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Viewpoint

The role of supporting ecosystem services in conventional and organic arable farmland

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ABSTRACT

Ecosystem services (ES) in agriculture are vital for the sustainable supply of food and fibre, but their economic value has rarely been evaluated in agricultural crops at field level. The current study quantified three key supporting ES associated with highly modified arable landscapes in New Zealand using a novel, experimental 'bottom-up' approach. These services were biological control of pests, soil formation and the mineralisation of plant nutrients. The results showed that background (unmanipulated) biological control of pests in conventional arable farming were severely and significantly reduced compared with fields under organic management. ES associated with soil formation and mineralisation of plant nutrients did not differ significantly between organic and conventional fields. This study also estimated the economic value of these services using experimental data, in contrast with 'value transfer' approaches used in previous studies. The total economic value of these three ES was significantly higher in organic fields as compared to conventional ones. Yields obtained in organic fields were similar to those in conventional ones. This work quantified the role that land management practices play in the maintenance and enhancement of supporting ES in agricultural land and showed that conventional New Zealand arable farming practices can severely reduce the ecological and financial contribution of some of these services in agriculture.

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1. Introduction

Natural and modified ecosystems support human life through ecosystem services (ES) or nature's services (Daily, 1997). These are the life-support systems of the planet (Myers, 1996; Daily, 1997; Daily et al., 1997) and it is evident that human life cannot exist without them. However, human activity is rapidly changing the ability of ecosystems to provide ES (Naeem et al., 1997; Kremen, 2005; Reid et al., 2005). Natural landscapes have been substantially altered by humans to derive more and different benefits from ecosystems (Daily, 1997; Vitousek et al., 1997; Palmer et al., 2004). The expansion and intensification of agriculture have contributed to the provision of food and fibre for the growing world population but have led to a change in the ability of ecosystems to provide ES (Matson et al., 1997; Tilman, 1999). Modern agriculture is feeding more than six billion people worldwide (but with 800 million under-nourished; UN, 2005) but at the same time the 'external costs' of agriculture are of great concern (Pretty et al., 2000; Tegtmeier and Duffy, 2004). Such costs include damage to water, air, soil, biodiversity, landscapes and human health. In the next 50 years, the human population is projected to grow to nine billion and global grain demands will double (Pimentel and Wilson, 2004). The key challenge therefore is to meet the food demands of a growing population by maintaining and enhancing the productivity of agricultural systems without further damaging (and ideally, enhancing) their ES provision (Tilman et al., 2002; Robertson and Swinton, 2005). The need to address the threats to ES is more acute in agriculture than in other ecosystems (Robertson and Swinton, 2005) so that agricultural land can increase the rate at which it provides vital multiple ES in addition to the production of food and fibre.

Key recent work has estimated the value of global ecosystem goods and services (Costanza et al., 1997; de Groot et al., 2002; Millennium Ecosystem Assessment, 2003), generating increased awareness of their classification, description, economic evaluation and enhancement (Gurr et al., 2004). To date, ES value has been assessed using a 'top-down' approach, i.e., the economic value of 17 ES in 16 biomes was calculated by Costanza et al. (1997) to be in the range of US \$16–54 trillion year^{-1}, with an annual mean of US \$33 trillion. This assessment was based on published studies and used 'value transfer' techniques (Wilson

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et al., 2004), supported by a few original calculations. Pimentel et al. (1997) estimated the annual economic and environmental benefits of biodiversity in the world to be about US \$3 trillion year^{-1}, while in New Zealand, Patterson and Cole (1999) calculated the economic value of that country's ES to be US \$26.4 billion for 1994, using value transfer methodology. However, there is a lack of detailed understanding of the ES associated with highly modified or 'engineered'/designed landscapes (Balmford et al., 2002; Robertson and Swinton, 2005). These have been extensively modified by humans explicitly to provide a set of ecosystem goods and services (Heal and Small, 2002; Cullen et al., 2004). In spite of this extensive modification, high potential values of ES have been recognized in arable farming systems (Cullen et al., 2004; Takatsuka et al., 2005) but arable farming has an 'ecological footprint' (Wackernagel and Rees, 1996) as well as being an ES provider.

In contrast with the above evaluations of ES, which used 'value transfer' approaches, the current work assesses three key supporting ES (biological control of pests, soil formation, and the mineralisation of plant nutrients; Sandhu et al., 2007) experimentally. It focuses on one sector of an engineered ecosystem (arable farming) and addresses both conventional and organic systems at a regional scale, attributing economic value (in 2005 US dollars; NZ \$1 = US \$0.7085, http://www.rbnz. govt.nz) to these key supporting ES.

ES associated with farming are classified into four groups (Sandhu et al., 2007) based on their functional characteristics – regulating, provisioning, cultural and supporting services as described in Millennium Assessment (Reid et al., 2005). The supporting services are required to support the production of other ES. In this case they support food, fibre, feed and wood. Key supporting ES associated with arable farmland in New Zealand are described below.

