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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.

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.

Table 1
Cropping history, current yield, current value of the crop, total carbon, total nitrogen, pH and bulk density in organic and conventional fields. Organic fields (O1–O14) and conventional fields (C1–C15).

Field type	Cropping history								
	2002–03	2003–04	2004–05	Current yield (tonnes ha^{-1})	Value (US \$ ha^{-1})	pH	Volume weight (g ml^{-1})	Total carbon (%)	Total nitrogen (%)
O1	Pasture	White clover	Peas	3.70	1820	5.8	1.02	2.5	0.25
O2	Pasture	Wheat	Beans	16.70	2800	5.8	0.93	3.2	0.32
O3	Wheat	Rape	Wheat	5.00	3500	6.2	0.95	3.4	0.34
O4	Linseed	Wheat	Carrot seed	0.65	8750	5.7	1.02	2.5	0.25
O5	Linseed	Barley	White clover	0.30	1680	6.2	0.99	2.7	0.25
O6	Wheat	Pasture	Onion	27.00	18,900	5.9	0.99	2.7	0.27
O7	Pasture	Wheat	Peas	3.50	1155	6	0.96	3.1	0.31
O8	Beans	Pasture	Wheat	3.80	1645	6	1.00	2.6	0.26
O9	Wheat	Pasture	Carrot seed	0.50	7000	6.2	1.02	2.8	0.27
O10	Pasture	Wheat	Peas	6.00	1680	6	0.97	2.8	0.27
O11	Linseed	Peas	Wheat	6.00	2100	6.3	1.01	2.4	0.23
O12	Pasture	Linseed	Barley	5.00	1750	6.2	1.00	2.4	0.21
O13	Pasture	Wheat	Peas	6.50	1799	5.8	0.99	3.0	0.29
O14	Beans	Pasture	Barley	4.00	1176	6.2	1.03	2.6	0.25
C1	Barley	Wheat	Peas	4.00	1995	6.3	0.92	3.0	0.31
C2	Wheat	Pasture	Beans	16.70	2380	5.5	1.08	2.1	0.2
C3	Barley	Pasture	Wheat	11.00	1925	5.7	0.96	3.0	0.28
C4	Peas	Wheat	Carrot seed	0.65	7787	5.9	1.01	2.7	0.25
C5	Oats	Wheat	White clover	0.50	1925	6.4	1.03	2.4	0.23
C6	Pasture	Wheat	Onions	30.00	14,000	5.3	1.01	2.9	0.26
C7	Barley	Wheat	Peas	3.60	1764	5.9	1.02	2.8	0.25
C8	Pasture	Barley	Wheat	10.00	1820	6.2	0.96	3.0	0.3
C9	Wheat	Beans	Carrot seed	0.60	7350	6.2	1.05	2.3	0.22
C10	Barley	Wheat	Peas	5.00	1120	5.7	0.94	3.1	0.3
C11	Barley	Pasture	Wheat	7.50	1312	6	0.98	2.5	0.24
C12	Pasture	Wheat	Barley	8.50	1487	6	0.98	2.8	0.27
C13	Pasture	Oats	Peas	4.50	945	6	0.98	3.1	0.31
C14	Rape	Wheat	Barley	8.70	1610	6.4	1.02	3.0	0.29
C15	Barley	Wheat	Peas	4.50	812	5.9	1.08	2.6	0.23

All fields were marked using GARMIN GPS 12XL by taking GPS readings at the four corners of each field. The fields were mapped by using ArcGIS 9 and are shown in Fig. 1.

2.2. Predation rate of aphids and fly eggs and its economic value

Aphids in many arable crops and the carrot rust fly (*P. rosae* Fab.) in carrots are important pests in Canterbury, New Zealand and elsewhere. Live pea aphids (*Acyrthosiphon pisum* Harris) were used and frozen eggs of the blowfly (*Calliphora vicina* R.D.) simulated carrot rust fly eggs. Predation of these two prey types was assessed in selected fields in January 2005. Aphid- and carrot fly-infested fields were not selected or used in this study. Predation experiments were carried out before any scheduled pesticide spray event to avoid any effect in conventional fields. Two prey densities for each prey type were assessed. The aphid densities were 4/25 and 10/25 cm^2 based on previous studies in arable land (Ekbom et al., 1992; Winder, 1990; Winder et al., 1994). Two densities of blowfly eggs were used, based on the literature on the abundance of carrot rust fly egg populations. Published egg densities are in the range of 3–8/25 cm^2 (Burn, 1982) in the field.

