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Nutrient management, innovative techniques and nutrient legislation in intensive horticulture for an improved water quality

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(2) The application of the Nitrates Directive to vegetable crops: tools and strategies from NEV2013 for an integrated fertilisation management

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Abstract: *The European Commission DG Environment and the University of Turin (Italy) have organized the NEV2013 Workshop on 'Nitrogen, Environment and Vegetables' for providing support to the implementation of the Nitrates Directive (91/676/EEC). NEV2013 has focused on the critical issues of the Nitrates Directive in vegetable crops in European Countries. NEV2013 covered Nitrogen fertilization management, strategies to improve Nitrogen and water use efficiency, relationship of Nitrogen and other nutrients, Nitrogen effects on product quality, vegetable growing systems and their effect on waters pollution, crop residues management, crop rotation, and monitoring of the environmental pollution caused by Nitrogen losses from vegetable cultural systems. The critical issues of the Nitrates directive for vegetable crop systems of different European Countries were tackled. The outcome indicated that the environmental impact due to the Nitrogen fertilization varies not only from country to country but also locally within the same country or region. There is a striking need for increasing the Nitrogen fertilizer use efficiency for all crops in order to reduce its potential negative effects on the environment and, in the case of vegetable crops, its effects on human health when accumulated as nitrate in the plants. In recent years, numerous research programs have assessed the effects of Nitrogen fertilizer rate, fertilization methods, and Nitrogen fertilizer source on Nitrogen uptake and plant growth of many vegetable species. On this base, tools to determine the Nitrogen losses owing to the different cultivation systems for vegetables and to the different climate and soil conditions have been developed. Their spread implementation can lead to environmental-friendly fertilization strategies, applied taking into consideration the needs and suggestions of researchers, farmers, and consumers, and involving policy makers. As any other cropping system, also vegetable systems need valuable indicators: the tool box of indicators that can be used to sustainably manage fertilization is quite large, while modeling allows for quantifying environmental impacts. Combining indicators, empirical predictions and model predictions into expert systems helps to take decisions about management practices. Future strategies need better connection and data transferring among the actors, from policy makers to scientists, extension service technicians and growers.*

Keywords: *environment, fertilization strategies, indicators, models, EU directives*

The fresh vegetable business and the vegetable crops impact in the EU

The EU is still recording a deficit trade for many commodities, including fresh vegetables. In 2011, the import of fresh vegetables counted for 1,800 M€ and the export for 1,400 M€, while potatoes import counted for 200 M€ and the export for 700 M€ (EC, DG Agriculture and Rural Development, 2012). Potatoes counted for 28% of total vegetable (that is, fresh vegetables plus potatoes) exports. Two thirds of the import in terms of value were for tomatoes, beans and sweet peppers, and tomatoes alone now constitute the biggest share of imported fresh vegetables, making up around one fifth of imports. Most of fresh vegetables are imported from four Mediterranean countries: Morocco, Israel, Turkey, and Egypt. Import from this region is gradually increasing due to improved market access to the EU under preferential trade agreements with these countries. The leading supplier, Morocco, covers around 30% of EU fresh vegetable imports. Since 1999, imports from this country doubled and amounted to 534.4 M€ in 2011. Half of Moroccan supplies is taken up by tomatoes. Other imported vegetables include sweet peppers, beans, egg plants and cucumbers. Even though close to two thirds (around 64 %) of all the tomatoes produced in the EU-27 originates from Italy and Spain, the EU is still in deficit and needs import or will need to increase the domestic production.

Vegetables production in the EU 27 countries is ca. 57.5 Mt per year, 42% obtained in two countries alone (24% Italy and 17% Spain) (Fig. 1) (Eurostat, 2011). Out of the 2.35 million hectares used in the EU for vegetables crops, ca. 38% is located in the same two countries (23% Italy and 15% Spain) (FAO, 2010). These cropping areas are already facing environmental stresses and these stresses may increase if EU is willing to increase the domestic vegetable production for sustaining citizen livelihoods. Export of fresh vegetable products, especially to northern European countries, has significantly expanded in recent years in Spain in response to the demand of developed countries for fresh and high-quality products all year round (Romero-Gámez and Suárez-Rey, 2013). Furthermore, other major areas of intensive vegetable production have long been in place (e.g. France, The Netherlands) and will contribute to the environmental stresses as well.

