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Msc in Forestry and Environmental Sciences

Effects of conservation tillage on multiple ecosystem services supporting cereal production

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ABSTRACT

Soil management is expected to affect both below- and above-ground soil properties linked to multiple ecosystem services. We analyzed the effects of crop tillage management on the provision of 4 ecosystem services, i.e. grain production, control of weeds and pest (aphids) and soil fertility. In addition, we examined whether landscape complexity affected the delivery of pest and weed control. The experiment was performed in 15 pairs of fields (conventional tillage vs. conservation tillage) of winter cereals along a gradient of landscape complexity located in the agricultural landscape of North-East Italy. Grain production showed no differences between conservation and conventional tillage. Conservation tillage decreased weed control, but it enhanced weed diversity. Moreover, conservation tillage management was found to increase the pest control provided by ground-dwelling predators. Parasitism rate was not affected by tillage management, but it increased with landscape complexity. Finally conservation tillage positively affected soil fertility enhancing soil organic matter. Conservation tillage is a potential win-win practice in our study area, able to maintain levels of productivity similar to conventional tillage and simultaneously to enhance multiple ecosystem services.

RIASSUNTO

È riconosciuto che la gestione del suolo influenzi le proprietà sia sopra che sotto il suolo connesse con i diversi servizi ecosistemici. Abbiamo analizzato gli effetti della lavorazione del suolo nelle colture agricole sulla provvigione di quattro servizi ecosistemici, ovvero produzione, controllo delle erbe infestanti, controllo dei parassiti (afidi) e fertilità. In aggiunta, abbiamo esaminato se la complessità di paesaggio ha influenzato la capacità di controllo di parassiti ed erbe infestanti. L'esperimento è stato effettuato in 15 coppie di campi (lavorazione del suolo convenzionale contro lavorazione conservativa del suolo) di cereali invernali lungo un gradiente di complessità di paesaggio nel Nord-Est Italia. Non ci sono state differenze di produzione a seconda dell'utilizzo di lavorazione del suolo conservativa o convenzionale. La lavorazione conservativa del suolo ha diminuito il servizio di controllo delle erbe infestanti, ma ha migliorato la diversità di specie delle erbe infestanti. Inoltre, è risultato che la lavorazione conservativa del suolo ha aumentato il controllo dei parassiti da parte dei predatori di terra. Il tasso di parassitismo non è stato influenzato dalla lavorazione del suolo, ma è aumentato con la complessità di paesaggio. Infine, la lavorazione conservativa ha influenzato positivamente la fertilità del suolo migliorando la presenza di sostanza organica. La lavorazione conservativa del suolo è una potenziale pratica "*win-win*" nella nostra area di studio, capace di mantenere livelli di produttività simili a quelli ottenibili con lavorazione del suolo convenzionale migliorando allo stesso tempo diversi servizi ecosistemici.

1. INTRODUCTION

1.1 Importance of ecosystem services in agriculture

1.1.1 Ecosystem services

The notion of an ecosystem is ancient, and there were many definitions through the past. Arthur Tansley provided an initial scientific conceptualization in 1935 and in his definition he specified that ecosystem is "not only the organism-complex, but also the whole complex of physical factors forming what we call the environment" (Tansley 1935). He noted that ecosystems "are of the most varied kinds and sizes." The main identifying feature of an ecosystem is that it is indeed a system; its location or size is important, as well. (Tansley 1935)

Nowadays, according to the definition adopted by the Convention on Biological Diversity (CBD, 1992), and ecosystem is "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" and ecosystem can refer to any functioning unit at any scale (United Nations 1992:Article 2). By many scientific studies, is strongly undisputed that each ecosystem provides many services and humans depend on all of them for their survival and welfare.

From the following two definitions "Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life. They maintain biodiversity and the production of ecosystem goods, such as seafood, forage timber, biomass fuels, natural fiber, and many pharmaceuticals, industrial products, and their precursors" (Daily 1997b) and "Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from eco-system function" (Costanza et al. 1997), the Millenium Ecosystem Assessment (MEA) derive that ecosystem services are the "benefits that people obtain from ecosystems" (MEA, 2005, Box 1, p.3). MEA definition follows Costanza et al. in including both natural and human-modified ecosystems as sources of ecosystem services, and it follows Daily in using the term "services" to encompass both the tangible and the intangible benefits humans obtain from ecosystems, which are sometimes separated into "goods" and "services" respectively (Haines-Young, Potschin, 2007). There are different classifications of ecosystem services.

1.1.2 Ecosystem services classification

MEA classifies into four main groups "… provisioning services, such as food and water; regulating services such as regulation of floods, drought, land degradation, and diseases; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other non-material benefits" (MEA, 2005, Box 1, p.3), as shown in Fig. 1.1.

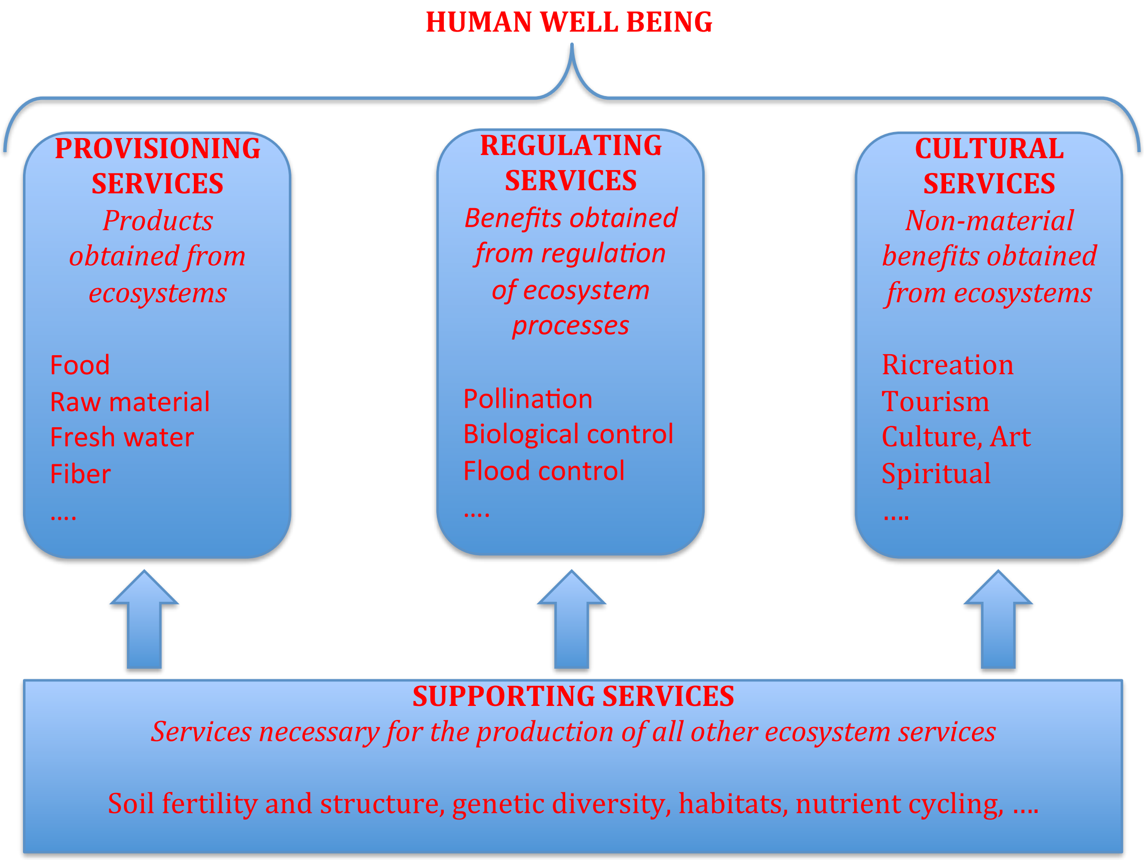

Fig. 1.1 Classification of ecosystem services from the Millennium Ecosystem Assessment (adapted from TEEB).