Predation rate was assessed using ‘prey surrogates’ comprising 25 cm^2 waterproof sandpaper squares pinned to the soil surface by wooden toothpicks (Merfield et al., 2004; Frank et al., 2007). Live aphids (dorsal side uppermost) were glued onto the sandpaper (P150, Norton) using 3 M repositionable glue in a grid pattern with 1 cm between aphids. The blowfly eggs were not glued onto the surface but were placed in a similar pattern. The sandpaper sheets were pinned at the field boundary, the field centre and midway between the two in two transects (5 m apart) in each field and had a 225 cm^2 metal plate supported 10 cm above to protect them from rain.

Predation rate was calculated from the removal of ‘prey’ types per 24 h period. At each site, each type of ‘prey’ at both densities (minimum and maximum) were positioned 1m apart at the locations described above. For each prey type, overall mean prey disappearance was calculated separately from the means of the two prey densities. Predation rate (%removal/24 h) was required per field to calculate the economic value of biological control of aphids and carrot rust fly. Therefore, mean of all the locations was used to get a representative rate of predation per field. This rate of predation was used to estimate the economic value of biological control (Fig. 2).

The economic value of this ‘background’ (i.e., unmanipulated) biological control of aphids and carrot rust fly was estimated by using avoided cost (AC) (de Groot et al., 2002; Wilson et al., 2004) of pesticides, based on their cost in New Zealand (conventional farmers’ spending to control aphids; Chapman, 2004), and total avoided cost (TAC) of pesticides, which includes US \$61.00 ha^{-1} year^{-1} as the external cost of pesticides (Pretty et al., 2000). UK data were used for the latter as appropriate data are not available in New Zealand. The mean costs of pesticides used on Canterbury, New Zealand arable farms to control aphids and carrot fly are US \$35.00 and US \$30.00 ha^{-1} application^{-1}, respectively. Also, US \$10.50 ha^{-1} is spent as an application cost for each pest.

The economic estimates of the value of ‘background’ predation presented here are based on an ‘instantaneous’ (24 h) assessment of a complex predation process but economic results based on TAC are provided on a ha^{-1} year^{-1} basis. Conventional farmers should use pesticides only to reduce pest populations below economic thresholds. It is assumed in this study that when the instantaneous reduction of pest numbers by soil-surface predators over 24 h reduces the population below the economic threshold level, then this is equivalent to one effective pesticide application.

To calculate the economic value of aphid predation, three densities (with equal probability of occurrence) were used. These were: density 1 (d1: 10 aphids/25 cm^2, maximum density used in

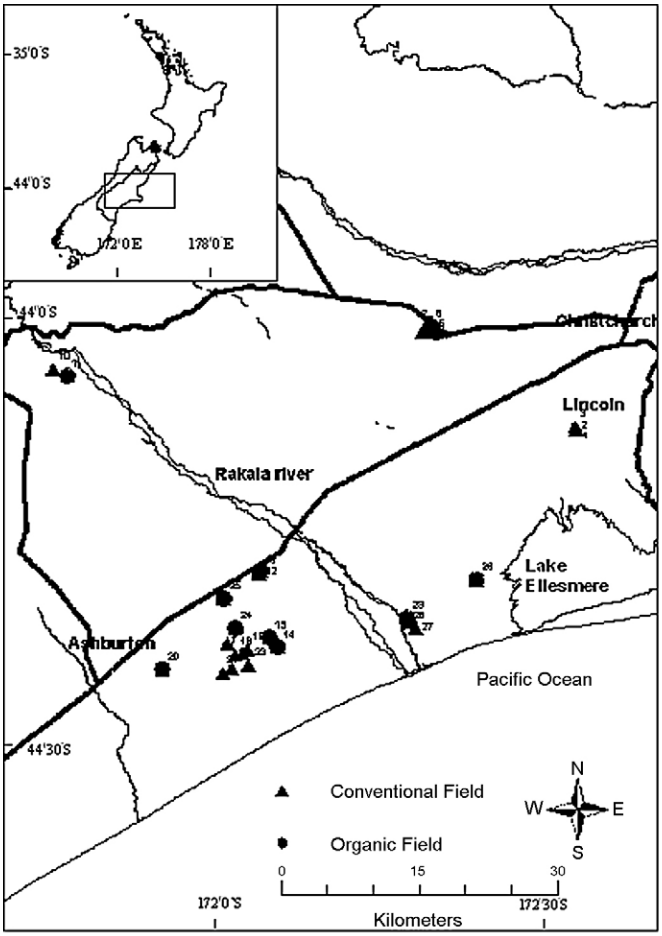

Fig. 1. Map of New Zealand showing the study area (selected fields).