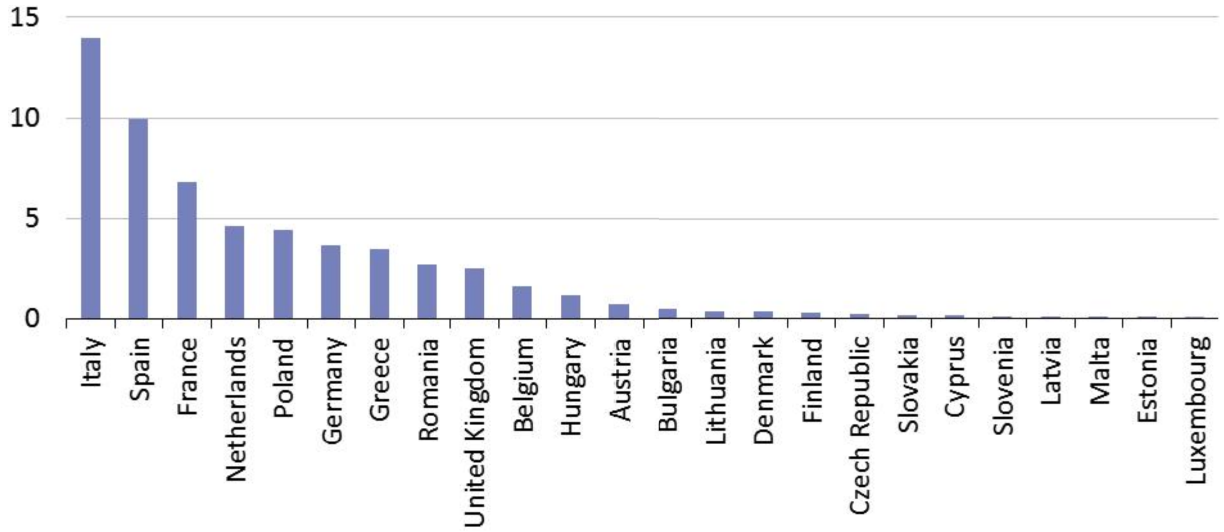

Figure 1 Production of vegetables (million tonnes) in most EU-27 in 2011 (Eurostat) (Data from Ireland, Portugal and Sweden not available).

General considerations on the application in the EU of Nitrates Directive to the vegetable sector

Horticulture is a complex system because of the diverse cultural systems, great variety of species and cultivars, and extended large variability of soil and climatic conditions among the geographic areas cultivated for vegetable productions. Vegetable crop intensification in the EU will continue in the future due to market demand and growers income. However, the importance of efficiency and standardization of practices will increase to reduce production and supply chain costs. Good agricultural practices are in increasing demand from the consumers and from the chain retailers across Europe. Practices include the application of the EU Nitrates Directive as well as any other directive, although the former has often been perceived by stakeholders as related to livestock or arable farms only. In the livestock sector the Nitrates Directive has been successful since it has spread good agricultural practices, aimed at preventing pollution created by excessive fertilization and, at the same time, stimulating efficient manure management. In the application of the Nitrates Directive horticultural systems across Europe can learn lessons from the livestock farming experience.

The environmental impact due to the nitrogen fertilization in the EU varies not only from country to country but also locally within the same country or region. Some intensive vegetable production areas are showing quite high environmental risks deriving from current fertilization and management practices of horticultural crops (Calabrese et al., 2013; Pietrzak and Wojcieszak, 2013; Suárez-Rey and Romero-Gámez, 2013; Thompson et al., 2013a, c). Unfortunately, in some cases there is a lack of awareness by the growers of the environmental issues related to mismanagement of fertilization practices, or even lack of awareness of the relevance of the Directive; this has been highlighted in some surveys conducted (Suárez-Rey and Romero-Gámez, 2013; Thompson et al., 2013c). Consequently, some work has to be done by administrators to train the vegetable growers because there is a need to steer further improvements in nitrogen and phosphorous management practices, without affecting product quality and yields and therefore farmer income. At the moment, the Nitrates Directive is being applied in different ways in the different Member States (e.g. whole territory approach; one or more action programs applying to the designated nitrates vulnerable zones). Regional adaptation is a value, because it fully considers specific climatic conditions as well as characteristics of the agricultural sector in the area.