Provisioning services are the products obtained from ecosystems, including food products derived from plants, animals, and microbes, as well as materials such as wood, fiber and many others; fuel, genetic resources, biochemicals, natural medicines, pharmaceuticals and fresh water.

Regulating Services are the benefits obtained from the regulation of ecosystem processes, including air quality maintenance, climate regulation, water regulation, erosion control, water purification and waste treatment, as well regulation of human diseases, biological control, pollination and storm protection.

Cultural Services are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences, including cultural diversity, spiritual and religious values, educational values, inspiration, social relations, sense of place, cultural heritage, recreation and tourism.

Supporting services are those that are necessary for the production of all other ecosystem services. Their impacts on people are either indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people. For example, humans do not directly use soil formation services, although changes in this would indirectly affect people through the impact on the provisioning service of food production (MEA, 2005). Some other examples of supporting services are primary production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling, and provisioning of habitat .

Ecosystems are characterised by complex interactions between biotic and abiotic components and biodiversity is strongly related with the provisioning of services (Tamburini et al., 2015). According to Mace et. al (2012), biodiversity is in fact an important regulator of fundamental ecosystem processes that underpin multiple ecosystem services. For example the biological control of pests in many cropping systems is determined by the composition of predator communities (Cardinale et al. 2003).

1.1.3 Ecosystem services degradation

In the last years, ecosystems and the biodiversity that underpins these services have been degraded at an unprecedented scale. The value of ecosystems to human welfare is still underestimated and not fully recognized and they are not fully captured in conventional market economics (IUCN, 2014). Furthermore, the costs of externalities of economic development (e.g. pollution, deforestation) are usually not accounted for, while inappropriate tax and subsidy (incentive) systems encourage the over-exploitation and unsustainable use of natural resources and other ecosystem services at the expense of the poor and future generations (IUCN, 2004).
The biodiversity loss caused by human activities has been altering the functioning of ecosystems and their capacity to provide services (Hooper et al., 2005; Balvanera et al. 2006, Cardinale et al. 2012).
Most of the ecosystem services in Europe are judged to be 'degraded' — no longer able to deliver the optimal quality and quantity of basic services such as crop pollination, clean air and water, and control of floods or erosion (Harrison, 2010 about RUBICODE project 2006–2009; marine ecosystems not included) as shown in Fig. 1.2.

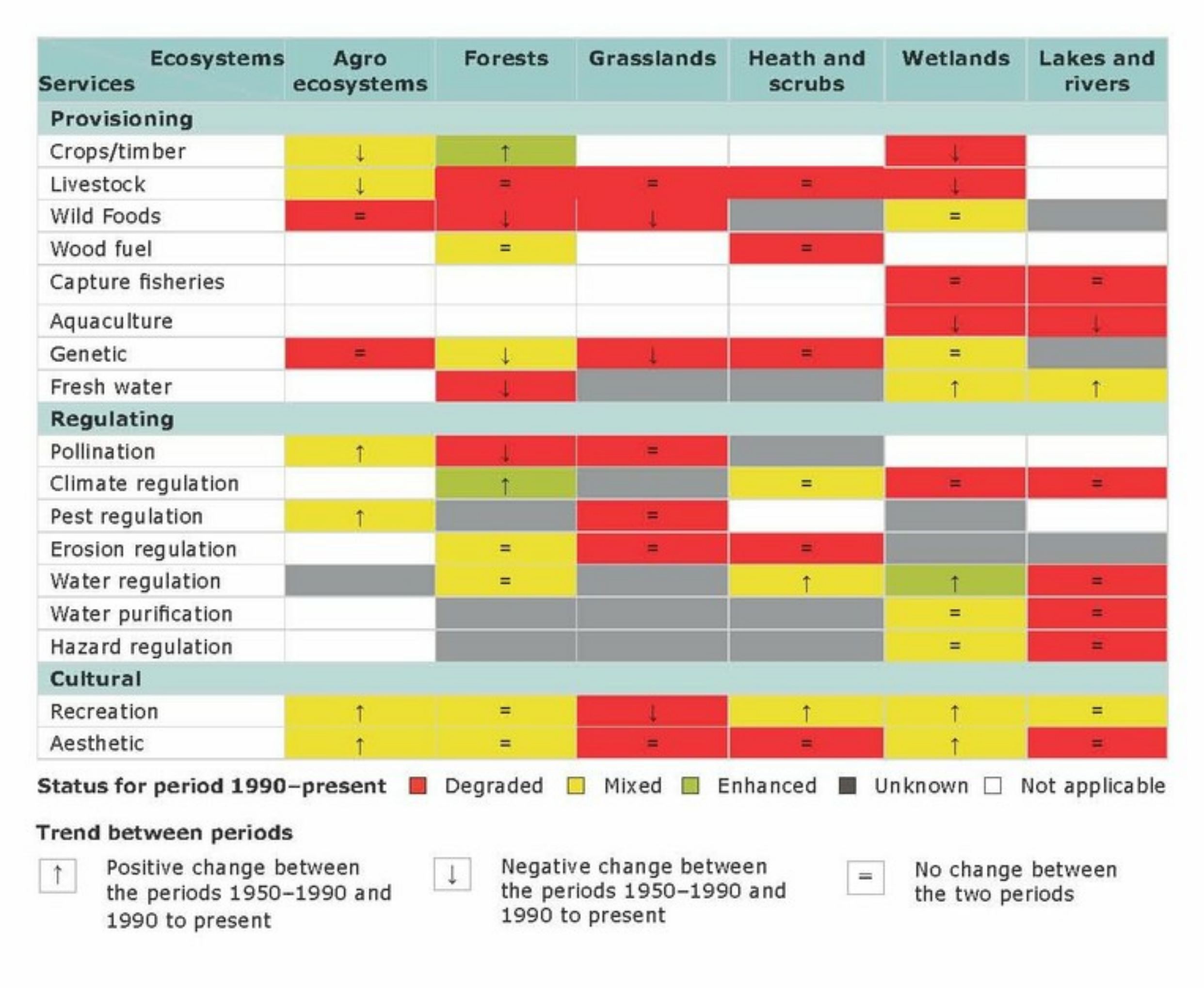

Fig. 1.2 Ecosystem services degradation 1990-2010 (Source: EEA).

In this study we analysed the importance of ecosystem services in agricultural ecosystems.

1.1.4 Ecosystem services' importance in agriculture

Agriculture is the main way of land management all around the world and agricultural ecosystems cover around 40% of the whole Earth's surface (FAO 2014). Agro-ecosystems can maximize the provisioning services; they can also provide ecosystem services and disservices (Zhang et al. 2007), and many of them are unvalued, unmanaged and underestimated (Swinton et al. 2007). Moreover, these services are influenced by agriculture management practices (Power 2010) and on the other side, agriculture depends on many supporting and regulating services (De Simone et al., 2015). According to Zhang et al. (2007), agriculture can receive benefits from ecosystem services (ES, e.g. pollination, soil fertility, biological control and others) and costs from disservices (ESD, e.g. pests, diseases, pathogens and others), and these are supplied by varied species, functional groups, and guilds over a range of scales and influenced by human activities both intentionally and unintentionally (De Simone et al., 2015). The main services in agriculture are soil structure and fertility, pest control and pollination from insects, water provision and purification, genetic diversity and climate (Zhang et al., 2007). All of these services have a huge importance in agriculture for many reasons, and in this study we analysed the first three above services.

