Focus Group Fertiliser efficiency in horticulture

Mini-paper - Agro-ecological Service Crops to mitigate the risk of nitrate leaching from vegetable cropping systems

Stefano Canali[1], Franky Coopman[2]

[1] Centro di Ricerca per lo Studio delle relazioni fra pianta e suolo (CRA-RPS), Italy

[2] INAGRO, Belgium

Background

Agro-environmental Service Crops (ASC) are those crops introduced in the agro-system in order to provide or enhance its environmental functions. Therefore, ASC are not directly aimed to yield, even if they indirectly contribute to sustain agricultural production by a wide range of mechanisms.

Different terms have been used so far to indicate the crops having an environmental and or an agronomic role (i.e. catch crops, cover crops, complementary crops, green manure, etc.). However, these names were often connected with a specific purpose or with a determined position in the rotation and they have not always been considered completely appropriate in any situation or broad enough to comprehend all the crops having agro-environmental functions. Therefore, the novel terminology of Agro-environmental Service Crops has been recently introduced to overcome this issue.

In sustainable/organic farming systems, the ASC represent a powerful tool for farmers to positively influence the agro-ecosystem, promoting the whole soil-plant system equilibrium in space and time (Kremen & Miles, 2012; Canali, 2013; Wezel *et al.,* 2014). ASC may have impact on soil fertility (Thorup Kristensen *et al.*, 2012; Montemurro *et al.,* 2013), occurrence of weeds (Bàrberi, 2002; Hayden *et al.*, 2012), diseases and pests (Masiunas, 1998; Patkowska *et al.*, 2013). It has been proven they increase soil carbon (C) sink potential (Mazzoncini *et al.*, 2011), influence (greenhouse gas) GHG emission (Sanz-Cobena *et al.*, 2014) and improve system energy use efficiency (Gomiero *et al.,* 2008; Canali *et al.*, 2013). ASC can also greatly contribute to reduce nutrient leaching – soil nitrate (NO_3^-) in particular - from the agro-ecosystem (Kristensen & Thorup-Kristensen, 2004).

Introducing Agro-environmental Service Crops in cropping systems

The introduction of ASC in agro-ecosystems is achieved by several complementary strategies that are taken into account in designing the cropping system. Accordingly, an ASC can be cultivated as **environmental structures**, in the border of the fields and/or in their immediate surroundings, using the parts or portions of a farm/field that are generally not destined to grow the cash crops (i.e. high slope areas, border of ditches, etc). This environmental structure may act as buffer zones (or strips) and they are functional in water quality improvement for both surface runoff and water flowing into streams through subsurface or groundwater flow. Particularly, the attenuation of risk of NO_3^- losses or denitrification from fertilisation in this buffer zone is important. Buffer zones can play a role in lowering NO_3^- contamination in surface runoff from agricultural fields, which runoff would otherwise damage ecosystems and human health. The use of wetland riparian zones shows a particularly high rate of removal of NO_3^- entering a stream, thus having a place in agricultural management.

ASC can also be introduced in the cropping system as **living mulches** (LM): the ASC is intercropped with a cash crop. The living mulched systems are managed in order to let most of the system resources (i.e. water, nutrients, light) available for the cash crop that produces the appropriate yield. Simultaneously, the management of the ASC is optimised to provide its environmental services at field/farm level (i.e. increase nutrient availability, contribute to weed, pest and diseases management and pest control, biodiversity conservation, NO_3^- leaching reduction, etc.) and to reduce competition with the cash crop (Cerruti *et al*., 2004; Swenson *et al*., 2004; Vanek, 2005; Bath *et al*., 2008; Theriault *et al*., 2009; Canali *et al*., 2014).