1.1. Biological control of pests

Biological control services provided by pests' natural enemies can prevent outbreaks of pests and stabilise agricultural systems worldwide (Naylor and Ehrlich, 1997). Ninety-nine per cent of the populations of agricultural pests and diseases are controlled by their natural enemies – predators, parasites and pathogens (de Bach, 1974). Such background suppression is of even greater significance in organic agriculture (Anon, 1994) as that system is more dependent on such services to keep pest and other populations low. Intensification of agriculture, with associated habitat destruction, has led to a severe reduction of this ES, which is worth US \$100 billion annually in cropland worldwide (Pimentel et al., 1997). Severe detrimental effects from increasing pesticide applications in agriculture are well documented. Very high environmental, economic and human health costs of pesticide use occur worldwide (Pimentel et al., 1992; Pretty, 2005).

The process of pest removal by soil-surface predators (one of many natural-enemy guilds; Root, 1967) was assessed in the current work by using real pests and 'prey surrogates' to assess 'predation rate'. This provided information on one subset of biological control carried out by natural enemies in arable farmland, that of soil-surface predation of aphids and eggs of carrot rust fly (*Psila rosae* Fab.), using egg 'surrogates' in the latter case.

Polyphagous predators in arable ecosystems can reduce aphid populations considerably (Vickerman and Wratten, 1979; Chambers et al., 1983; Chiverton, 1986; Lys, 1995; Schmidt et al., 2003). Many of these predators forage mainly on the ground. Their contribution is partly because a high proportion of aphids can fall from the crop canopy (up to 90% per day; Sunderland et al., 1986; Winder, 1990). Also, the exposed position of dipteran pests' eggs at or near the soil surface makes them vulnerable to predation by polyphagous predators (Coaker and Finch, 1971; Jones, 1975; Ryan, 1975) and predators play an important role in the population dynamics of the carrot rust fly (Burn, 1982).

1.2. Soil formation

Soil formation is an important ES provided by soil biota (Breemen and Buurman, 2002). Earthworms are the most important component of the soil biota in this respect and in the maintenance of soil structure and fertility (Lee, 1985; Stockdill, 1982; Edwards, 2004). Their activities bring up sub-surface soil (between 10 and 500 tonnes ha^{-1} year^{-1}), providing nutrients in the plant root zone and aiding the formation of approximately 1 tonne ha^{-1} year^{-1} of topsoil (Pimentel et al., 1995).

1.3. Mineralisation of plant nutrients

Organic matter breakdown by soil micro-organisms and invertebrates (Parkinson and Coleman, 1991; Brady and Weil, 2004) is one of the most important services provided by soil. Through decomposition, plant residues are broken down, releasing previously organically bound nutrients such as nitrogen for use by plants (Coleman et al., 1984; Edwards and Arancon, 2004).

The overall aim of this work was to assess the effects of arable farming on the provisions of key supporting ES under conventional and organic production systems in New Zealand.

2. Materials and methods

2.1. Study sites

The province of Canterbury is the major arable area of New Zealand. There are 10,000 farms with a total farmed area of 3,150,891 ha, of which 205,724 ha is under arable and fodder crops and fallow land, comprising 2900 farms (Statistics New Zealand, 2003). The remainder consists of land in horticulture, grasslands, forest plantation, etc.

Twenty-nine arable fields were selected in September 2004, distributed over the Canterbury Plains and comprised 14 organic and 15 conventional fields with a mean area of 10 ha. Of the 14 organic fields, seven were certified by AgriQuality, New Zealand (http://www.agriquality.co.nz) and seven by BIO-GRO, New Zealand (Anon, 1994). Both certifiers are accredited with IFOAM, the International Federation of Organic Agriculture Movements (http://www.ifoam.org).

A list of arable farmers in Canterbury was obtained from the Foundation for Arable Research, Lincoln (http://www.far.org.nz) and OPENZ (Organic Products Exporters of New Zealand; http://www.organicsnewzealand.org.nz) provided the contacts for all organic farmers. The latter were contacted first by a letter, followed by a telephone call and a meeting to collect detailed information about the farming practices and the crops grown, as well as soil type, crop rotation practices, etc. (Table 1). Arable organic farms were selected from the above list, one to three fields being selected per farm based on there being an arable crop grown at the time of the survey. After this, conventional arable farms that were within 5 km of the organic fields were contacted. The latter were selected because they were growing similar crops and had similar soil types. The crops were wheat, barley, carrots for seed, process peas, field beans, white clover for seed and onions (Table 1). The number of conventional and organic fields in each of those crops was the same. The 29th field (conventional) was in peas. Codes O1–O14 were assigned to the organic fields and C1–C15 to the conventional ones.

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