Environmental issues of sunflower

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Résumé: Le tournesol est depuis 20 ans une culture majeure dans les systèmes de grande culture dans le Sud de l'Europe. En 1993 le tournesol représentait 3.000.000 ha en Espagne, France et Italie, quand en 1979 il représentait seulement 750.000 ha: cette rapide augmentation a aussi posé des problemes concernant l'impact du tournesol sur l'environnement. En décrivant les relations entre la prodution du tournesol et l'environnement il faut considérer: i) les atouts pour l'environnement; ii) les points faibles pour l'environnement; iii) la conduite du tournesol dans un environment pollué. Les aspects envisagés pour évaluer l'impact du tournesol sur l'environnement ont été : ressource en eau, nitrates, produits phytosanitaires, biodiversité et paysage, systèmes de culture, risques de ruissellement et d'érosion, pollution des sols et de l'atmosphère. Dans ce papier, nous présenterons une revue des plus récent résultats des recherches concernant ces aspects.

Summary: In the last two decades, sunflower has become a major crop in cropping systems of southern Europe. The increase of harvested areas in Spain, France and Italy (from 750,000 ha in 1979 to more than 3,000,000 ha in 1993) introduced also some environmental problems. Three main aspects can be considered in describing the relationships between sunflower production and environment: i) environmental hazard related to sunflower production; ii) environmental opportunities related to sunflower production; iii) behaviour of sunflower in polluted environments. Several topics have been considered in describing environment-sunflower relationships : water resources, nitrogen in soils and waters, use and fate of agrochemicals, biodiversity and landscape, cropping systems and soil conservation, soil pollution and climate change. A review of the most significant findings of recent research on these topics is presented.

In the last two decades, sunflower has become a major crop in cropping systems of southern Europe.

Large areas of Spain (Medi-terranean regions: Andalucia, Murcia, Castilla-La Man-cha), France (Sud-Ouest and Centre-Ouest: Poitou-Cha-rentes, Midi-Pyrénées and Centre) and Italy (internal and coastal hills of central regions: Toscana, Marche, Umbria, Lazio) have been increasing-ly devoted to sunflower during the 80's, while a steady state seems to be reached at the beginning of 90's and a slight decline can be noticed in the last years of the past decade (Figure 1). Total production of France, Spain and Italy increased from less than 1000 * 106 t in 1980 to about 3000 * 106 t in 1999, with a peak production of 4150 * 106 t in 1990 (Figure 2). On the average of the two decades, grain yield in Italy and France was similar and more than double than grain yield in Spain (Figure 3).
However, the slump in prices of sunflower seeds – as a consequence of the new Common Agricultural Policy – and the concurrent diffus-ion of massive *Phomopsis* attacks in large areas of France and Spain suggested adjustments in crop management. Extensive rain-fed cropping systems, based upon the growth of early cultivars at low plant density and with reduced nitrogen fertilization rates, has been recently preferred to the previous intensive cropping systems – where late culti-vars were grown in irrigated areas at high plant densities and nitrogen rates. While new genotypes suitable for this agricultural scenario – i.e. disease and drought tolerant – are already available, improvements in crop management are still required, mainly in water supply, nitrogen fertilization and crop protection (Ceccon et al., 1998; Debaeke et al., 1998a).
Therefore, the role of sunflower in the agricultural systems of southern Europe dramatically changed in the last 20 years

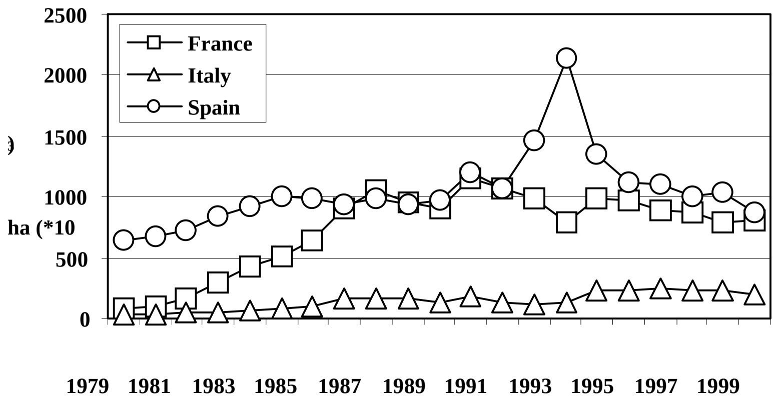

Figure 1. Sunflower harvested areas in France, Italy and Spain (FAO, 2000). Data of 1999 are provisional.