Vegetables with a high nitrogen (N) demand, such as cauliflower, can cause intensive leaching of NO_3^- to the environment in conventional as well as in organic production. In organic cropping system, the use of an in-season LM may decrease the risk of NO_3^- leaching after harvest when left to grow in the field to the end of the leaching season in spring. It has been recently demonstrated that the continued presence of LM in the field over winter compared to bare soil after the sole crop may reduce the soil mineral N content during the leaching season and, consequently, contribute to lower the NO_3^- leaching risk from the cauliflower systems (Kristensen *et al*., 2014).

Another option to design sustainable cropping ecosystems in accordance to agro-environmental sound criteria, is based on the use of ASC as **interposed crops**. These crops are cultivated as sole crop in the rotation, between two subsequent cash crops. Low input/sustainable and organically managed agro-ecosystems for vegetable production widespread in the European environments are often designed introducing interposed ASC in the rotation. In Central and Northern Europe interposed ASC crops are mainly cultivated in the winter season in order to avoid direct competition for land with the cash crops which, conversely, are mainly cultivated during the warm season (Masiunas, 1998). In milder climatic areas (i.e. Southern Europe), vegetable cropping systems are based on rotations in which cash crops are grown either in the warm or in the cold winter season. From an economic point of view, these vegetable cropping systems are rather important, since they provide quality products to be consumed locally or exported to the Northern European areas year round. In the Southern European areas, the farmers grow the ASC in the rainy season, to exploit the rain water which is not a limiting factor in this season. Nonetheless, they would be interested in the possibility to introduce warm season interposed ASC in order to optimise the rotations and to achieve the best economic and environmental performances (Butler *et al*., 2012). Otherwise, ASC and especially the grasses can take up all the available water in the soil, so there is a lack of water for the following cash-crop.

In vegetable cropping systems, the interposed ASC contribute to the attenuation of risk of NO_3^-losses principally because they take up mineral N from the soil that, in a certain period of the year, is left bare. This circumstance happens when the vegetable cash crops cannot be grown because of the adverse climatic condition (i.e. winter in Central and Northern Europe) and/or because cash crops are not grown due to unfavourable market opportunity. The effectiveness of interposed ASC in lowering the risk of N losses is remarkable when they are introduced in the period of the year with high rain intensity, when the soil mineral N not used by the previous crop and/or mineralised during the bare period, is highly potentially leachable. The mineral N taken up by the interposed ASC and transformed into organic molecules of the plant tissue, is then returned to the cropping system when, after termination at the end of the ASC cropping cycle, the plant material returns to soil and mineralises. According to the termination techniques utilised (see below), the mineralisation rate of plant material

funded by European Commission

may be opportunely modulated in order to synchronise the availability of soil mineral N with the N needs of the subsequent cash crop (Canali *et al.*, 2013).

The role of ASC genotype and mixtures of ASC

A wide range of plant species belonging to different botanical families can be utilised as ASC. However, the most of them are encompassed within three families: ***Graminaceae* (grasses)**, *Brassicaceae* and ***Leguminosae* (legumes)**, only a minor number of species belong to **other families (i.e. *Poligonaceae* or *Boraginaceae*)**.

Since plants of the different families show differences in terms of physiology and agronomic characteristics, they have different attitudes to provide agro-environmental services. In relation to N, grasses and brassicas have strong element requirements and thus they take up high amount of N during their cropping cycle. If this N is not available in the soil, their growth is limited. Conversely, the growth of the legumes is not limited by the soil available N concentration since, if not adequate, they get the element by biological nitrogen fixation (BNF). It is probably worth to underline that, similarly to the non legume ASC, also the legumes use mineral soil N to grow if available, instead of activate the BNF processes (Moller *et al.* 2008; Pan *et al.*, 2011; Zhou *et al.*, 2011). Consequently, all the ASC, regardless their family, may behave as catch crop of the mineral N, if in excess, contributing to reduce the risk of NO_3^- leaching (Thorup-Kristensen, 1994). Nitrogen fixed (in the case of legumes) or taken up by the ASC is returned to the system after their termination, when the plant tissues incorporated into or posed onto the soil, mineralise and thereby release mineral N. The mineralisation process is controlled by either environmental (i.e. soil temperature and moisture) and intrinsic factors, as the plant materials characteristics (i.e. lignin and cellulose content, total and soluble N content, C/N ratio; Jensen *et al.*, 2005). In particular, the C/N ratio of the plant material, even if considered only an approximate guide to the likely net mineralisation, is often able to give a valuable prediction of N mineralisation and can be effectively utilised in the current practice (Canali *et al.*, 2011). In general, the legume ASC have, at termination, a lower C/N ratio than the non legumes crops. Grasses in particular have higher values of this parameter. For this reason, the legume plant materials are generally considered less resistant to mineralisation and release the N in the inorganic form more promptly than the other crops families.