Soil structure and fertility influence the quantity and quality of agricultural output; the quality of soil depend on the presence of earthworms and macro and micro invertebrates, through partial digestion and commutation of soil organic matter (Edwards, 2004). Microorganisms (bacteria, fungi, …) regulate the nutrient cycling, and this maintains soil fertility, since they can fix atmosphere nitrogen (so nitrogen will be more available); they can also enhance soil fertility liberating nutrients from detrital organic matter and retaining nutrients in their biomass that might otherwise be lost downstream (Paul and Clark, 1996). Retention of nutrient is kept by non-crop plants (Ramakrishnan, 1992). Conservation tillage, including both no tillage and minimum tillage (Brown, 2003) represents a valid approach to conserving these ES (Zhang et al., 2007).

Crop pollination is a fundamental ES, since the production of over 75% of the world's most important crops that feed humanity and 35% of the food produced is dependent upon pollinators (Klein et al., 2007), and it is mainly provided by bees (*Apis mellifera* L.), but also by birds, bats, moths, flies, butterflies and others (Zhang et al., 2007). There has been increasing evidence that conserving wild pollinators in habitats adjacent to agriculture improves both the level and stability of pollination, leading to increased yields and income (Klein et al., 2003).

Insects also provide biological control of pests, and these insects can be generalist or specialist predators or parasitoids. Birds and spiders can be considered as natural enemies of pests in agriculture, as well. This ES in the short term suppresses pest damage and improves yield, while in the long-term maintains an ecological equilibrium that prevents herbivore insects from reaching pest status (Zhang et al., 2007). This ES, however, is increasingly threatened by biodiversity loss (Wilby and Thomas, 2002), modern agricultural practices (Naylor and Ehrlich, 1997), and human alterations of natural ecosystems, and it is very important to leave nectar, pollen, sap, or seeds (Wilkinson and Landis, 2005) as alternative food sources to fuel adult flight and reproduction and non-crop area can provide habitat where beneficial insects mate, reproduce, and overwinter. Enhanced abundance and diversity of natural enemies, however, do not necessarily provide enhanced pest control, since pest densities may also respond positively to landscape complexity (Zhang et al., 2007).

In a future where agriculture will face severe environmental, economic, and social challenges (Foley et al. 2005, MA 2005), improving the BC service provided by natural enemies arises as an ecologically and economically promising solution (De Simone et al., 2015). Besides ES, we should take into account also the main EDS in agriculture provided by crop pests, non-crop plants and competition for ecological resources. Crop pests (herbivores, frugivores, seed-eaters, fungi, bacteria and viruses) can decrease or destroy the productivity and over-reliance on pesticides has led certain species to evolve genetic resistance to specific pesticide compounds, triggering pest outbreaks and resurgence. This can make chemical control more costly and result in negative health outcomes for non-target organisms, including humans (Thomas, 1999). Non-crop plants can reduce agricultural productivity because they compete for resources and for pollination services with crops (Stoller et al., 1987). Competition for pollination services from flowering weeds and non-crop plants can also reduce crop yields (Free, 1993). All of these above services and dis-services can interact between each other and there can be some consequences.

1.2 Potential interactions and trade-offs between services

There is evidence of relationships among ES, and these need to be better understood to improve ecosystem management and in their study, Bennet et al. (2009) identified two types of ES mechanisms that cause relationships between them: effects of drivers (management practices) on multiple ecosystem services (i.e. common drivers) and interactions among ES.

About management practices, for instance, building new infrastructures to enable people to do new activities can enhance cultural ecosystem services (such as recreation) without having any effects on crop production, but if we increase the use of fertilizer to improve crop production, this can have a significant negative effect on local provision of clean water in addition to the intended effect of increasing crop yields cultivation (Bennet et al., 2009), or for example cultivation of perennial grasslands was found to enhance both pollination and biological control service (Werling et al. 2014).

About ecosystem services interactions, if we enhance or destroy one or more services, this can influence the provision of another service, positively or negatively (De Simone et al., 2015) and for instance, if we increase pest control, there will be also enhancement of pollination, which will bring benefits to yield (Lundin et al., 2013). Anyway, nowadays our understanding of the relationship between ecosystem processes and provision of services still remains fairly dim for most ecosystems and most services (Carpenter et al., 2009), although above- and below-ground ecosystems are known to influence each other (e.g. Bezemer et al. 2005) and supporting ecosystem services are expected to strongly affect regulating services (MA, 2005). Without knowledges about the relationships among ecosystem services, we are at risk of incurring unwanted trade-offs, squandering opportunities to take advantage of synergies, and possibly experiencing dramatic and unexpected changes in provision of ecosystem services (Bennet et al., 2009).

1.3 Impacts on services (local management and landscape management)

In the last decades, due to an increasing demand for food forecasted to double by 2050 (Tillman et al., 2011), agriculture increased intensification and this and other related practices are very harmful, since they compromise the ability of ecosystems to provide ES (MA, 2005). The land-use changes include also the conversion of complex natural ecosystems to simplified managed ecosystems and the intensification of resource use, including application of more agrochemicals and a generally higher input and output, which is typical for agro-ecosystems as relatively open systems (Tscharntke et al., 2005). All of these practices are known to be the main drivers of global biodiversity loss and the related degradation of ecosystem services (e.g. Daily 1997, Schröter et al. 2005, Hooper et al. 2005). For example landscape simplification and fragmentation have been shown to harm pollination service (Klein et al. 2007), whereas high applications of nitrogen fertilizer to negatively affect soil biota activity (Tilman et al. 2001, Guo et al. 2010). Landscape composition affects natural enemy communities. Complex landscapes with large proportions of semi-natural habitats provide a more stable environment than landscapes dominated by annual crops (De Simone et al., 2015). Semi- natural habitats can maintain populations of alternative hosts and preys for parasitoids and predators, protecting natural enemies against crop disturbance, offering additional nectar resources during the vegetative season and shelter during overwintering (Denys and Tscharntke 2002, Bianchi et al. 2006). Some studies shows how complex landscapes support more diverse and abundant communities of natural enemies (Bianchi et al. 2006, Chaplin- Kramer et al. 2011, Chaplin-Kramer & Kremen 2012, Martin et al. 2013, Rusch et al. 2013; Winqist et al. 2011).

Various farming practices affect biological control, as well. For instance, organic farming has been shown to locally support higher biological control compared to more intensely managed systems (Crowder et al. 2010, Winqvist et al. 2011). To avoid and limit the negative effects of these local managements while preserving the maximum level of production, some authors proposed to use ecological intensification, which can bring enhancements in several agricultural ecosystems (ecological enhancement; e.g. soil fertility restoration in highly degraded soils and ecological replacement; e.g. biological control partially replacing pesticide use) (De Simone et al., 2015). There are also some recent agricultural practices, such as conservation tillage, which can improve and decrease negative impacts on ES; for instance, conservation tillage can reduce soil disturbance (Holland, 2004) and enhancing floral resources and nesting sites to promote pollinators (Carvell et al. 2011).

Soil can positively or negatively influence ES, as well, for this reason is really important to pay attention to soil management.