the predation work), density 2 (d2: 7.5 aphids/25 cm^2) and density 3 (d3: 6.25 aphids/25 cm^2). Densities 2 and 3 are between the economic threshold and the maximum density used in the predation work. The economic threshold was based on the work by Thies et al. (2004). These authors gave an economic threshold for 3–5 aphids per shoot for *Sitobion avenae*, *Metopolophium dirhodum* and *Rhopalosiphum padi* in wheat fields. This is converted here to a unit-area measure, giving an economic threshold of five aphids/25 cm^2 based on numbers of shoots per unit-area (McCloy, 2004). For each of the three densities (d1, d2 and d3), the number of aphids consumed by the soil-surface predators (based on predation rate in that field) was estimated.

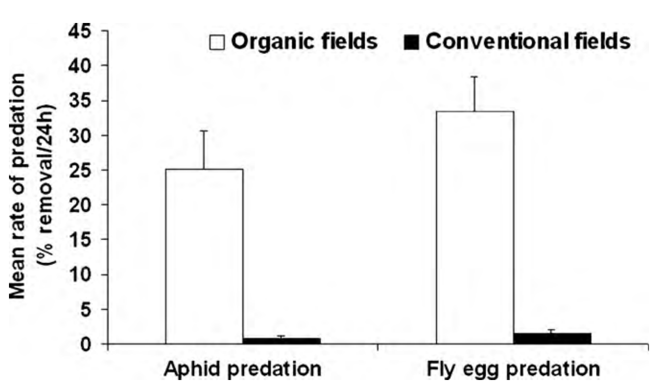

Fig. 2. Mean rate of predation (%removal/24 h) of aphids and blowfly eggs in organic and conventional fields. Error bars are 0.5 SE. Predation rates of aphids ($p < 0.001$). Predation rates of blowfly eggs ($p < 0.001$).

For the carrot rust fly, an economic threshold based on egg densities is not available; this is not surprising, as assessing these densities is technically very demanding (Burn, 1984). Therefore, three economic thresholds (ET1: 6.25 eggs/25 cm^2, ET2: 5 eggs/25 cm^2, ET3: 3.75 eggs/25 cm^2) within the published densities used in this predation work with equal probability of occurrence were simulated. In each field, predation rates were used to estimate the decrease in pest populations below the simulated economic thresholds.

The economic value based on TAC was assigned to the fields in which predation rate was able to bring the pest population below the economic threshold.

2.3. Earthworm populations and their economic value in soil formation

Earthworm populations were assessed to estimate the quantity of soil formed ha^{-1} $year^{-1}$. Sampling was done during the spring as earthworm populations are generally highest at this time in New Zealand (Martin, 1978). Four 25 cm^3 soil samples were taken from each field using a spade avoiding field edges and double cultivation areas (Beare et al., 2001). The soil was spread on a 2 m^2 polythene sheet and earthworms were extracted by hand and their number was recorded.

The economic value of earthworms in soil formation was calculated based on the assumptions that the mean biomass of an earthworm is 0.2 g (Fraser et al., 1996) and that one tonne of earthworms forms 1000 kg of soil ha^{-1} $year^{-1}$ (Pimentel et al., 1995). The value of farmland includes the contribution made by the value of its topsoil, which in New Zealand is US \$23.60 $tonnes^{-1}$ (City Care, 2005).