Mineral N derived from the ASC plant materials is available to the subsequent cash crops and the prediction of the mineralisation rate is a key aspect to synchronise it with the next crops needs. Indeed, if the mineral N release is not well synchronised with the crop needs, its nutritive efficiency is reduced. Moreover, if adverse environmental conditions (i.e., heavy rainfall) occur after the ASC termination, the nitric component of the mineralised N may be even leached (Neeteson *et al.*, 2003). However, N mineralisation from different organic sources can be opportunely managed if a mixture of residues with variable quality are used, including low N (high C/N ratio, as plant material from grasses) and high N (low C/N ratio, as legume tissue) (Sikora and Enkiri, 2000; Nyiraneza and Snapp, 2007).

Therefore, the selection of different ASC species and families, because of their different properties and potential mineralisation rate, is an effective tool to manage N nutrition and the risk of NO_3^- leaching.

Farmers can decide to seed pure (100%) legume ASC if high amount of N in a short time are needed (i.e. nutrition of high demand vegetable crops) or, conversely, they may seed pure grasses in case of low N requirement of the next crop and/or, in their conditions, high potential risk of NO_3^- leaching. Moreover, sowing a **combination (a mixture)** of different proportions (i.e 50/50 or 30/70) of legume and not legume ASC can determine a range of intermediate scenarios, useful to seek for the "fine-tuning" on N dynamic in the soil plant system (Tosti *et al*, 2012).

funded by European Commission

ASC management strategies

As far as the management of the living mulch is concerned, recent scientific literature reports emerging evidences of the influence of several factors on the effectiveness of this technique in modulating the NO_3^- leaching risk. One of these factors is the time of sowing of LM in respect to the transplanting of the associated cash crop. In addition, differences in term of soil mineral N content and potentially leachable soil NO_3^- have been observed between LM substitutive (reduction of cash crop plant density to leave room to LM) and additional design (same crop plant density) and these differences have been attributed to the different N uptake ability of the LM and the cash crop (Canali *et al*. 2014; Kristensen *et al*., 2014).

ASC need to be terminated well in advance to the next cash crop planting in order to provide their services to the system and avoid competition. The phenological stage of the crop, the time and method of termination represent crucial management factors, especially in vegetable cropping systems where complex rotations and peculiar soil/plant interactions are in place.

The traditional, and most widespread, technique used to terminate the cropping cycle of the ASC is the incorporation as **green manure** into the soil by tillage (i.e. plough and/or rotary hoe). However, since tillage is an energy and labour consuming and soil disturbing operation, in recent years, systems that use no/reduced tillage have received increasing interest. In this perspective, **the rolling crimping technology, which terminates ASC by flattening**, represents a promising choice (Mäder & Berner, 2012). In fact, due to the formation of a natural mulch on the soil surface, derived from the ASC plant materials, the potential capability of the roller crimping technology to control weeds, reduce soil erosion, maintain or increase soil organic matter content, as well as reduce labour use and fossil fuel energy consumption, has been acknowledged (see Renewable Agriculture and Food Systems, 2012 - Special Issue: Conservation Tillage Strategies in Organic Management Systems). In addition, evidences of the potential of the roller crimping technology to enhance vegetable cropping systems resistance to pathogen and pest attacks are emerging (Bryant *et al*., 2013). Furthermore, recently, the roller crimper technology has been investigated as a potential technique to mitigate NO_3^- leaching risk in vegetables production (Montemurro *et al*., 2013).