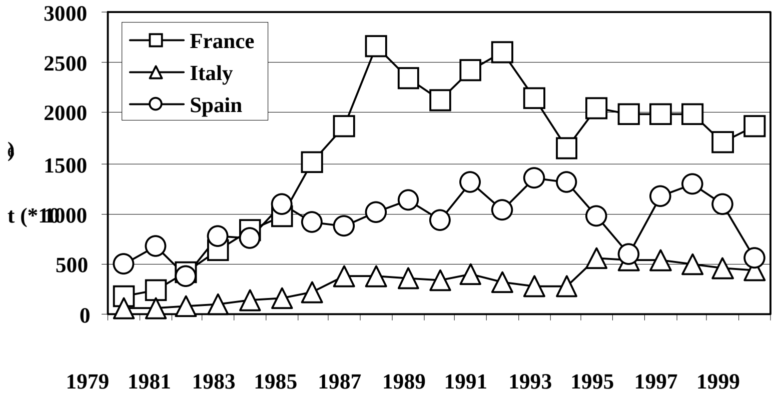

Figure 2. Sunflower seed production in France, Italy and Spain (FAO, 2000). Data of 1999 are provisional.

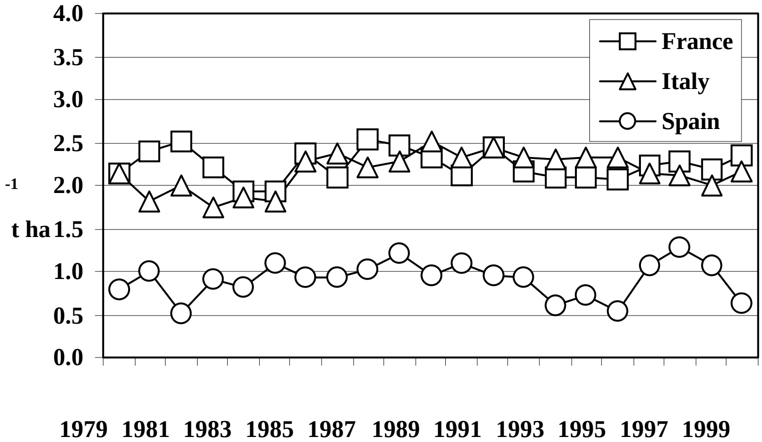

Figure 3. Sunflower seed yield in France, Italy and Spain (FAO, 2000). Data of 1999 are provisional.

Concurrently, environmental issues associated to sunflower production has been thoroughly taken under investigation by researchers in different countries (Meynard et al., 1998).
Three main aspects can be considered in describing the relationships between sunflower production and environment: i) environmental hazard related to sunflower production; ii) environmental opportunities related to sunflower production; iii) behaviour of sunflower in polluted environments.
Several processes and phenomena are involved in determining the environmental role of sunflower as related to each of these aspects. Moreover, the same process can often affect more than a single environmental aspect, owing to the complex interactions among natural resources (soil, climate) and management practices (soil tillage, fertilization, irrigation, crop protection, etc.) established in the agroecosystem.
A review of the most significant findings of recent researches on these basic processes are here reported.

Sunflower and water resources

Botanical and ecophysiological traits allow sunflower to be considered a drought-tolerant crop, therefore highly useful in water conservation strategies.
As compared with most of the other spring crops, sunflower has three distinguishing features in using soil water resources:

– when soil layering does not hinder root deepening, sunflower can extract soil water from up to 2 m (Berengena and Henderson, 1980; Connor and Sadras, 1992). Similar results were found in Italy (Giardini and Giovanardi, 1983), Spain (Gimenez and Fereres, 1986), France (Maertens et al., 1974, Blanchet et al., 1980), Argentine (Sadrlas and Hall, 1989) and U.S.A. (Hattendorf et al., 1988). These authors agree on the evidence that sunflower can extract water from the soil from depths higher than maize, sorghum, bean, millet and soybean. Maertens and Bosc (1981) attributed this attitude to sunflower taproot system as well as to its rapid growth – which is directly related to soil temperature (Seiler, 1997b) – but emphasized that roots can well deepen in rainfed conditions (Maertens et al. 1974), while irrigation encourages water uptake from the shallow soil layers, restricting the colonization of deep soil horizons;

- sunflower leaves keep stomata open also when air humidity is very low, thus preserving transpiration and gas exchanges (Merrien and Blanchet, 1983; Martin et al., 1993). Moreover, sunflower leaves have much more stomata than maize and wheat (Sutcliffe, 1979);
- sunflower usually shows high values of carbon exchange rate (up to 35 mg CO2 dm-2 h-1; Blanchet et al., 1982, Connor and Sadras, 1992; Martin et al., 1993; Rivelli et al., 1999), which are similar to some C4 plants (e.g., maize: 50 mg CO2 dm-2 h-1) more than to the other C3 plants (e.g., soybean: 20 mg CO2 dm-2 h-1).