2.4. Mineralisation of plant nutrients and its economic value

Mineralisation of plant nutrients was assessed in 29 fields using bait-lamina probes (Kratz, 1998; Torne, 1990). Those used here were made in a workshop and were 16 cm long, 0.6 cm broad and 1 mm thick strips of rigid plastic with sixteen 2 mm holes (Helling et al., 1998). These are filled with gel comprising by weight cellulose (65%), agar-agar (15%), bentonite (10%) and wheat bran (10%) that matches to some extent the key constituents of dead plant material on or in the soil (Weil and Magdoff, 2004). They were inserted into the soil at the same locations as the predation facsimiles described above. The probes were left in the ground for 10 days in January 2005. Soil micro-organisms and invertebrates consume the 'bait' and the number of holes that are empty (partially or fully) gives a relative measure of the rate of mineralisation (Kratz, 1998):

$$N_{min} = nb10^{-3}\ \text{kg} \quad (1)$$

where N_{min} = amount of nitrogen mineralised; n = total amount of nitrogen (%) in soil; b = bulk density of soil ($g\ cm^{-3}$); v = volume of soil (cm^3); k = percentage mineralisation (%).

In this study, the economic value of plant nutrient mineralisation provided by soil micro-organisms and invertebrates is assessed using data on mineralisation of organic matter obtained from field experiments. Total organic matter content in the fields was estimated using the total weight of soil (obtained from bulk density at 10 cm depth) and total nitrogen obtained from soil testing results. It was based on the assumptions that the ratio of organic matter to nitrogen is 20:1 (Brady, 1990). The amount of organic matter mineralised in each field was calculated from this by using nutrient mineralisation rate from the bait-lamina probes. The total amount of nitrogen mineralised was estimated from Eq. (2) and valued at the equivalent price of N kg^{-1} (US \$0.84 kg^{-1}; Ravensdown, 2005) providing the economic value of nutrient mineralisation.

2.5. Statistical analysis

Statistical analyses were carried out using SPSS version 15.0.1. Predation rate, number of earthworms and rate of mineralisation, economic value and yield data in organic and conventional fields was compared using a *t*-test for unequal sample variances.

2.6. Total economic value

Economic value of three ES (in 2005 US dollars; NZ \$1 = US \$0.7085, http://www.rbnz.govt.nz/keygraphs/graphdata.xls) was calculated for each of the 14 organic and 15 conventional fields. Total economic value of ES for each field was calculated by summing the total of all the individual ES values measured. These were: biological control of pests, ES_1; soil formation, ES_2; mineralisation of plant nutrients, ES_3; (Eq. (2)) which will be detailed on the following pages:

$$ES_{\text{total}} = \sum ES_n = \sum ES_{1-3} \quad (2)$$

These ES are usually not traded in market and are considered as non-marketed ES (Sandhu et al., 2008). Marketed ES from agriculture comprise of marketable produce (grains, seed etc) and its farm gate value is recorded for each field in this study.

3. Results

3.1. Predation rate of aphids and blowfly eggs and its economic value

The aphids removed in 24 h ranged from 4.7 to 48.8.0% in organic fields and 0–5.9% in conventional fields (Fig. 3). The blowfly eggs removed in 24 h ranged from 11 to 50.0% in organic fields and 0–6% in conventional fields (Fig. 4).

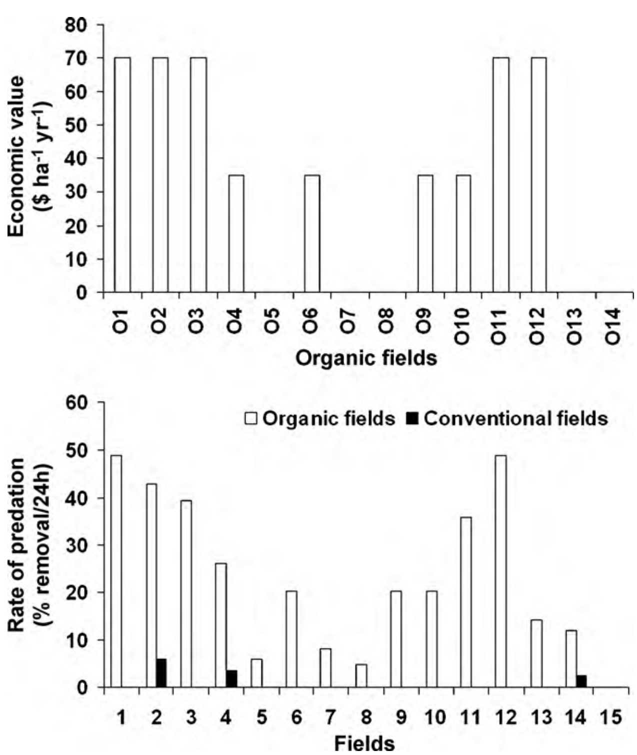

Fig. 3. Predation rates and economic value of biological control of aphids in organic fields. Total avoided cost includes external cost (see Section 2). In five organic and all conventional fields, predation rate was so low that total avoided costs could not be calculated (see text).