When an ASC is terminated by green manuring, its entire belowground and aboveground soil biomass is incorporated into the soil. According to the biomass amount and the N content of the plant tissue, it is likely that 50 to 200 kg ha^{-1} of organic N, ready to be mineralised, are incorporated into the soil. Depending on the characteristic of the plant biomass (i.e. C/N ratio), and soil moisture and temperature, mineralisation rates vary greatly, up to very high values in favourable conditions. Indeed, in the case of interposed ASC green manure in spring or in early autumn, large quantities of mineral N may be rapidly released in the soil. If the subsequent cash crop is not ready to take up the mineral N (i.e. not yet in the fast growing phenological phase), this mineral N is potentially leachable and/or can be subjected to re-immobilisation processes in the soil, contributing in a limited extent to the cash crop N nutrition. On the other hand, when the interposed ASC is terminated by the roller crimper, the soil is no or *minimally* tilled and the ASC aboveground biomass is not incorporated into the soil and left on the soil surface to form a natural mulch. In these conditions, the mineralisation of the organic matter, of the ASC plant material, occurs only in the soil-mulch interface, and the mineral N release may proceed slower than in the green manure.

Bottlenecks and research needs

In order to further empower the use of Agro-environmental Service Crops to mitigate the risk of NO_3^- leaching from cropping systems, in accordance to what above reported, bottlenecks and research needs can be identified. Following, a list of topics, that is not necessary exhaustive but that considers the main issues, is reported:

- the cultivation of warm season ASC in European Mediterranean eco-climatic zones is limited by several constrains (i.e. lack of knowledge about the best performing genotypes, slow growth, high water needs) since, in the last decades, research activities to overcome these problems have been rare and, consequently, nowadays Southern Europe (organic) vegetable farmers have no or very limited feasible options consequently reducing or disabling the possibility to design more resilient cropping systems. Accordingly, research activities aimed to verify the effectiveness of warm season ASC to contribute to build up soil N fertility as well as to reduce NO3 leaching at the beginning of the leaching season (autumn) should be encouraged;
- the roller crimper technology to terminate by flattening ASC has been successfully tested in a number of cropping systems and eco-zone across Europe. However, either the experiences made so far and the current scientific literature have identified some constrains in the use of this technology. They are mainly related to (i) the production of proper amount of cover crop biomass before rolling, (ii) the cover crops re-growth during the subsequent main crop cycle, (iii) the nitrogen (N) immobilisation and the encumbered fertilisers application due to the mulch and (iv) the poor quality of planting. These constrains could even more limit the success of the roller crimper technology in the Continental and Northern Oceanic eco-climatic area of Europe where the cash cropping season (spring – summer) is short and soil temperatures remain low for longer. Moreover, the application of the roller crimper technology could be limited because the low competitive ability of vegetable species towards other plant species (i.e. cover crop and weeds) and their high nutrients demand (Mortensen *et al.*, 2000). Therefore, further research to verify if this technology is applicable in vegetable production over the whole of Europe is needed. In detail, additional studies should be aimed to understand the dynamic of N mineralisation in the soil-mulch interface and the synchronisation of release of mineral N with the subsequent cash crop N requirements;
- despite a novel machinery to perform an extremely reduced tillage system relying with the concept of the in-line tillage to implement the vegetable transplanting and the use of the roller crimper is since recently for rent to the farmers in Italy, further research is needed to develop this technology and combine it with the mechanical transplanting;
- a ready to use Decision Supporting System (DSS) to give guidance among the different available options regarding the introduction of (mixtures of) ASC into vegetable cropping systems, the choice of the suitable ASC genotypes and the proper terminations strategies to be adopted, should be developed, tested and disseminated to farmers.