1.4 Importance of soil management

As described before, soil provides many ES (par. 1.1.4). Intensive management practices such as powered tillage, repetitive harvesting of crops and inadequate nutrients replacement can degrade soil structure, fertility, the functioning of soil biota communities and degradation in soil organic matter (Oldeman 1994; Paul et al., 1996). It is fundamental to find the best soil management practices in order to avoid loss and degradation of soil structure, since there are some practices that can maintain and restore soil fertility and structure, such as the addition of organic inputs that enhances soil organic matter, the inclusion of perennial grasses and legumes in the crop rotation and the adoption of cover crops that limits soil nutrient runoff; these practices can preserve soil-based ecosystem services (De Simone et al., 2015). Managing the soil in the best way can help to optimise biological processes that are fundamental to many soil functions and to provide many ES. The processes mediated through biological action include decomposition of organic matter, transformation of nutrient elements, releasing them in plant-available, soluble or volatile forms, which predispose them to loss from soil, mixing and formation of channels within the soil matrix by soil fauna, stabilisation of soil structure through the production of extra-cellular peptides and enmeshing filaments and bio-control of soil-borne plant pathogens and pests (Powlson et al., 2011).

There is still not so much information about the mechanisms linking soil management (e.g., crop rotation, soil tillage) to above-ground ecosystem services such as biological control (Rusch et al. 2013). Conservation tillage is a farming practice that includes all the techniques characterized by non-inversion of soil often combined with a permanent vegetation cover of the soil (De Simone et al., 2015). It has been pointed as a promising soil management able to minimize negative impacts of farming operations with several beneficial consequences on soil structure, hydrology and biodiversity (Kladivko 2001, Holland 2004, Collette et al. 2011, Soane et al. 2012). Which are the actual effects of conservation tillage on BC service and whether it interacts with landscape composition is, by now, only speculative (De Simone et al., 2015).

1.5 Objectives and hypothesis of the work

In this study we considered and analysed potential interactions between management intensity, landscape complexity and multiple ecosystem services in cereal crops. During an exclusion experiment in field, we analysed how tillage management and landscape complexity influence biological control on aphids; natural enemies in winter cereal crops include specialized natural enemies such as parasitoids and more generalist predators such as carabid beetles or cursorial spiders (Brewer and Elliot, 2004), while the role of birds has never been studied in winter cereal crops. Quantifying the level of biological control provided by different natural enemy guilds might be considerably important if we are planning sustainable management strategies in agricultural landscapes (Loreau et al. 2003).

In this study we also tried to link soil management, landscape complexity, natural enemy communities and biological control service.

We used a design where landscape complexity and tillage management (conservation vs. conventional tillage) were statistical orthogonal factors, and we made three hypothesis:

(1) conservation tillage management can improve biological control provided by ground-dwelling predators (carabid beetles, spiders and rove beetles) since with this kind of management there are reduced soil disturbance, increased surface residues and higher weed diversity, that all together provide a more suitable environment at multiple life stages (Ball et al. 1998, Kendall 2003,);

(2) all natural enemy guilds will influence aphids control in the field;

(3) biological control will increase with landscape complexity which can act additively or synergistically with local tillage management.

2. MATERIALS AND METHODS

2.1 Study area

Our field experiments took place between April and June 2014. We performed our experiments in the agricultural landscapes of Udine province, a lowland area with temperate climate (13°C year average) and mean annual precipitation ranging between 1200 and 1800 mm (ARPA FVG, 2014), located in Friuli Venezia Giulia region (N-E of Italy) as shown in red colour in Fig. 2.1. Lithology is characterized by Holocene alluvial and Pleistocene fluvial-glacial sediments (Martinis, 1993; Carulli, 2006).

Fig. 2.1 Study area

2.2 Preparation of experiment fields

In this area, from autumn 2013 there were prepared 15 pairs of winter cereal fields placed in a landscape gradient (from more natural landscapes until more anthropised ones). Seven couples were planted with barley and the other 8 were planted with winter wheat. Distance from field pairs was at least 1 km except for two that were distant around 300 m. Within the pairs, the environmental characteristics were comparable because of the short distance between fields (not more than 400m). Every pair had its fields with the same species; moreover, within every pair one field under conservation tillage management (CT) whereas the other one was managed with conventional tillage (CoT). Conservation tillage was characterized by non-inversion of soil for at least 5 years (10 years on average). This kind of management included also the adoption of cover crops through the year (the most used was *Lolium multiflorum* L. sown after the summer crops). Typical rotation of the fields included as main crop maize, wheat and soybean (De Simone et al., 2015). With conventional tillage, the seedbed was prepared by mouldboard ploughing (30 cm depth), and later there were one or two tills for seedbed preparation. Field pairs were selected along a gradient in landscape complexity ranging from 1.2 to 22.4 % of semi-natural habitats (forests, shrubby areas, grasslands, hedgerows, and field margins) in a 1060 m radius around each field. The proportion of agricultural and urban areas was also measured, defining three land use classes (agricultural, semi-natural and urban areas). The increase in % semi-natural habitats was consistent with the increase in landscape complexity (correlation index = 0.62). ArcGIS 9.3 was used for landscape analyses of regional land use maps, verified and ameliorated with aerial photographs to increase class discrimination accuracy (De Simone et al., 2015; Tamburini et al., 2015).

In each field, were identified one 60x20m strip located on one side of each field. Within each pair, the strips were bordered with an edge habitat of similar structure and composition (either a grass margin or a hedgerow). Each strip was divided into six 10x20m plots, of which two (the outer ones) were considered as buffer zones and just two of the other four stripes were fertilized following farming recommendations (80 kg ha-1 of ammonium nitrate in two applications). Two non-adjacent plots were randomly selected for the exclusion experiment and the natural enemies sampling. No chemical pesticides and herbicides were applied on the plots during all the experiments.

Data collection was performed in the different plots as described in the following section (Fig.2.2).

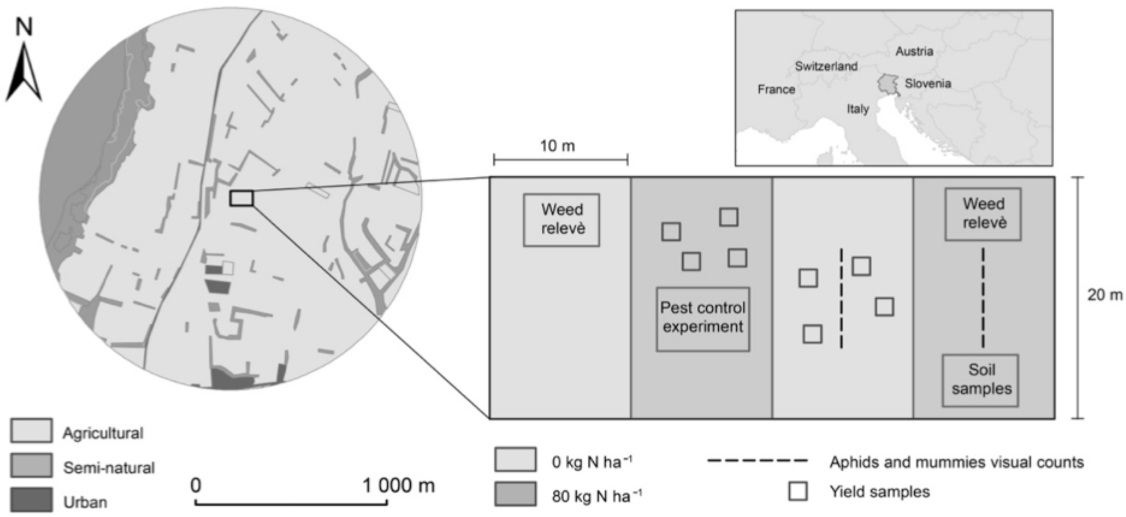

Fig. 2.2 Experimental plots (source: De Simone et al., 2015).

2.3 Data collection and analysis

We collected data about yield production, weed control, aphid control and soil fertility. We also collected data about diseases incidence. Ground-dwelling predators and parasitoids' biological control of aphids was measured in different ways.