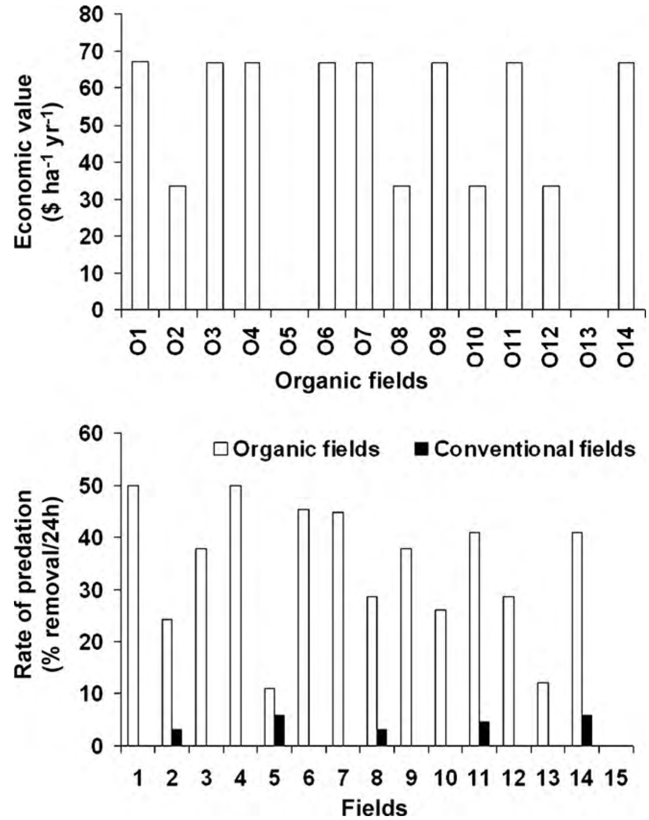

Fig. 4. Predation rates and economic value of biological control of carrot rust fly in organic fields. Total avoided cost includes external cost (see Section 2). In two organic and all conventional fields, predation rate was so low that total avoided costs could not be calculated (see text).

Predation rate of aphids and blowfly eggs in organic fields was compared with that in conventional fields using *t*-test for unequal sample variances (Fig. 2). Predation rate of aphids was significantly higher in organic fields than in the conventional ones ($p < 0.001$). That of blowfly eggs was also significantly higher ($p < 0.001$) in organic fields than the conventional ones.

The economic value of the biological control of aphids was in the range of US \$35.00–70.00 ha^{-1} $year^{-1}$ (TAC; mean US \$35.00) in nine organic fields (O1, O2, O3, O4, O6, O9, O10, O11, O12) (Fig. 3). Predation in the remaining fields did not have any economic value, as the rate was too low to bring the pest population below economic threshold level. The economic value of biological control of the carrot rust fly was estimated to be in the range of US \$33.00–67.00 ha^{-1} $year^{-1}$ (TAC; US \$47.00) all the organic fields except O5 and O13 (Fig. 4). None of the conventional fields demonstrated any economic value of biological control at any population density or threshold level, due to extremely low predation rates.

3.2. Earthworm populations and their economic value in soil formation

The range of earthworm population densities in organic fields was 12–244 m^{-2} (mean 132 m^{-2}) and 36–184 m^{-2} (mean 99 m^{-2}) in conventional fields (Fig. 5). There were no significant differences between organic and conventional fields. From the assumptions and economic information in Section 2.3 above, the value of soil formation was calculated (Fig. 5). It was in the range of US \$0.60–11.60 ha^{-1} $year^{-1}$ (mean US \$6.00 ha^{-1} $year^{-1}$) in organic fields and US \$1.70–8.75 ha^{-1} $year^{-1}$ (mean US \$4.75 ha^{-1} $year^{-1}$) in conventional fields.

