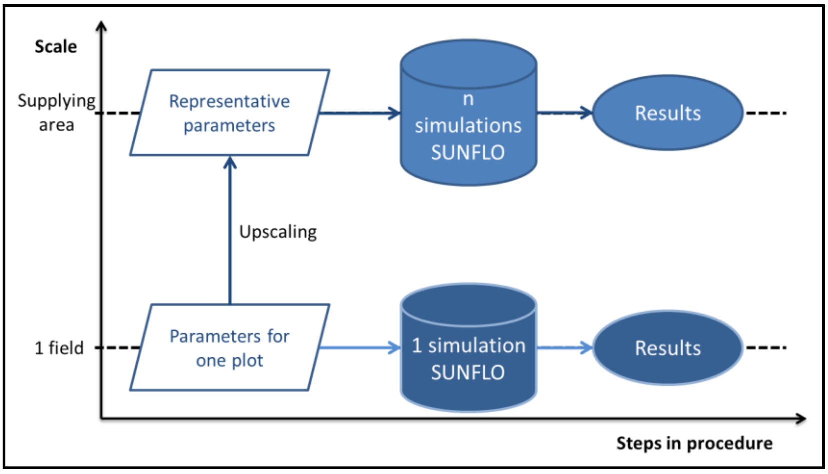


**Figure 1.** Upscaling SUNFLO – general approach (inspired from Bierkens *et al.*, 2000)

The SUNFLO model (Casadebaig *et al.*, 2011) has four different families of inputs. An upscaling solution must be proposed for each of them.

- Weather: the answer could be either working with a spatialized meteorological database or choosing data from one representative location;
- Soil: regional databases are available;
- Variety: amounts of seeds sown in each area can be provided by the agricultural cooperatives;
- Crop management: spatialized databases do not exist; here stands the main question to address.

Crop management is not frequently described at regional scale because this information is quite difficult to collect: numerous independent actors (the farmers), wide diversity of production situations and high number of fields to survey.

At a field scale, crop management is quite easy to survey but sampling representative fields should be carefully done. For two years, two supplying areas of sunflower grains were surveyed in Southwest France. Crop management data were collected on about one hundred plots per year.

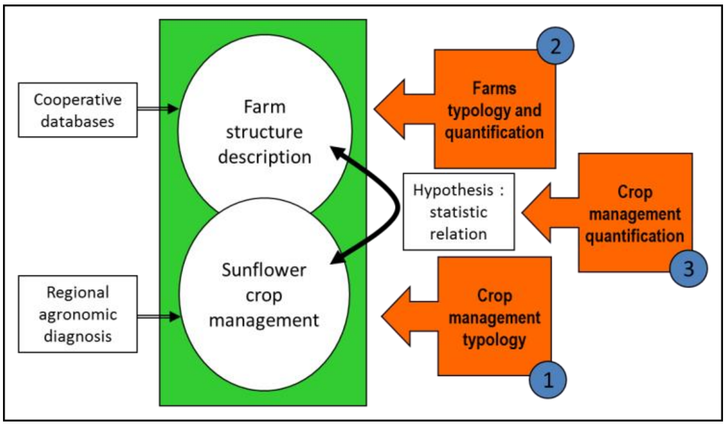


**Figure 2.** Description of study pattern and main steps

We assumed that farm structures and crop management were related because the decisions of the farmers follow a technical and economical rationality. Rough farm information was available from cooperative databases. Field descriptions came partly from the same farms. So, studying the relationships between farm type and representative sunflower field management should result in a quantification of each type of identified crop management (Fig. 2).

## Materials and methods

**General description of the area.** The study took place in two different natural regions located in the Southwest of France: the Lauragais area (south-east of Toulouse in Haute-Garonne department - 31) and the Lomagne area (north-west of Toulouse in Gers department - 32). Both are specialized in field crop productions: cereals, maize, oilseeds and pulses. About 25% of the agricultural area has irrigation facilities, but mostly in Lomagne, which has more diverse rotations, irrigated maize being predominant and the most important crop. Lauragais has more uniform rotations, mostly based on sunflower succeeding to durum wheat.