Parasitism rate was measured twice by visual inspection of 50 tillers per field (first during stem elongation stage, and lately during fruit development). Per each field, parasitism rate was the ratio between the number of mummified aphids and the whole amount of aphids in the field. Preliminary analyses on the natural density of aphids per field showed no differences between treatments (De Simone et al., 2015).

About ground-dwelling predators, their biological control service was measured with an exclusion experiment. We performed a close treatment (all natural enemies excluded) and an open treatment (access to ground-dwelling predators only), for a total of two cages ion one fertilized plot per field. In the close treatment, a 0.3 m (diameter) and 0.25 m (height) plastic ring was dug 10 cm deep, an insect glue band (8 cm wide) was applied along the perimeter and a polyester fine (1 mm) mesh supported by poles was sealed to the cylinder. In the open treatment, we did not use plastic rings but we fixed the net to the support poles 5 cm above the ground. We put one pitfall inside each cage and for all the experiment duration we checked and emptied it. To have the same aphid abundance, we inoculated aphids (*Sitobion avenae* grown in laboratory and provided by Katz Biotech AG®) in the field plants inside every cage. 10 days before the inoculation, to have better comparisons we left just 7 plants inside every cage and each of those plants and the ground inside the cage were cleared from natural enemies and then covered by a nonwoven fabric supported by sticks to exclude recolonization. After 10 days, we inoculated around 150 aphids per treatment including both adults and nymphs and this operation took place at the heading stage of the cereals during good weather conditions (absence of precipitation, of strong wind and minimum air temperature 18°C). After 5 days we counted the number of aphids remained and plants were re-inoculated if the number of aphids were too low (less than 15 aphids). After 10 days from the first inoculation aphids were counted (time 0). We visually counted aphids in each treatment at two occasions, 5 and 10 days after the onset of the exclusion experiment. For each 5 days period, predation rate was calculated as the proportion of aphids predated in the open cages compared with the aphid population growth in the close cage, as following:

$$Predation\ rate = \frac{N_{treatment\ 5}}{R_{close} \times N_{treatment\ 0}}$$

where N*treatment 5* is the number of aphids in the open cage after 5 days; R_{close} is the aphid population growth in the close cage, N*treatment 0* is the number of aphids in the open cage at the beginning of the experiment. Predation rate values ranged from 0 to 1, where 0 indicates no net loss of aphids in the open cage and 1 indicates that 100% of aphids was predated (Gardiner et al. 2009). The exclusion experiment was performed only in the fertilized plots because we did not expect any short-term effect of N fertilization on predation rate (De Simone et al., 2015).

We took data about weeds from one fertilized plot and from a not fertilized one per every field during the 3rd decade of may at the last weed stage and considering a rectangular area (2x5m) along the midline of each plot. We summed the cover value of all species of vascular plants in the fields and we quantified the overall weed cover in each plot.

We also took data about production and soil fertility. When crops were mature, we randomly harvested from one fertilized plot and from a not fertilized one per every field, four 0,25 m^2 samples to record the yield, afterwards dried at 60°C for one day.
Production was measured as the dry e of grains per square meter (kg/ m^2).

To analyse the soil, we randomly collected with a drill 5 soil samples (15 cm in depth and 3 cm in diameter) in each fertilized plot with and then we mixed them altogether, measuring the organic matter (Soltner 1988). We did not sample non-fertilized plots because we did not expect any short-term effect of N fertilization on the organic matter.

Lastly, we visually valuated diseases incidence randomly inspecting 50 leaves per plot and we calculated the number of leaves affected by fungal disease (i.e. rust, leaf spot, mildew and *Fusarium sp.*). Generalized linear mixed model (GLMM) (family = Poisson) was used to analyse disease incidence. Tillage management and fertilization treatment were included as fixed factors and number of leaves affected as independent variable. The type of crop (barley or wheat), pair id and field id were included as random factors. GLMM showed no effect of any of the variables considered on disease incidence (p-value> 0.05) (De Simone et al., 2015). Linear mixed models were used to verify the combined effects of tillage management, fertilization and landscape composition on the provision of the ecosystem services considered ("nlme" package in R environment; Pinheiro et al. 2009, R Core Team 2009). Linear mixed model assumptions were verified using diagnostic plots of model residuals. A total of six models were run. For the analysis of yield production (production service), weed cover and weed species richness (weed control), tillage management, fertilization and landscape composition were included as fixed factors and crop type, pair id and field id as random factors. For the analysis of aphid predation (aphid control service) tillage management and landscape composition were included as fixed factors and crop type, pair id and counting round as random factors. The parasitism rate was log-transformed to achieve normal distribution of model residuals. The model included fertilization as covariate, tillage management and landscape composition as fixed factors and crop type, pair id and counting round as random factors. The analysis of organic matter content (soil fertility service) included tillage management as fixed factor and crop type and pair id as random factors. Before the onset of the experiment, a local storm event damaged the cages in 3 pairs (6 fields) compromising the aphid establishment. The analysis regarding predation rate were thus based on data from 12 field pairs (24 fields) (De Simone et al., 2015).

3. RESULTS

According to LMMs results, tillage management does not affect yield production (Fig. 3.1a) and fertilization with nitrogen increased crop yield (Tab. 3.1). We recorded 91 species during the weed sampling, 63 species in conventional tillage managed fields and 76 in conservation tillage managed ones. Tillage affects both weed cover and weed species richness and fields managed with conservation tillage presented higher values of weed cover and richness of species (Fig. 3.1b and 3.1c). Weed communities were not influenced by landscape composition. Ground-dwelling predators reduced aphid populations, and there was stronger biological control with conservation tillage management (Fig. 3.1d). Aphid predation was not affected by landscape composition, as well. On the contrary, parasitism rate responded to landscape composition and it was not affected by tillage management (Fig. 3.1e). Parasitism rate decreased at the increase of proportion of agricultural areas in the landscape. Lastly, results showed that that conservation tillage enhanced SOM content (Fig. 3.1f).

Ecosystem service	Response variable	Factors	DF	F-value	*p*-value
Production	yield	tillage	12	2.52772	0.1378
		fertlization	28	74.13785	<0.0001
Weed control	weed cover	tillage	13	4.98717	0.0437
		fertilization	28	0.21914	0.6433
		tillage:fertilization	28	0.20097	0.6574
	weed species richness	tillage	13	5.33301	0.038
		fertilization	28	1.88431	0.1807
		tillage:fertilization	28	3.05228	0.0916
Pest control	predation index	tillage	21	8.84051	0.0073
	parasitism rate	tillage	25	0.04859	0.8273
		% agricultural areas	25	6.25005	0.0193
		tillage: % agricultural areas	25	0.29065	0.5946
Soil quality	SOM	tillage	14	4.37271	0.0552

Tab. 3.1: results of LMM relating yield production, weed cover and diversity, predation rate, parasitism rate and SOM content to explanatory variables (source: De Simone et al., 2015).