Vegetable production characteristics

Intensive production systems are by definition using a high level of external resource inputs per area and time. Thereby, vegetable production systems are at the upper limit of production intensity, relying on the high economic value of the produce. Obtaining great yield is thus of paramount importance, taking into account also the high investment costs intensive production systems imply. Nitrogen fertilization represents the ground foundation to reach high yields for many vegetable species, and fertilization costs, despite steadily increasing, do not seem to be a major concern for farmers in vegetable production. In other words, the high cost of fertilizers is not considered by vegetable growers as a sufficient justification to reduce fertilizer use, unless specific product quality aspects are involved (e.g. nitrates accumulation in the edible parts). Farmers concerns are highly concentrated on other aspects such as quantity and quality of the commercial product, market demand and marketing strategies, and above all pest management and maximum residue level allowed.

Most of vegetables are marketed on a fresh weight basis and turgor is one of the first quality attributes that consumers recognize; fertilization and irrigation practices are aimed to maximize the commercial quality. Thus, the physiological nitrogen use efficiency (Novoa and Loomis, 1981) (or utilization efficiency) in many vegetable species is low, being directly related to a low Nitrogen harvest index since immature generative organs are harvested (Kage, 2000). There is also a variation in nitrogen efficiency within populations of same species and accessions, shown on lettuce (Burns et al., 2013; Di Gioia et al., 2013; Ferrante et al., 2013) and endive (Gajc-Wolska et al., 2013), that can be promising for future breeding programs to select low-nitrates varieties. In addition, the uptake efficiency of vegetable species is generally low: not only most of vegetable species are dicotyledonous, but also they have been adapted to modern fertilization practices (e.g. fertigation and mineral fertilization). Root architecture is crucial in determining water and nutrient uptake (Nicola, 1998). Breeding programs might be directed toward higher root density per plant, accompanied by a highly branched system (De Pessemier et al., 2013), but the horticultural sector must be managed now with available varieties, in view of achieving water quality objectives (Nitrates Directive and Water Framework Directive objectives).

Fertilization strategies

In most horticultural systems there are strong interactions between fertilization and irrigation, thus an efficient N fertilization requires an efficient irrigation system. This is especially the case in the Mediterranean regions. Optimal irrigation and salinity management are additional key components of improved N management of vegetable crops (Thompson et al., 2013b). There is probably a need for different fertilization standards for drip irrigation and other irrigation systems. Until now, diversified standards are not often available both in nitrates action programs and in suggested best practices. Plus, there are conflicting interests between single crop quality achievement and farm crop rotation that have to be tackled and solved for reducing fertilizer inputs. Too high fertilizer inputs in turn can lead to an increase in crop residues that are an important source of N and that must be accounted for in the fertilization plan. Therefore, fertilization strategies should take into account the incorporation of nutrients from farmyard manure or from vegetable residues: they are not only amendments but also a source of nutrients while a costly output of vegetable growth. Compost mineralization is often ignored in fertilization plans. The amount of mineralized N should be predicted using specific indicators (such as the fiber fractions content, i.e. NDF). If compost mineralization is disregarded by considering composts only as soil improvers, there is a risk of over fertilization, causing water pollution often long after the growing season. Ultimately, composts have a high nutritional value.

For using organic municipal wastes there is still lack of confidence due to the heterogeneous medium usually obtained, jeopardizing vegetable quality products, and the fear of heavy metal accumulation in soils and in the plants. Recent findings are however pointing out that the bioaccumulation factor depends mostly on species and on soil conditions, more than the concentration in the amendments, due to the fact that only a fraction of the total metals is available for plant uptake (Antonious et al., 2013) leaving for opportunities to a more rational use in the future of waste and residues. Reported results indicate that in several cases municipal solid waste compost can represent a good strategy to incorporate nutrients, and nitrogen in particular, to the crop and improve the soil structure (Barboza et al., 2013a). By fostering the understanding of the crop physiology and the nitrogen use efficiency better crop rotations can be planned and a more rational use of nutrients can take place (Barboza et al., 2013b; Sambo and Lazzaro, 2013). The use of animal slurry is rare in intensive vegetable production in Mediterranean Region, mainly due to food safety issues; in fact, several food outbreaks in the recent decade have taken many vegetable growers away from manure and slurry, most probably as a preventive action and because the quality in terms of safety of the available slurry and manure can be limited. The survival of foodborne pathogens in these products is a potential threat for humans, far more important than any other quality aspect. The reported transfer of *Escherichia coli* from animal slurry fertilizer to lettuce represents food safety hazards (Jensen et al., 2013). Future research must be directed toward providing consistency of results (Matthews, 2013).