As a consequence of the joint action of these three elements (deep rooting, stomatal regulation and carbon assimilation), sunflower well adapt to different conditions of soil water availability: when water supply is not limiting, water use as well as dry matter accumulation can be very high, thus grain yield will depend mainly on dry matter translocation to the seeds. On the other hand, under limiting soil water availability sunflower behaves as a typical drought-tolerant crop, supporting grain yield by prolonging the growth season as compared to non tolerant crops. Cox and Jolliff (1987) found that grain yield of sunflower was reduced by 34% in the absence of irrigation, while soybean reduced grain yield by 80% under the same conditions. Experiments carried out by Cabelguenne et al. (1982), Massée (1995) and Giovanardi et al. (1999), where sunflower was compared to maize, soybean, potato and sorghum under irrigated and rainfed conditions, showed similar results. Breeding programs are in progress aimed at improving drought tolerance of sunflower (Baldini and Vannozzi, 1998; Gomez Sanchez et al., 1998).

Sunflower and nitrogen

The same traits previously reviewed also affect nitrogen uptake: since sunflower can extract water from deep soil layers, nitrates leached out during wintertime can be recovered – at least in part – by roots during the following growing season, therefore reducing crop nitrogen requirements (Connor and Sadras, 1992). Researches on sunflower nitrogen nutrition demonstrate that yield reduction is mainly related to nitrogen shortage during the early growth stages (between bud formation and flowering), as a consequence of a reduction in the number of grains per plant (Coïc et al., 1972, Steer et al., 1984). In the same period, vegetative organs can accumulate significant amounts of nitrogen: Merrien and Blanchet (1983) found that sunflower can accumulate up to 250 kg ha-1 N, according to nitrogen fertilization rate. More than 70% of this reservoir will be translocated to grains during the following grain filling period, when root uptake does not adequately support crop requirements (Vrebalov, 1974). On the average, sunflower nitrogen offtake by grains is roughly 0.25-0.3 kg per ton (Merrien and Le Dilosquer, 1998), i.e. 55-75 kg ha-1 N for a grain yield of 2.4 t ha-1. Therefore, nitrogen fertilization rates are usually quite low, seldom exceeding 80-100 kg ha-1 (Lecomte, 1999): high rates of nitrogen fertilization stimulate vegetative growth of the crop, but does not enhance grain yield, also because of a higher occurrence of diseases (Debaeke et al., 1998b).

Nitrates can also accumulate in the soil profile during the growing season, remaining available for leaching induced by spring and summer thunderstorms. After the harvest of sunflower, the total amount of soluble nitrogen retained by the soil is correlated to nitrogen fertilization rates (Decau et al., 1984; Giovanardi et al., 1999). When in the crop rotation a winter cereal follows sunflower, part of these reservoirs can be used; in any case, the risk of massive leaching during wintertime is very high. In a lysimeter study, Giovanardi et al. (1999) pointed out that water shortage during flowering increased cumulated nitrogen losses in comparison with well watered conditions (Table 1) as a consequence of the reduced nitrogen uptake of water-stressed crop (-55% and – 70%, respectively at 120 and 240 kg ha-1 N).

N rate	Soil Water Regime		
(kg ha-1)	ETM	Water Stress	Leachings
0	24.3 f	28.8 ef	35.3 def
120	74.4 abc	97.3 a	43.5 cdef
240	63.0 bcd	59.1 bcde	80.6 ab

Table 1. Nitrogen leaching (NO3-N, kg ha-1) cumulated over the growing season and the following winter in sunflower grown under different soil water regimes. Water stress was imposed at flowering and two leachings were artificially produced after each nitrogen application; two other artificial leachings were applied after harvest and at the end of winter (after Giovanardi et al., 1999).

When nitrogen fertilization is managed according to the above-described principles, sunflower can therefore contribute to limit nitrogen leaching losses and to improve nitrogen use by crops in rotation.

Sunflower and agrochemicals

According to several surveys carried out by CETIOM in France (see Lecomte, 1999), on the average 2 to 3 treatments per year (1.8 kg a.i. per hectare) are applied to sunflower crops. In details:

- 20% of fields receive 1 herbicide application;
- 80% of fields receive 2 herbicide applications;
- 30% of fields receive 1 fungicide application;
- 20% of fields receive 1 insecticide application.