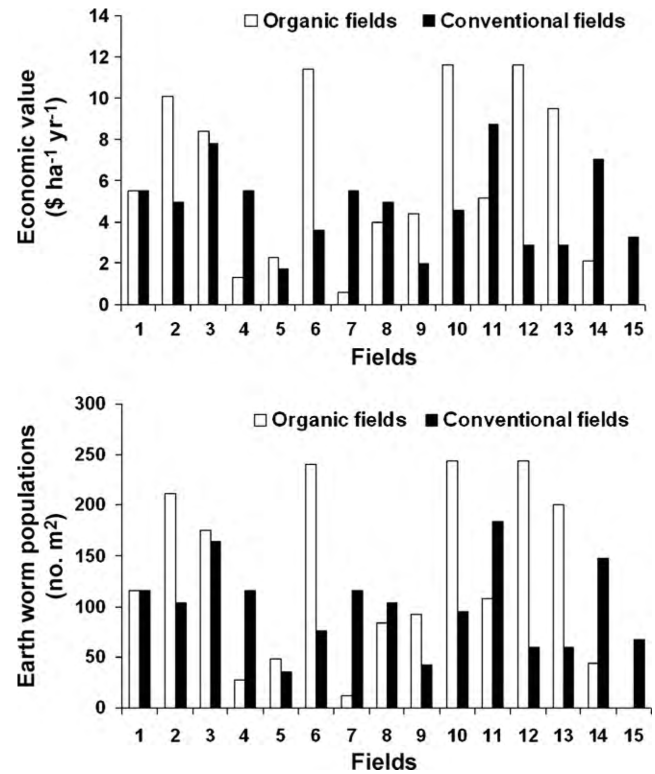

Fig. 5. Earthworm populations (no. m^{-2}) and their economic value in soil formation (\$ ha^{-1} $year^{-1}$) in organic and conventional fields.

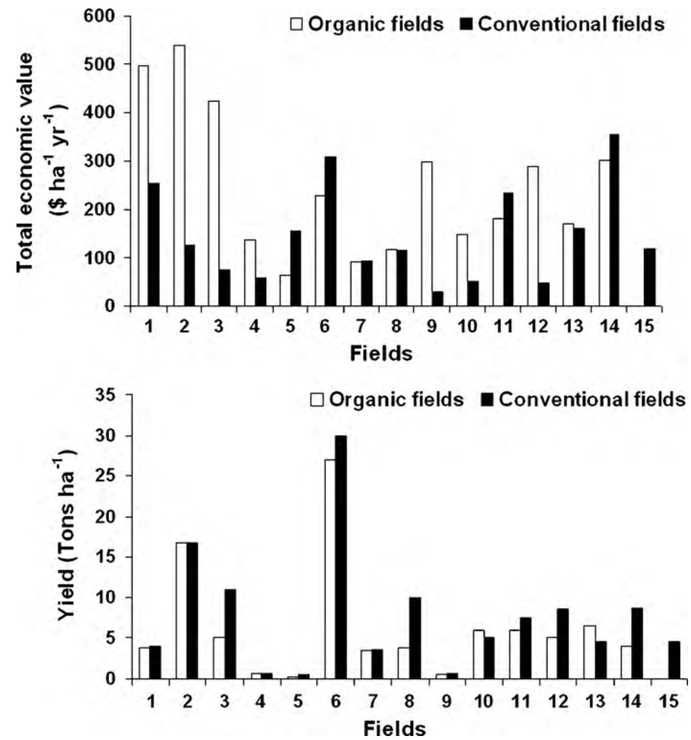

Fig. 7. Total economic value of three ES in organic and conventional fields. Yield figures in organic and conventional fields are also presented.

3.3. Mineralisation of plant nutrients and its economic value

The mean rate of mineralisation was calculated as the mean removal of baits and is given in Fig. 6. The extent of removal in organic fields was 1.04–17.18% (mean 7.1%) and 1.56–14.06% (mean 6.3%) in conventional ones. There were no significant differences between organic and conventional fields. The range in mineralisation was from US \$25.00 to 425.50 ha^{-1} $year^{-1}$ (mean US \$160.00 ha^{-1} $year^{-1}$) in organic fields and US \$30.00–348.00 ha^{-1} $year^{-1}$ (mean US \$142.00 ha^{-1} $year^{-1}$) in conventional ones (Fig. 6).