References

Bàrberi, P., 2002. Weed management in organic agriculture: Are we addressing the right issues? Weed Research 42, 177–193. doi:10.1046/j.1365-3180.2002.00277.x

Båth, B., Kristensen, H.L., Thorup-Kristensen, K., 2008. Root pruning reduces root competition and increases crop growth in a living mulch cropping system. Journal of Plant Interactions 3, 211–221. doi:10.1080/17429140801975161

Bryant, A., Brainard, D.C., Haramoto, E.R., Szendrei, Z., 2013. Cover crop mulch and weed management influence arthropod communities in strip-tilled cabbage. Environmental Entomology 42, 293–306. doi:10.1603/EN12192

Butler, D., Rosskopf, E., Kokalis-Burelle, N., Albano, J., Muramoto, J., Shennan, C., 2012. Exploring warm-season cover crops as carbon sources for anaerobic soil disinfestation (ASD). Plant Soil 355, 149–165. doi:10.1007/s11104-011-1088-0

Canali, S., 2013. Ecological Services providing crops (ESCs) in organic vegetable production systems.

Canali, S., Campanelli, G., Bavec, F., von Fragstein, P., Leteo, F., Jocop, M., Kristensen, H.L., 2014. Do living mulch based vegetable cropping systems yield similarly to the sole ones? Building Organic Bridges 1, 167–170.

Canali, S., Campanelli, G., Ciaccia, C., Leteo, F., Testani, E., Montemurro, F., 2013. Conservation tillage strategy based on the roller crimper technology for weed control in Mediterranean vegetable organic cropping systems. European Journal of Agrony 50, 11–18.

Canali, S., Di Bartolomeo, E., Tittarelli, F., Montemurro, F., Verrastro, V., Ferri, D., 2011. Comparison of different laboratory incubation procedures to evaluate nitrogen mineralization in soils amended with aerobic and anaerobic stabilized organic materials. Journal of Food, Agriculture & Environment 9, 540–546.

Gomiero, T., Pimentel, D., Paoletti, M.G., 2008. Energy and environmental issues in organic and conventional agriculture. Critical reviews in plant sciences 27, 239–254.

Hayden, Z.D., Brainard, D.C., Henshaw, B., Ngouajio, M., 2012. Winter annual weed suppression in rye-vetch cover crop mixtures. Weed Technology 26, 818–825. doi:10.1614/WT-D-12-00084.1

Hooks, C.R., Johnson, M.W., 2004. Using undersown clovers as living mulches: effects on yields, lepidopterous pest infestations, and spider densities in a Hawaiian broccoli agroecosystem. International Journal of Pest Management 50, 115–120. doi:10.1080/09670870410001663462

Jensen, L., Salo, T., Palmason, F., Breland, T., Henriksen, T., Stenberg, B., Pedersen, A., Lundström, C., Esala, M., 2005. Influence of biochemical quality on C and N mineralisation from a broad variety of plant materials in soil. Plant Soil 273, 307–326. doi:10.1007/s11104-004-8128-y

Kremen, C., Miles, A., 2012. Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecology and Society 17, Art. 40.

Kristensen, H.L., Campanelli, G., Bavec, F., von Fragstein und Niemsdorff, P., Canali, S., Tittarelli, F., 2014. Effect of an in-season living mulch on leaching of inorganic nitrogen in cauliflower (Brassica oleracea L. var. botrytis) cropping in Slovenia, Germany and Denmark. Building Organic Bridges 1, 199–202.

Kristensen, H.L., Thorup-Kristensen, K., 2004. Uptake of 15N labelled nitrate by root systems of sweet corn, carrot and white cabbage from 0.2-2.5 meters depth. Plant and Soil 265, 93–100. doi:10.1007/s11104-005-0696-y

Mäder, P., Berner, A., 2012. Development of reduced tillage systems in organic farming in Europe. Renewable Agriculture and Food Systems 27, 7–11. doi:10.1017/S1742170511000470

Masiunas, J.B., 1998. Production of vegetables using cover crop and living mulches - a review. Journal of Vegetable Crop Production 4, 11–31.