Similar management practices are suggested also in Italy (e.g., Rapparini, 1993). In comparison, wheat receive 3 to 4 treatments (2 herbicides, 1 fungicide, 0.5 insecticide, 1 growth regulator, not considering seed treatments), i.e. 2.5-3 kg a.i. per hectare (CORPEN, 1999). When in the crop rotation wheat follows wheat, one more fungicide treatment should be considered (Verjux, 1996). However, the rotation of crops allows to apply different active ingredients over years, limiting the risk of accumulation in the soils and waters. Cropping system simulation models have been evaluated by Debaeke (1992a) with the aim of describing the environmental fate of different herbicides: the author stressed that crop rotations with alternate winter and summer crops are more environment-friendly than monocultures and that irrigation usually contribute to deteriorate the quality of both soils and waters. Under this framework, since sunflower tends to expand in southern Europe as a summer rainfed crop, its role in environment protection could be better exploited.

The adoption of best management practices (BMP) for reducing nitrogen leaching losses has been recently tested and applied on sunflower in Spain, where a number of management practices were simulated using nitrogen, tillage and crop-residue management (Fernandez Santos et al., 1993). The results showed that if decision makers give the same importance to the preservation of water quality as to economic returns of farmers, a targeted subsidy of at least 16700 Pts ha-1 must be paid to motivate farmers to adopt BMP.

Sunflower and biodiversity

According to Usher (1997), biodiversity can be described at four different levels: gene, population, community and landscape.

At the gene level, it must be stressed that the genus *Helianthus* is highly diversified and that wild genetic resources have been widely used in conventional breeding programs for many years (e.g., Martin et al., 1993; Baldini and Vannozzi, 1998; Baldini and Vannozzi, 1999). Also the source of cytoplasmic male sterility presently used in the production of commercial hybrids has been discovered in the wild species *Helianthus petiolaris*. For these purpose, one of the richest collections of wild sunflower genotypes is retained by INRA in Montpellier (Serieys,1982; Seiler,1997a).

In the different agroecosystems, associations between sunflower crop and local flora and fauna show some common traits.

The role of bees in sunflower pollination as well as in honey production is well known and does not deserve further comments. An inventory of useful and harmful insects associated to sunflower crop has been compiled in France by Ballanger et al. (1985). The highest diversity of insect populations has been observed during the vegetative development stages, when also an equilibrium between predators and preys can be established. Since sunflower is not autochthonous in Europe, it has not yet developed specific predators, acting therefore as a temporary refugee for species – such as *Brachycaudus helicrysi* – which are usually hosted by other plants. However, a specific biocenosis has been recorded in Camargue (France), where sunflower moth (*Homeosoma nebullela*) develops a first cycle on milk thistle (*Silybum marianum*) and the following ones on sunflower.

Birds are often considered harmful for sunflower both at emergence (larks) and harvest stage (sparrows), mainly when harvested areas do not represent a significant percentage of the region. Researches have been carried out in the United States on the impact of crops and crop management on bird behaviour (Lokemoen and Beiser, 1997). In autumn, birds visit sunflower more than fallow or wheat, while in spring birds are observed mainly on fallow: in effects, sunflower represents an important source of feed when other crops become scarce or dry. Conservative soil tillage (minimum tillage, sod seeding) usually increases the attitude of birds to nest within crops.

Only few data are available on the flora associated to sunflower crop. In southern France, Marty (1991) monitored the weed populations of soybean and sunflower: the author counted 98 different species, 50 of which were present on both crops, 25 only on sunflower plots and 23 only on soybean plots. He concluded that, despite the application of herbicides, each crop maintained a specific weed community. Moreover, crop rotations with alternate winter and summer crops allow to maintain a richness in weed populations that can reduce the risk of prevailing of a single weed (Debaeke, 1992b).

The size and composition of weed population are also influenced by cropping system input level: Barberi et al. (1997) found (i) species sporadically associated with cropping systems (most of weeds); (ii) species associated with a specific input level (e.g. *Papaver rhoeas* with low and intermediate input levels and *Veronica persica* with high input level) and (iii) species associated with specific plots that become important every other year (e.g. *Convolvulus arvensis* and *Stellaria media*).