**Sunflower crop management (C.M.) description.** Data about sunflower field characteristics and crop managements were collected from 211 farmer's fields (table 1) to carry out a regional agronomical diagnosis. So, our database contained a lot of variables such as technical operations: soil preparation, sowing, fertilization, crop protection, crop performances (yield, oil content); limiting factors, context description and soil description were also available from the survey. 19 variables were chosen by expertise (table 2) to describe crop management.

**Table 1.** Distribution of plots

| | Lauragais | Lomagne | Total |
|---|---|---|---|
| 2007 | 66 | 45 | 111 |
| 2008 | 59 | 41 | 100 |
| **Total** | **125** | **86** | **211** |

**Table 2.** Crop management variables

| | |
|---|---|
| **Implantation** | Soil tillage |
| | Sowing date (gap with regional average) |
| | Sowing density |
| | Variety |
| **Weed control strategy** | Hoeing |
| | Number of herbicides |
| | Weed control program |
| | Weed control program cost |
| **Fertilizing** | Phosphate-potassium fertilizer |
| | Phosphorus dose (on rotation) |
| | Potassium dose (on rotation) |
| | Nitrogen dose (on sunflower) |
| | Dispatching of N supplies |
| | Fertilizers program/type |
| | Boron fertilizer |
| **Crop Protection** | Insecticide at sowing |
| | Number of molluscicides |
| | Fungicide treatment |
| **Irrigation** | Irrigation on sunflower |

**Farm description.** Farm features came from previous surveys and cooperative databases. Each member of the cooperative in the considered area was described by general farm information including: total agricultural area, field crop area, sunflower area, irrigation, mixed farming, proportion of sunflower area (table 3). The S.A. and their farms are described briefly in table 4.

**Table 3.** Farm descriptive variables

| | |
|---|---|
| **General description** | Supplying area |
| | Agricultural area |
| | Field crop area |
| | Sunflower area |
| | Irrigation facilities |
| **Specialization degree** | Field crop specialization |
| | Mixed farming |
| | Sunflower importance |

**Table 4.** Description of both supplying areas and members of cooperatives

| | **Lauragais** | **Lomagne** |
|---|---|---|
| Number of farms | 49 | 158 |
| Farm size (average in ha) | 120 | 109 |
| Total agricultural area (ha) | 5 900 | 17 300 |
| Irrigation practice (%) | 27% | 55% |
| Sunflower (ha) | 1850 | 4790 |
| Sunflower (%) | 33% | 29% |
| Mixed farming (%) | 10% | 18% |

**Data analysis.** Sunflower crop management schemes were first submitted to a multiple factor analysis (results not shown). With this multivariate method, quantitative and qualitative data could be mixed. The first 10 resulting synthetic variables took part in a cluster analysis (Hierarchical Ascendant Classification with WARD method).

Farm types were carried out by expertise. According to some recent works in France (Tisseyre, 2007), structural drivers proposed for sunflower crop management were farm size, degree of specialization in field crops, farmer's investment in sunflower crop, presence of irrigation facilities and available labor. Thanks to multivariate analysis (results not shown), a classification tree was built up with available data.

The third step of our analysis pattern was to study relations between these two levels. Because of the sample size, we could not conclude with statistical method (decision tree, results not shown). So, the relations were highlighted by expertise. In the end, crop management schemes were related to farm types. Then, the quantification of crop management types at the S.A. was just a mathematical operation.

Thus, the supplying area was described by a reduced number of production situations capturing most of the crop management diversity. One simulation was carried out for each situation. Simulation results were aggregated as a function of their spatial contribution to the total production area.

## Results

**Sunflower crop management.** Multivariate methods build up impure cases. Types are described with their differences from the medium management. So, they are not monolithic and the characteristics used for their description express the gap with the average of the studied population.

Seven types of crop management were identified. Fields were segregated mostly on the basis of two factors: soil tillage and intensity of farming. Table 5 presents the type designation and main features.

The first type, called "low inputs", concerned 14% of the plots. This crop management was very extensive, with very small quantities of inputs, generally no fertilizer and very few pesticides.

The type 2, called "low inputs in reduced tillage", concerned 19% of fields. This crop management was less extensive than the first one but was still very low in inputs, the main difference being the absence of ploughing.