A reduction in N fertilization might conflict with profitability of crop production, i.e. production of crop leading to high yield and product quality. However, this is not always the case, as there are instances where dose applications are greater than plant need and thus reductions of N supply might take place, without decrementing yield (Frick et al., 2013). Sometimes legal requirements may be at stake, specifically when preventing the excess of N-NO_3 input: this is the case of the application of the EU Reg. 1258/2011, amending EU Reg. 1881/2006, as regards to maximum level of nitrates in foodstuffs, including baby food, which in turn force the growers to limit N applications. There is a striking need for increasing the Nitrogen fertilizer use efficiency for all crops to reduce its potential negative effects on the environment and, in the case of vegetable crops, its effects on human health when accumulated as nitrate in the plants (Fontana et al., 2013). The EU limits of nitrates in foodstuff are more often required at present by several large scale retail organizations not only for the regulated species but for several vegetables, due to the longer shelf-life of vegetables when less nitrate is accumulated in the edible part and due to the World Health Organization recommendations related to the maximum daily intake of 3.7 mg NO^{-}_{3} per kg of body weight. This can induce an extended reduction of N application to the crop, a market driven behavior more than a regulation driven behavior. Sometimes, national regulations exist (Gajewski, 2013). Unfortunately, local and independent retailers are not stimulating the demand for low nitrate levels in foodstuffs, leaving growers to continue in over dosing N supply to vegetables. Several investigations aimed to reduce the nitrates accumulation in foodstuff can eventually lead to a reduction in N application during plant growth, helping indirectly to optimize N inputs, without detriment yield (Awaad et al., 2013; Di Gioia et al., 2013; Ferrante and Trivellini, 2013; Gajewski, 2013; Kowalczyk et al., 2013; Massa et al., 2013).

Indicators for fertilization management

Intensive vegetable production systems have different potential environmental impact according to cultural systems, soil and climate. Thus, punctual and local specific situations have to be considered when programming fertilization efficiency strategies. When soil is prone to leaching even more attention must be paid.

The complex horticultural systems require adequate and tailored indicators to soundly manage fertilizations. Even though indicators ought to be as simple as possible they have to be reliable and informative. Given the different situations occurring in vegetable fields, often several indicators have to be combined to deliver the optimal decision making. The input-output N budget, despite non sophisticated and simple, remains a cheap and informative indicator; it has been used in many research experiments and surveys to show the potential effects of experimental treatments and regional case studies (Jadoski et al., 2013; Willekens et al., 2013). Further work still needs to be done to refine this indicator while still retaining its simplicity and low cost. The soil residual N check (e.g. the quantity of nitrate-N measured in the upper 90 cm of the soil at the end of the growing season) is often used to assess how good the fertilization with respect to the crop need was (Willekens et al., 2013). The cost of this indicator is high, as many samples are needed to have meaningful information and results.

There is a growing interest on using foliar color and foliar reflectometry as indicators of N availability, and it has been shown to be widely used in many experiments (Armbruster et al., 2013; Fernández Fernández et al., 2013; Weisler et al., 2013. Methods such as "SPAD", "N-Tester" and "Sufficiency Index" have the problem to consider an extremely small leaf area. The "Canopy Reflectance" method has the advantage of integrating the measurement on large canopy area and has been tested in many instances (Peña-Fleitas et al., 2013; Thompson et al., 2013b). The “tool box” of indicators that can be used to sustainably manage fertilization is quite large. The different tools have different effectiveness and efficiency, which may change in relation to local situations. The need is now to have them applied systematically to case studies and pilot farms in the different regions. This applied research activity can increase knowledge on effectiveness and efficiency of the different tools.

The prediction of harvestable production is still a weak point in any ex-ante fertilization plan. A suggested optimal N management approach for intensive vegetable production is based on a combined prescriptive-corrective management (Thompson et al., 2013b). Prescriptive management being an N fertilizer plan that matches N supply to estimated crop N requirements taking into account other N sources, and corrective management being the use of a monitoring approach that assesses crop/soil N status to subsequently adjust and optimize N management.

Models and Decision Support Systems

Models are always necessary to quantify environmental impacts. A number of them are available and adapted to the vegetable production systems. Information about the crop, the soil and weather conditions as well as the cultivation techniques must be known and efficiently combined to predict N leaching losses or other impacts. Models can also analyze economic and environmental effects of nitrogen fertilizer use strategies, using multi-criteria decision model based on economic and ecological indicators (Frick et al., 2013). These indicators include yield per hectare, net returns, land requirement, nitrogen surplus and greenhouse gas emissions per hectare and per unit of product.