Mazzoncini, M., Sapkota, T.B., Bàrberi, P., Antichi, D., Risaliti, R., 2011. Long-term effect of tillage, nitrogen fertilization and cover crops on soil organic carbon and total nitrogen content. Soil & Tillage Research 114, 165–174. doi:10.1016/j.still.2011.05.001

Möller, K., Stinner, W., Leithold, G., 2008. Growth, composition, biological N_2 fixation and nutrient uptake of a leguminous cover crop mixture and the effect of their removal on field nitrogen balances and nitrate leaching risk.

funded by European Commission

Nutrient Cycling in Agroecosystems 82, 233–249.

Montemurro, F., Fiore, A., Campanelli, G., Tittarelli, F., Ledda, L., Canali, S., 2013. Organic fertilization, green manure, and vetch mulch to improve organic zucchini yield and quality. HortScience 48, 1027–1033.

Mortensen, D.A., Bastiaans, L., Sattin, M., 2000. The role of ecology in the development of weed management systems: an outlook. Weed Research 40, 49.

Neeteson, J.J., Langeveld, J.W.A., Smit, A.L., de Haan, J.J., 2003. Nutrient balances in field vegetable production systems, Acta Horticulturae.

Nyiraneza, J., Snapp, S., 2007. Integrated Management of Inorganic and Organic Nitrogen and Efficiency in Potato Systems. Soil Science Society of America Journal 71, 1508–1515.

Parr, M., Grossman, J.M., Reberg-Horton, S.C., Brinton, C., Crozier, C., 2011. Nitrogen delivery from legume cover crops in no-till organic corn production. Agronomy Journal 103, 1578–1590.

Patkowska, E., Konopin´ski, M., 2013. Harmfulness of soil-borne fungi towards root chicory (Cichorium intybus L. var. sativum Bisch.) cultivated with the use of cover crops. Acta Scientiarum Polonorum - Hortorum Cultus 12, 3–18.

Sanz-Cobena, A., García-Marco, S., Quemada, M., Gabriel, J.L., Almendros, P., Vallejo, A., 2014. Do cover crops enhance N_2O, CO_2 or CH_4 emissions from soil in Mediterranean arable systems? Science of the Total Environment 466/467, 164–174.

Swenson, J.A., Walters, S.A., Chong, S.-K., 2004. Influence of Tillage and Mulching Systems on Soil Water and Tomato Fruit Yield and Quality. Journal of Vegetable Crop Production 10, 81–95. doi:10.1300/J068v10n01_09

Thériault, F., Stewart, K.A., Seguin, P., 2009a. Incidence of Pieris rapae in Organic Broccoli Grown With Living Mulches Under Floating Row Cover. International Journal of Vegetable Science 15, 218–225. doi:10.1080/19315260902727809

Thériault, F., Stewart, K.A., Seguin, P., 2009b. Use of Perennial Legumes Living Mulches and Green Manures for the Fertilization of Organic Broccoli. International Journal of Vegetable Science 15, 142–157. doi:10.1080/19315260802598896

Thorup-Kristensen, K., Dresbøll, D.B., Kristensen, H.L., 2012. Crop yield, root growth, and nutrient dynamics in a conventional and three organic cropping systems with different levels of external inputs and N re-cycling through fertility building crops. European Journal of Agronomy 37, 66–82. doi:10.1016/j.eja.2011.11.004

Vanek, S., Wien, H.C., Rangarajan, A., 2005. Time of Interseeding of Lana Vetch and Winter Rye Cover Strips Determines Competitive Impact on Pumpkins Grown Using Organic Practices. HortScience 40, 1716–1722.

Zhou, X., Liu, X., Rui, Y., Chen, C., Wu, H., Xu, Z., 2011. Symbiotic nitrogen fixation and soil N availability under legume crops in an arid environment. J Soils Sediments 11, 762–770. doi:10.1007/s11368-011-0353-4

funded by European Commission