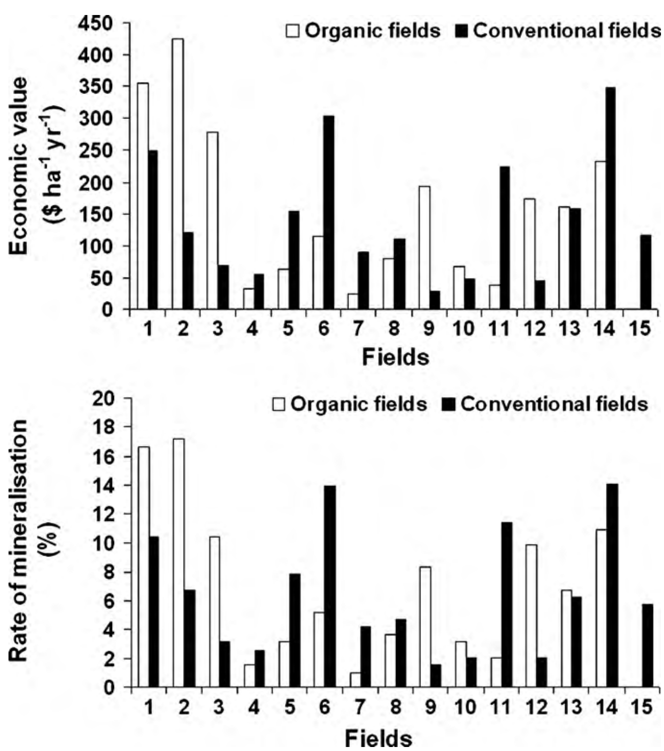

Fig. 6. Mineralisation of plant nutrients (mean %removal of bait) using bait-lamina probes and its economic value (\$ ha^{-1} $year^{-1}$) in organic and conventional fields.

3.4. Total economic value

The total economic value for organic fields was in the range of US \$66–538.00 ha^{-1} $year^{-1}$ (mean US \$232.00 ha^{-1} $year^{-1}$) and US \$31–355.00 ha^{-1} $year^{-1}$ (mean US \$146.00 ha^{-1} $year^{-1}$) in conventional ones (Fig. 7). Total economic value was significantly higher in organic fields as compared to conventional ones ($p < 0.05$). Range of yields was from 0.30 to 27 tonnes ha^{-1} (mean 6.33 tonnes ha^{-1}) in organic fields and 0.50–30 tonnes ha^{-1} (mean 7.70 tonnes ha^{-1}) in conventional ones (Fig. 7). There was no significant difference between the yields under two different production systems. Marketed value of produce from each field is provided in Table 1.

4. Discussion

This study was designed to assess the role of key ES in arable farmland in New Zealand using experimental assessment in contrast to 'value transfer' approaches used in earlier studies. It also provides the economic value of each of these ES and compares two land management practices. Experimental assessment of ES presented here provides a snapshot in time and economic valuation is based on assumptions described in Section 2 above. As more and better methods are available, better estimates of economic value of ES can be obtained.

Conventional arable farming can suppress the ability of farmland to provide biological control ES. Conventional farmers use pesticides whereas organic farmers depend to a greater extent upon natural pest control services to keep pest populations below economic threshold levels. It is not economical to spray below these threshold levels; therefore in this study the economic values were estimated only for the fields where natural pest control was able to keep the pest population below the threshold. Every year, tonnes of pesticides worth billions of dollars are used in agriculture worldwide (Pretty, 2005), resulting in high external and economic costs. It was demonstrated in field experiments in the current work that the biological control service provided by soil-surface predators is highly effective and has high value in organic fields in the absence of most pesticides.

There is evidence that ground-level predation in some crops can reduce pest populations to such an extent that a yield increase results (Östman et al., 2003). The level of biological control estimated in this study is based on only one of the many ecological guilds of predators and parasitoids which are potentially active in crops, so the potential total value of biological control in arable fields is likely to be very high compared with the minimal values presented here. The predation rates recorded in this study using 'prey surrogates' provided useful estimates of the phenomenon of predation, given that using living, mobile prey is technically very difficult. Absolute rates of predation calculated here may not accurately reflect real field rates. However, they do provide a useful comparative measure (Merfield et al., 2004; Frank et al., 2007). These predation rates were used to estimate the economic value of biological control of aphids and carrot rust fly. With the significantly higher predation rates in organic fields (Fig. 2), biological control of pests services provided by polyphagous predators could be an important factor for pest control in arable fields in New Zealand. However, there is a risk due to high reliance on natural biological control during unfavourable climatic conditions. The 'bottom-up' approach used in the current work demonstrates experimentally that conventional agricultural practices can suppress biological control, which is often assumed but rarely demonstrated using the methods employed here. Although such ES are declining world wide (Reid et al., 2005), ecological techniques are increasingly becoming available for 'ecological engineering' to be used to remediate such decline in ES (Gurr et al., 2004).