Sunflower and landscape

The appealing value of flowering sunflower fields is widely and positively recognized. Considering also other aspects of landscape, such as the risk of soil erosion, techniques have been developed in the Great Plains of the United States in order to keep high the point of stalk cut at harvest: this because tall crop residues reduce wind erosion and stabilize snow cover, allowing adequate overwinter soil water recharge (Nielsen, 1996; Nielsen, 1998).

Sunflower and cropping systems

As thoroughly described by Cabelguenne and Marty (1983) and by Debaeke et al. (1998a), the role of sunflower in rainfed cropping systems of mediterranean areas is mainly associated to some properties related to on-farm organization:

- plainness of crop management: besides irrigation, sunflower barely respond to intensification strategies (Bonari et al., 1996, Debaeke and Hilaire, 1997, Debaeke et al., 1998b). Main agricultural practices are grouped near sowing, and do not require investment for specific technical requisites;
- fitness to a wide range of environmental conditions and yield stability: grain yield is seldom lower than 1.8-2 t ha-1, owing to an appreciable drought tolerance;
- good exploitation of on-farm working calendars: sunflower is usually sown before maize, soybean and sorghum, and it is harvested early in the season, before the same crops. This also allows an early and easy sowing of the following winter crop (e.g., wheat), owing to the good conditions of soil structure.

Sunflower and soil conservation

Crops and crop rotation dramatically affect soil erosion. Roggero et al. (1997) monitored soil losses in a hilly area of central Italy, comparing sunflower to fallow and wheat: they found that in early spring erosion was greater on set-aside plots than on sunflower plots, while late in the season (August-September) soil losses were much higher from sunflower plots (up to 12 t ha-1) and quite insignificant from set-aside plots (0.1-0.4 t ha-1). In a long-term project established in central Queensland (Australia), wheat showed lower average annual runoff and soil loss than sorghum and sunflower (Carroll et al., 1997). Zero tillage wheat had the lowest average annual runoff and soil loss, and conventional sunflowers had the highest. The erosion risk associated with sunflowers was reduced by a wheat-sunflower crop rotation, particularly when zero-tilled, while monoculture sunflower must be avoided. Sunflower residues, if left standing after harvest, may provide adequate soil protection during the winter and early spring months following harvest.: Lyon (1998) measured dryland sunflower residue weights and percent ground cover at harvest, early spring, late spring after the initial stubble-mulch tillage operation, during mid-summer fallow, and after winter wheat seeding. Residue weights declined to an average of 570 kg ha-1 after winter wheat seeding. Percent ground cover declined over this same period from 39 to 4%.

Sunflower and soil pollution

Sunflower may be grown in polluted soils. Waste waters can be used in agricultural fields, but often exhibit significant phytotoxic effects: Gadallah (1996), comparing the effect of waste water from a fertilizer or a detergents and oils factory or sewage effluent, showed that waste water from the fertilizer factory collected in February, May and June showed almost 100% inhibition of sunflower radicle growth, while January and April samples had a stimulatory effect. Most of the waste water samples exhibited significant inhibition of shoot growth and waste water-treated plants showed a lower transpiration rate than the control. The accumulation of heavy metals in compost-amended soils and crops influence plant productivity and quality. Sunflower plants accumulate Pb, Cu, Cd and Zn in roots (range 6.3-3256.2 µmol 100 g-1 d.w.) more than in shoot (range 0.4-214.7 µmol 100 g-1 d.w.). Excess concentrations of heavy metals significantly affect plant water status, causing water deficit and subsequent changes in the plants. Plant stress caused by the heavy metals was in the decreasing order Cd, Cu, Zn and Pb (Kastori et al., 1992). Lombi et al., (1998) found that the concentration of Cd, V and Zn was generally greater in leaves than in seeds, while the opposite was true for Cu and Ni. Toxicity effects were related to the mobility of the heavy metals in the soil. Nickel and other heavy metal contents were determined by Kohiyama et al. (1992) in 16 species of oilseeds and 19 types of vegetable oil: nickel was detected in all the oilseeds, and its average content was >1 p.p.m. in sunflower seeds, a lower level than soybean, walnut and cottonseed.

Sunflower and climate change

The impacts of climate change caused by a doubling of atmospheric carbon dioxide on the production of sunflower were simulated in different studies. A longer growing season, increased growing season precipitation and increased minimum temperatures were predicted in southern Quebec (Singh and Stewart, 1991): the higher temperatures would lead to higher crop evapotranspiration and an increased plant water deficit during the growing season. Decreased potential and anticipated yields of sunflower were also predicted. European and Australian scenarios were simulated by Mayr et al. (1996) and by Islam et al. (1999).

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