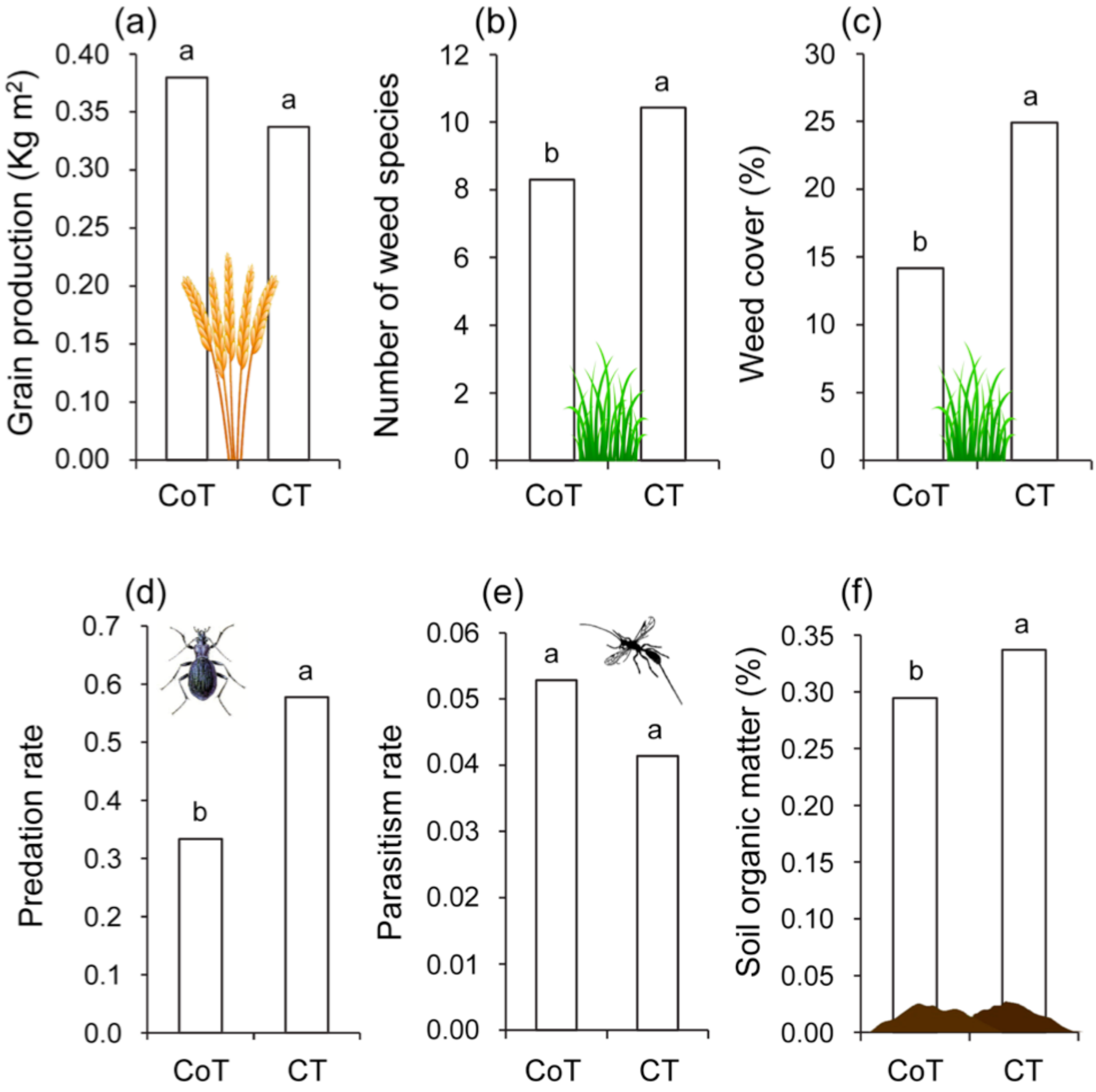

Fig. 3.1 Effects of tillage management (CT, conservation tillage; CoT conventional tillage) on yield production (a; dry weight of grain, kg/m2), weed species richness (b; number of species), proportion of weed cover (c), aphid predation rate (d; Pr), aphid parasitism rate (e; Pa; n. of mummies/n. of aphids) and proportion of soil organic matter (f). Bars with the same letter are not significantly different ($P > 0.05$). (source: De Simone et al., 2015).

4. DISCUSSION AND CONCLUSIONS

Our results showed that conservation tillage can improve ground-dwelling insects biological control of aphids and soil fertility, but there are no differences about production levels if we compare conservation tillage management with conventional tillage management. According to this, the adoption of conservation tillage can be done without causing negative effects and trade-offs between the different ecosystem services kinds.

About regulating services, conservation tillage management negatively affected weed control, with an increase of weed cover and species richness, as showed in other studies e.g. Murphy et al. in 2006, Tolimir et al. in 2006 and Demjanová et al. in 2009, but we should also say that in recent studies scientists found that high weed diversity also supports agro-ecosystem functioning (Albrecht, 2003; Franke et al., 2009) as for instance it can provide habitats for natural enemies (Schellhorn and Sork, 1997) and resources for pollinators (Gabriel and Tscharntke, 2007). Weed services were not affected by landscape composition, since the dispersal of several arable weeds is in fact limited and their occurrence in the field is principally related to the local seed bank (Bischoff and Mahn, 2000).However, the effect of fertilization on weeds depends also on management practices and local habitat conditions (O'Donovan et al. 2001).

Our results showed that both local management and landscape composition are important in shaping biological control service (Rush et al. 2013). Regulating service of aphid control differently responded to and it is influenced by both tillage management and landscape composition (Rusch et al. 2013). There are different responses between aphid control and parasitoids. Conservation tillage management had a positive effect on ground-dwelling predators aphids control, because the decrease of tillage intensity and soil disturbance has been show to increase the abundance of ground-dwelling insects (Holland 2004). Parasitism rate was affected only by landscape composition since is known that landscape simplification reduces the availability of natural and semi-natural habitats for parasitoids (Olson and Wäckers 2007).

Moreover, conservation tillage management combined with cover crops positively affected soil fertility enhancing SOM content. Conservation tillage also includes the use of cover crops that are well known to limit soil erosion and to increase soil organic matter (Holland, 2004). We studied the effect of tillage and fertilization on the provisioning service and we found that the application of nitrogen fertilizers increased yield since this is the most common practice to enhance nutrient availability for crops and therefore production (e.g. Campbell et al. 2011). Conservation tillage did not decrease grain production. The results could be also related to the improved SOM in the CT fields (De Simone et al., 2015). Although there are contrasting results in literature on the effect of conservation tillage on crop production, these discrepancies seem to be caused by local differences in soil and climate properties or concomitant farming practices (De Vita et al. 2007).

In this study we also considered very important the trade-offs between environmental and economic benefits and the cost-effectiveness of promoting conservation tillage management. An adoption of conservation tillage instead of the conventional one may lead to a better economic efficiency reducing fuel and energy consumption and decreasing time and energy required for seedbed preparation (Tabatabaeefar et al. 2009) and the identification of trade-offs and synergies between provisioning, regulating, supporting services and farming practices is a crucial step towards sustainable management of agricultural ecosystems (Bommarco et al. 2013). Our result showed that conservation tillage management performed as well as conventional tillage in providing grain yield and enhanced local soil quality, pest control and weed diversity. Further research is, however, needed to test whether conservation tillage can effectively be applied in other crops and in different agricultural regions.

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6. REFERENCES

Albrecht, H. (2003). Suitability of arable weeds as indicator organisms to evaluate species conservation effects of management in agricultural ecosystems. Agriculture, Ecosystems & Environment, 98, 201–11.

ARPA FVG - Struttura OSMER, Osservatorio Meteorologico Regionale, (2014). Il Clima del Friuli Venezia Giulia (http://www.osmer.fvg.it/)

Ball, B. C., Tebrügge, F., Sartori, L., Giráldez, J. V., González, P. (1998). Influence of no-tillage on physical, chemical and biological soil properties. In: Tebrügge, F., Bohrnsen, A. (Eds.), Experience with the Applicability of No-tillage Crop Production in the West-European Countries. Final Report, Fachverlag Kohler, 35396 Giessen, Germany, pp. 7–27.

Balvanera, P., Pfisterer, A. B., Buchmann, N., He, J. S., Nakashizuka, T., Raffaelli, D., & Schmid, B. (2006). Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecology Letters, 9, 1146–1156.