Soil formation by earthworms is another key ES which plays a vital role in maintaining the structure and fertility of the soil. Higher populations of earthworms in agriculture can be maintained or enhanced by practising conservation agriculture (Curry, 2004). This ES, which has high potential value, is damaged due to intensive arable farming (which can be conventional or organic) and is at high risk of being reduced in future if the same trend continues. However, in this work no significant difference was found between earthworm populations in organic and conventional fields. This could be due to gradual accumulation of organic material in organic fields after conversion (Reganold et al., 1993). Earthworms are more responsive to organic matter content and it takes a number of years to accumulate enough to be able to show differences in earthworm density due to management practices.

Mineralisation of plant nutrients by soil biota is also an important ES (Tate and Rogers, 2002) and its economic value for organic and conventional fields is estimated in the current study. Mineralisation in this study is translated into nitrogen availability. However, it is important to note that conventional fields do not utilise this nitrogen as it leads to oversupply due to additional fertiliser application. Whereas organic fields depend on this natural process to meet the nutritional requirements by crops. Soil microbial biomass increases significantly under no-tillage systems compared with conventional tillage (Andrade De Souza et al., 2003), although there were no significant organic/conventional differences in the current work. This is not surprising, as weed control in organic systems is often a major technical challenge (Stonehouse et al., 1996; Barberi, 2002) and the mechanical methods which are often used can reduce soil carbon levels (Russell and Williams, 1982; Grace et al., 1995; Heenan et al., 1995; Sherrod et al., 2005) and potentially nutrient mineralisation. Improving soil mineralisation through the addition of prepared mulches or by mulching cover crops can dramatically improve soil functions, including its ability to reduce populations of crop pathogens, the life cycle of which includes a soil phase (Jacometti et al., 2007). Therefore the ability to mineralise the nutrients available in soil can be increased by adopting no-tillage (or minimum tillage) to enhance this ES (Papini et al., 2002).

The total economic value of three ES estimated in this work was significant higher in organic fields as compared to conventional ones (Fig. 7). At the same time there was no reduction in yields in organic fields in the absence of most of the chemical inputs. Therefore, each of the supporting ES is providing that input in the organic fields to support the provision of food (Sandhu et al., 2008). The challenge of growing more food and maintaining vital ES can be met by adopting such production systems that utilise ES thereby replacing unsustainable inputs. Although benefit cost ratio of organic and conventional fields was not calculated in this study, but the estimated economic value of non-marketed ES in organic fields represents the benefit to organic producers as they are saving costs on inputs (pesticides and nitrogenous fertilisers in this case). Also there is no significant reduction in yield, therefore, organic agriculture offer better options to maintain production and sustainability (Sandhu et al., 2010). At present, organic practices are adopted on 31 million hectare worldwide and its market is growing at 20% per year (Willer and Yussefi, 2006). It is unlikely that all the farmers will adapt to organic systems despite of its advantages, partly due to variation in soil properties, different climatic zones, market options and also due to concern of weed control (Beveridge and Naylor, 1999) which is perceived as a major hurdle for those thinking of converting (Turner et al., 2007).

5. Conclusion

The current study was designed to assess the effects of arable farming on the provision of supporting ES at the field level. This work demonstrates that the engineered system studied is both a consumer and a provider of three key supporting ES. The economic and ecological benefits of biological control of pests, soil formation by earthworms and the mineralisation of plant nutrients are substantial to farmers as demonstrated in terms of the economic values of these services, which in most cases are not traded in markets (Costanza, 2001; Farber et al., 2002; Kumar, 2005). Rates of ES for biological control were significantly higher in organic fields. Current intensive and high-input agricultural practices appear to affect the ability of these systems to provide some ES, which in the longer term can offset their ability to produce large amounts of food and fibre. The future challenge is to improve the understanding of biological processes and environmental consequences of agricultural intensification, so that they can be managed and enhanced to ensure food production for the growing human population.

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