The type 3 (17%) gathered fields where crop establishment was secured and where recommended practices are applied in the early stages of crop.

Types 4 and 5 were conducted with a high level of insurance: inputs were systematic. Types 4 (7%) and 5 (20%) differed only in soil tillage: with or without ploughing.

The type 6, about 10%, corresponded to the "recommended" crop management.

The type 7 was the most intensive: "high inputs in reduced tillage" (12%). To balance inconvenience due to reduced tillage, more herbicides and molluscicides are used.

**Table 5.** Description of the seventh crop management types

| | Quantification | Implantation | | | | Fertilization and crop protection | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Soil tillage | Weed control | Sowing earliness | Sowing density | Insecticide at sowing | Molluscicide | Boron and fongicide inputs | N dose | PK fertilization |
| **Low inputs** | 14% | - | low | - | medium | - | low | No | low | very low |
| **Low inputs in reduced tillage** | 19% | reduced | medium | - | high | - | medium | No | low | low |
| **Secured implantation in ploughing** | 17% | ploughing | medium | - | medium | yes | high | No | high | high |
| **Secured crop management in reduced tillage** | 7% | reduced | high | - | high | - | high | Yes | medium | medium |
| **Secured crop management in ploughing** | 20% | ploughing | high | - | low | no | low | Yes | medium | rather high |
| **Recommanded crop management** | 10% | ploughing | medium | early | medium | yes | medium | Yes | high | high |
| **High inputs in reduced tillage** | 12% | reduced | high | - | low | - | high | Yes | high | rather high |

Results derived from a comparison to the average intensity of the population.
'-' mean not different from the average

**Farm typology.** Table 6 presents the classification and quantification of the seven classes of farms.
The first type A (16%) concerned mixed oriented farms with livestock or specialized crops.
The rest of the population was then distinguished by its size: above or below 100 ha, and with or without irrigation facilities.
Farms without irrigation were gathered in the type B (24%) for small farms and the type E (21%) for large farms. Afterwards, farms concerned by irrigated field crops were segregated depending on their investment in sunflower (mainly fraction of sunflower in the cropping plan). Thus, small specialized farms with irrigation were linked to the type C with predominant sunflower (9%) and the type D where it was a secondary crop (8%). Large specialized farms with irrigation were divided between type F where sunflower was marginal (15%) and type G with significant sunflower areas (7%).

**Table 6.** Description of the seven farm types

<table>
<tr><td colspan="4">A- Non specialized in field crops</td><td>16%</td></tr>
<tr><td rowspan="6">Specialized in field crops</td><td rowspan="3">Small farms</td><td colspan="2">B- Without irrigation facilities</td><td>24%</td></tr>
<tr><td rowspan="2">With irrigation fac.</td><td>C- Sunflower secondary</td><td>9%</td></tr>
<tr><td>D- Sunflower important</td><td>8%</td></tr>
<tr><td rowspan="3">Large farms</td><td colspan="2">E- Without irrigation facilities</td><td>21%</td></tr>
<tr><td rowspan="2">With irrigation fac.</td><td>F- Sunflower secondary</td><td>15%</td></tr>
<tr><td>G- Sunflower important</td><td>7%</td></tr>
</table>

**Correspondence between the two typologies.** From that point, results are all shown by supplying area. Indeed, crop systems were so different that it was much easier to study them separately.
The third step of our study concerning relevant relationships between farm structures and crop management types allowed us to transpose them to our quantified farm cases. This process enabled us to quadruple sunflower areas considered. In fact, our diagnosis covered about 1800 ha and described farms cultivated about 6600 ha of sunflower.
In table 7, both typologies were confronted, thus allowing us to stress out dominant crop management systems for few cases (grey background). Mainly large farms (types E, F, G) and non-specialized farms (A) were concerned by one or two main crop management types. Constraints on working-time might explain this result. These farms, generally ruled by a single person, have to simplify and specialize their crop managements.