There is a strong need to combine indicators, empirical predictions and model predictions into expert systems that help to take decisions about management practices (DSS, Decision Support Systems). A number of DSS have been developed and they are already applied in some regions: KNS system, Veg-Syst (Gallardo et al., 2013; Suárez-Rey et al., 2013; Thompson et al., 2013c), CropSyst (Giménez et al., 2013) Well-N, EU-Rotate_N (Ramos et al., 2013; Suárez-Rey et al., 2013), GesCoN (Elia and Conversa, 2013), and N-Expert (Armbruster et al., 2013; Große Lengerich and Rather, 2013; Wiesler et al., 2013). A comparison of the criteria used by the different systems should be promoted. There is a general consensus that DSS are interesting, but in order to be used in practice they must be user-friendly, reliable and results must be comprehensible to growers or technicians.

Horticulture versus water and air pollution: an integrated assessment

Environmental problems due to intensive horticulture are both related to water (N and P leaching to groundwater and surface water) and air (emissions of greenhouse gases and ammonia). Research should aim at integrated solutions, i.e., minimizing both emissions to water and air. Measures should not result in pollution swapping between pollutants or from one compartment to another compartment. Recent experimental activities are widening. Field experiments with vegetables often include quantification of nitrous oxide emission from vegetables cropping systems (Seiz et al., 2013). It has been shown that a rational fertilization input produces positive impacts on both emissions to water and air (Frick et al., 2013; Wiesler et al., 2013). NH_3 emission is not a major concern in vegetable production in which limited urea or livestock manure is used.

Ideas and suggestions for future research and extension activities

Several aspects can be taken into consideration for future activities. In general, the global analysis of the problems should start from local case-studies to take local conditions into account for better tackling and managing the environmental problems occurring in vegetable culture systems. A collaborative and participative process allows for studying possible solutions. The processes must include farmers, extension services, researchers and policy makers and would greatly benefit if pilot farms were in place, that could give a direct and local set of practical suggestions as well as valuable information to researchers. It has been pointed out that in several cases local extension services and technical assistance are rather scarce, limiting the application on the field of many research findings and outcomes. Future strategies need better connection and data transferring to enhance knowledge transfer and support advisory work. Also the decision makers need to get the information that the scientific community has developed and transfer it to the field and into practice.

Main management practices that can reduce the risk of water pollution in horticultural areas may include: accurate prediction of fertilizer demand (foliar and soil water tests); precision techniques, in view of calibrating timing and doses of fertilizers applications; crop residues management (removal from the field); optimization of crop rotations (deep/shallow roots); use of catch crops in certain situations. Each of them as well as their combinations need to be further studied and researched. But research should not be focused only on one point, it should consider the system entirely, i.e., the different aspects of the system must be considered together. Efforts are needed to harmonize methodologies for yield prediction as well as crop needs. N application standards established in action programs are sometimes different for the same crops, only partly justified by the specific local conditions. Integrated solutions could involve other cropping systems: possible alternative uses of crop residues, produced in great amount by vegetable species, should be investigated as potential integration not only in vegetable growing systems but also in cereals and other crops, or also as advanced recycling, from composting to metabolite extraction. More studies should be aimed to increasing N supply efficiency of the vegetable systems, with a particular aim of increasing knowledge of processes occurring at the root system level. The 'hidden half' is still mostly unknown for many vegetable species.

Towards an integrated fertilization management

Many progresses have been obtained in the vegetable sector in the last decades: yield, product quality and safety, agricultural practices, commercial standards, all factors have been enhanced globally and in the EU. Integrated pest management has been a driving force to enhance the environmental acceptability of the sector for the European consumer. Unfortunately, an integrated fertilization management is not yet in place, able to cope the need for high quality produce and environmental protection. There is still a lack of information related to the effect of a reduction of N fertilization supply on the quality of products. Consumer perception of quality is under investigation in several countries, mostly affected by cultural, societal and ethical priorities. The European consumer, and the market, can present advantages with respect to some other consumers and markets more driven by food security connected priorities, given that the former is expecting the environment and human health to be considered equally of great importance. There is the potential to stress the importance of enhancing fruit and vegetable consumption for well being, but with low anti-nutritional factors such as nitrates; these factors should be exploited more to raise environmental risk awareness of mismanaged agriculture.

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