Bennett, E. M., Peterson, G. D., & Gordon, L. J. (2009). Understanding relationships among multiple ecosystem services. Ecology Letters, 12, 1394–1404.

Bezemer, T. M., De Deyn, G. B., Bossinga, T. M., Van Dam, N. M., Harvey, J. A., & Van der Putten, W. H. (2005). Soil community composition drives aboveground plant–herbivore–parasitoid interactions. Ecology Letters, 8, 652– 661.

Bianchi, F. J., & Werf, W. V. D. (2004). Model evaluation of the function of prey in non-crop habitats for biological control by ladybeetles in agricultural landscapes. Ecological Modelling, 171, 177–193.

Bianchi, F. J. J. A., Booij, C. J. H., & Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proceedings of the Royal Society B: Biological Sciences, 273, 1715–1727.

Bischoff, A., & Mahn, E. G. (2000). The effects of nitrogen and diaspore availability on the regeneration of weed communities following extensification. Agriculture, Ecosystems & Environment, 77, 237–46.

Bommarco, R., Kleijn, D., & Potts, S. G. (2013). Ecological intensification: harnessing ecosystem services for food security. Trends in Ecology & Evolution, 28, 230–238.

Brewer, M. J., & Elliott, N. C. (2004). Biological Control of Cereal Aphids in North America and Mediating Effects of Host Plant and Habitat Manipulations. Annual Reviews in Entomology, 49, 219–242.

Brown, L.R., 2003. Plan B: Rescuing a Planet under Stress and a Civilization in Trouble. Chapter 8: Raising Land Productivity. Norton, New York. Available online at: http://www.earth-policy.org/Books/PB/PBch8_ss6.htm.

Campbell, C. A., Lafond, G. P., Vandenbygaart, A. J., Zentner, R. P., Lemke, R., May, W. E., & Holzapfel, C. B. (2011). Effect of crop rotation, fertilizer and tillage management on spring wheat grain yield and N and P content in a thin Black Chernozem: A long-term study. Canadian Journal of Plant Science, 91, 467–83.

Cardinale, B. J., Harvey, C. T., Gross, K., & Ives, A. R. (2003). Biodiversity and biocontrol: emergent impacts of a multi-enemy assemblage on pest suppression and crop yield in an agroecosystem. Ecology Letters, 6, 857–865.

Cardinale, B. J., Emmett Duffy, J., Gonzalez, A., et al. (2012). Biodiversity loss and its impact on humanity. Nature, 486, 59–67.

Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., Defries, R.S., Diaz, S. et al. (2009). Science for managing ecosystem services: beyond the millennium ecosystem assessment. Proc. Natl Acad. Sci. USA, 106, 1305–1312.

Carulli, G. B., (2006). Carta Geologica del Friuli Venezia Giulia, scala 1:150.000.

Carvell, C., Osborne, J. L., Bourke, A. F. G., Freeman, S. N., Pywell, R. F., & Heard, M. S. (2011). Bumble bee species' responses to a targeted conservation measure depend on landscape context and habitat quality. Ecological Applications, 21, 1760–1771.

CBD – Convention of Biological Diversity, 1992. http://www.cbd.int/

Chaplin-Kramer, R., O'Rourke, M. E., Blitzer, E. J., & Kremen, C. (2011). A meta- analysis of crop pest and natural enemy response to landscape complexity. Ecology Letters, 14, 922–932.

Chaplin-Kramer, R., & Kremen, C. (2012). Pest control experiments show benefits of complexity at landscape and local scales. Ecological Applications, 22, 1936– 1948.

Collette, L., Hodgkin, T., et al. (2011). Save and Grow: A Policy Makers Guide to the Sustainable Intensificationof Smallholder Crop Production. http://www.fao.org/ag/save-and-grow/index_en.html

Costanza, R., D'Arge, R., DeGroot R., Farber, S., Grasso, M., Hannon B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R., Sutton, P., van den Belt, M. (1997): The Value of the World's Ecosystem Services and Natural Capital. Nature 387:253–260.

Crowder, D. W., Northfield, T. D., Strand, M. R., & Snyder, W. E. (2010). Organic agriculture promotes evenness and natural pest control. Nature, 466, 109–112.

Daily, G. (Ed.) (1997). Nature's services: societal dependence on natural ecosystems. Island Press.

Daily, G. C. (1997): Introduction: What are Ecosystem Services? In: Daily, G.C. (Ed.) Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, D.C.: 1-10.

De Vita, P., Di Paolo, E., Fecondo, G., Di Fonzo, N., & Pisante, M. (2007). No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in southern Italy. Soil and Tillage Research 92, 69–78.

De Simone S., Tamburini G., Boscutti F., Sigura M., Marini L., (2015). Effects of conservation tillage on multiple ecosystem services supporting cereal production, 91-102.

Demjanová, E., Macák, M., Dalovic, I., Majernik, F., Tyr, S., & Smatana, S. (2009). Effects of tillage systems and crop rotation on weed density, weed species composition and weed biomass in maize. Agronomy Research 7, 785–92.

Denys, C., & Tscharntke, T. (2002). Plant-insect communities and predator-prey ratios in field margin strips, adjacent crop fields, and fallows. Oecologia, 130, 315–324.

Edwards, C., 2004. Earthworm Ecology. CRC Press, Boca Raton, FL.

441 pp.

EEA – European Environment Agency. Ecosystem Servicess in the EU. http://www.eea.europa.eu

FAO (2014). FAOSTAT. Rome, Italy: FAO http://faostat. fao.org.

Franke, A. C., Lotz, L. P., Van Der Burg, W. J., & Van Overbeek, L. (2009). The Role of Arable Weed Seeds for Agroecosystem Functioning. Weed Research, 49, 131–41.

Free, J.B., 1993. Insect Pollination of Crops. Academic Press, London.

Gabriel, D. & Tscharntke, T. (2007). Insect pollinated plants benefit from organic farming. Agriculture, Ecosystems & Environment, 118, 43–48.

Gardiner, M. M., Landis, D. A., Gratton, C., et al. (2009). Landscape diversity enhances biological control of an introduced crop pest in the north-central USA. Ecological Applications, 19, 143–154.

Guo, J. H., Liu, X. J., Zhang, Y., et al. (2010). Significant acidification in major Chinese croplands. Science, 327, 1008−1010.

Haines-Young, R. and Potschin, M. (2007): The Ecosystem Concept and the Identification of Ecosystem Goods and Services in the English Policy Context. Review Paper to Defra, Project Code NR0107, 21pp.

Harrison P. A. (2010). Ecosystem services and biodiversity conservation: an introduction to the RUBICODE project. 0960-3115(p) 1572-9710(e).

Holland, J. M. (2004). The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems & Environment, 103, 1−25.

Hooper, D. U., Chapin Iii, F. S., Ewel, J. J., et al. (2005). Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monographs, 75, 3−35.

IUCN (2004): Comparing the Ecosystem Approach with sustainable use. Seventh meeting of the Conference of the Parties to the Convention on Biological Diversity (COP7) (Kuala Lumpur, Malaysia, 9-20 February 2004). IUCN Information Paper February, 2004.

IUCN, 2014. Ecosystem services. https://www.iucn.org/about/union/commissions/cem/cem_work/cem_services/

Kendall, D. A. (2003). Soil tillage and epigeal predatory arthropod. In: “Soil Tillage in Agroecosystems” A. El Titi (Ed.), CRC Press, Boca Raton, Florida. pp. 297–342.

Kladivko, E. J. (2001). Tillage systems and soil ecology. Soil and Tillage Research, 61, 61−76.