**Table 7.** Cross-analysis with both typologies (for each farm cases, repartition on crop management types - % -, grey background = dominant C.M. systems)

| Supplying area | Main farm cases | Crop management types | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Lauragais | B | 20.0 | 20.0 | | | 20.0 | 30.0 | 10.0 |
| | E | | 4.3 | **21.7** | | **52.2** | 13.0 | 8.7 |
| Lomagne | A | 7.7 | 15.4 | 15.4 | 15.4 | | **38.5** | 7.7 |
| | D | 16.7 | 16.7 | 16.7 | | 16.7 | | 33.3 |
| | E | | **76.5** | 11.8 | | 11.8 | | |
| | F | | 11.1 | **66.1** | 22.0 | | | |
| | G | 25.0 | 25.0 | **50.0** | | | | |

Table 8 presents for each basin the quantification of C.M. types according to the cross-analysis with farm cases. When a farm case had no preferred crop management, this type was affected to all C.M. types in proportion of represented farm cases. If a farm case presented one or two preferred C.M. types, its proportion was completely assigned to them.

**Table 8.** Quantification of crop management types according to farm cases (%)

| Crop management types | Lauragais | | | | | Lomagne | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Farms cases without C.M. preference | | Farms cases with C.M. preference | | Total (%) | Farms cases without C.M. preference | | Farms cases with C.M. preference | | Total (%) |
| 1 | affected in proportion of their presence | 3.0 | | | **3.0** | affected in proportion of their presence | 5.2 | | | **5.2** |
| 2 | | 2.7 | | | **2.7** | | 7.4 | E | 23.8 | **31.2** |
| 3 | | 4.4 | E - 35% | 19.1 | **23.5** | | 4.6 | F + G | 33.4 | **38.0** |
| 4 | | 0.0 | | | **0.0** | | 9.1 | | | **9.1** |
| 5 | | 11.9 | E - 65% | 35.8 | **47.7** | | 1.0 | | | **1.0** |
| 6 | | 11.6 | | | **11.6** | | 11.3 | | | **11.3** |
| 7 | | 11.6 | | | **11.6** | | 4.3 | | | **4.3** |

C.M. = crop management

A general analysis showed that C.M. 3, which is "secured implantation", was predominant in Lomagne and quite important in Lauragais (2$^{nd}$ rank). These farmers invest quite a bit on sunflower crop but only at the start of the crop. Then, no intervention was possible. These farmers (types F & G, with irrigation facilities in Lomagne) are growing mainly maize and give the preference to careful irrigation on maize, leaving sunflower without care. The second type in Lomagne was "low inputs with reduced tillage" (N°2). In France, large farms are well-known to develop these conservation soil techniques. Ploughing is a very time-consuming operation and spends more energy. So, reduced soil tillage is very appropriate in big farms. Moreover, farms without irrigation facilities (type E) spend very low inputs in sunflower, confirming that sunflower is secondary crop in Lomagne. As no high yield is expected, even moderate intensification is less practiced than in Lauragais.

In fact, the first type in Lauragais, almost 50%, was "secured crop management with ploughing" (N°5). This was consistent with the expertise of the area. In Lauragais, sunflower is one of the two main crops. So, farmers adapt their level of inputs to the importance of the crop and the level of return expected.

## Discussion

In this study, we succeeded in characterizing and quantifying better than with a simple crop management analysis the different C.M. patterns composing a sunflower supplying area. Using some expertise, we highlighted meaningful C.M. types requiring each different advisory.

Among the issues to be discussed, one point to improve could be the representativeness of the databases used for the typology, especially the number of farms to characterize an area.

Stabilizing crop management typology was quite difficult. Chosen variables and computing methods influenced final results. And, even if the first two or three axes of our multiple factor analysis were generally correlated to the same factors, the definition of types could change quite significantly. Trying other statistical methods could help us to build up a more reliable typology.

Some confusion effects could appear when comparing the crop management options between the two areas. For example, the two regions changed by the dominant crop systems but also by the cooperative advisory system which might influence the technical decisions of the farmers. These confusing influences cannot be separated. Therefore, the analysis was finally done separately.

The information collected on a sample of fields, associated to a C.M. type and to farm structure could probably be enough in a first approach to propose a description and quantification of crop managements in similar pedoclimatic regions.

This method could be tested on other areas to evaluate its robustness. This offers new perspectives for aggregating management data as model inputs of a decision-support model applied at a micro-regional level.

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