Holland, J. M. (2004). The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems & Environment, 103, 1−25.

Klein, A., Steffan-Dewenter, I., Tscharntke, T., 2003. Fruit set of
highland coffee increases with the diversity of pollinating bees. Proceedings of the Royal Society of London. Series B 270, 955–961.

Klein, A., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Tscharntke, T., 2007. Impor- tance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society of London. B, Biological Sciences 274 (1608), 303–313.

Loreau, M., Mouquet, N., & Gonzalez, A. (2003). Biodiversity as spatial insurance in heterogeneous landscapes. Proceedings of the National Academy of Sciences of the USA, 100, 12765–12770.

Mace, G. M., Norris, K., & Fitter, A. H. (2012). Biodiversity and ecosystem services: a multilayered relationship. Trends in Ecology & Evolution, 27, 19–26.

Martin, E. A., Reineking, B., Seo, B., & Steffan-Dewenter, I. (2013). Natural enemy interactions constrain pest control in complex agricultural landscapes. Proceedings of the National Academy of Sciences of the USA, 110, 5534– 5539.

Martinis, B., (1993). Storia geologica del Friuli. La Nuova Base Ed., Udine.

MEA (2005): Ecosystems and Human Well Being. Island Press. Millennium.

Murphy, D. S., Clements, D. R., Belaoussoff, S., Kevan, P. G., & Swanton, C. G. (2006). Promotion of weed species diversity and reduction of weed seedbanks with conservation tillage and crop rotation. Weed Science, 54, 69–77.

Naylor, R., Ehrlich, P., 1997. Natural pest control services and agriculture. In: Daily, G. (Ed.), Nature's

Services: Societal Dependence on Natural Ecosystems, pp. 151–174. Washington DC.

O'Donovan, J. T., Harker, K. N., Clayton, G. W., Robinson, D., Blackshaw, R. E., & Hall, L. (2001). Implementing integrated weed management in barley (*Hordeum vulgare*). In: Blackshaw, R. E., & Hall, L. M., (Eds.), Integrated Weed Management: Explore the Potential. Sainte-Anne-de-Bellevue, Quebec: Expert Committee on Weeds. pp. 75–89.

Oldeman, L. R. (1994). The global extent of soil degradation. Soil resilience and sustainable land use, 99–118.

Olson, D. M., & WäCkers, F. L. (2007). Management of Field Margins to Maximize Multiple Ecological Services: Field Margins and Maximizing Ecological Services. Journal of Applied Ecology, 44, 13–21.

Paul, E.A., Clark, F.E., 1996. Soil Microbiology and Biochemistry. Academic Press, New York.

Paul, E. A., Paustian, K. H., Elliott, E. T., & Cole, C. V. (1996). Soil Organic Matter in Temperate AgroecosystemsLong Term Experiments in North America (Vol. 1). CRC Press.

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., & the R Core team (2009). Linear and Nonlinear Mixed Effects Models. R package version 3.

Power, A. G. (2010). Ecosystem services and agriculture: tradeoffs and synergies. Philosophical Transactions of the Royal Society B: Biological Sciences, 365, 2959–2971.

Powlson D.S., Gregory P.J., Whalley W.R., Quinton J.N., Hopkins D.W., Whitmore A. P., Hirsch P.R., Goulding K.W.T. (2011). Soil management in relation to sustainable agriculture and ecosystem services.

Ramakrishnan, P.S., 1992. Shifting Agriculture and Sustainable Development: An Interdisciplinary Study from North-Eastern India. Parthenon Publishing Group, Park Ridge, NJ.

Ratcliffe, B.C., 1970. Scarab Beetles. Dung Feeders, Jeweled Pollinations, and Horned Giants, vol. 59. University of Nebraska News, pp. 1–4.

Rusch, A., Bommarco, R., Jonsson, M., Smith, H. G., & Ekbom, B. (2013). Flow and stability of natural pest control services depend on complexity and crop rotation at the landscape scale. Journal of Applied Ecology, 50, 345–354.

Schellhorn, N. A., & Sork, V. L. (1997). The impact of weed diversity on insect population dynamics and crop yield in collards, *Brassica oleraceae* (Brassicaceae). Oecologia, 111, 233–40.

Soane, B. D., Ball, B. C., Arvidsson, J., Basch, G., Moreno, F., & Roger-Estrade, J. (2012). No-till in northern, western and south-western Europe: a review of problems and opportunities for crop production and the environment. Soil and Tillage Research, 118, 66–87.

Soltner D. (1988). Le bases de la production vegetale. Tome 1: le sol. 16 editione.

Stoller, E.W., Harrison, S.K., Wax, L.M., Regnier, E.E., Nafziger, E.D., 1987. Weed interference in soybeans (Glycine max). Reviews of Weed Science 3, 155–181 (1987).

Swinton, S. M., Lupi, F., Robertson, G. P., & Hamilton, S. K. (2007). Ecosystem services and agriculture: cultivating agricultural ecosystems for diverse benefits. Ecological Economics, 64, 245–252.

Tabatabaeefar, A., Emamzadeh, H., Ghasemi Varnamkhasti, M., Rahimizadeh, R., & Karimi, M. (2009). Comparison of energy of tillage systems in wheat production. Energy 34, 41–45.

Tamburini G., De Simone S., Sigura M., Boscutti F., Marini L., (2015). Conservation tillage enhances natural pest control in winter cereal crops, 73-78.

Tansley A.G. (1935). The Use and Abuse of Vegetational Concepts and Terms. Ecology, Vol. 16, No. 3 (Jul., 1935), pp. 284-307. Published by: Ecological Society of America. Stable URL: http://www.jstor.org/stable/1930070

TEEB – The Economics of Ecosystems and Biodiversity: Ecosystem Services. http://www.teebweb.org/resources/ecosystem-services/

Tilman, D., Fargione, J., Wolff, B., et al. (2001). Forecasting agriculturally driven global environmental change. Science, 292, 281–284.

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences of the USA, 108, 20260–20264.

Thomas, M.B., 1999. Ecological approaches and the development of “truly integrated” pest management. Proceedings of the National Academy of Sciences of the United States of America 96, 5944–5951.

Tolimir, M., Veskovic, M., Komljenovic, I., Djalovic, I., & Stipesevic, B. (2006). Influences of soil tillage and fertilization on maize yield and weed infestation. Cereal research communications 34, 323–326.

Tscharntke T., Alexandra M. Klein, Andreas Kruess, Ingolf, Steffan-Dewenter and Carsten Thies (2005). Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecology letters, (2005) 8: 857–87.

United Nations, 1992. United Nations Framework Convention on Climate Change. FCCC/INFORMAL/84. GE.05-62220 (E) 200705.

Werling, B. P., Dickson, T. L., et al. (2014). Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. Proceedings of the National Academy of Sciences of the USA, 111, 1652– 1657.

Wilby, A., Thomas, M.B., 2002. Natural enemy diversity and pest control: patterns of pest emergence with agricultural intensification. Ecology Letters 5, 353–360.

Wilkinson, T.K., Landis, D.A., 2005. Habitat diversification in biological control: The role of plant resources. In: Wackers, F.L., van Rijn, P.C.J., Bruin, J. (Eds.), Plant Provided Food and Plant–Carnivore Mutualism. Cambridge University Press, Cambridge, U.K.

Winqvist, C., Bengtsson, J., Aavik, T., et al. (2011). Mixed effects of organic farming and landscape complexity on farmland biodiversity and biological control potential across Europe. Journal of Applied Ecology, 48, 570–579.

Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., & Swinton, S. M. (2007). Ecosystem services and dis-services to agriculture. Ecological Economics, 64, 253–260.