Quantifying the economic value of ecosystem services on arable farmland: a bottom-up approach

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by

H. S. Sandhu

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For Somy, Zorawar and Sannawar, with love.

"Earth provides sufficient to satisfy everyone's need but not for everyone's greed"

- Mahatma Gandhi

Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Degree of Doctor of Philosophy

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The study concerns the evaluation and quantification of the economic value of ecosystem services (ES) or nature's services in arable farmland. The importance of ES is now very well established and ES have been demonstrated to be of very high economic value (US \$33 trillion yr^{-1}, 1994 US \$) worldwide. However, recent reports, such as the United Nations Millennium Assessment point towards damage being done to these services globally. Intensification of agriculture in the last century has resulted in the substitution of many ES with chemical inputs. This has resulted in some serious detrimental effects which have led to worldwide concerns about the environmental consequences of modern agriculture. Moreover, as the world approaches 'peak oil', so called conventional agriculture may no longer be able to depend as heavily or as easily on oil-derived 'substitution' inputs. Population growth and increasing food demands in the next 50 years also pose great challenges to the sustainability of modern farming practices. This study recognised these challenges and attributed dollar values to nature's services on arable farmland in Canterbury, New Zealand via experimentation and the subsequent integration of ecological and environmental economics techniques. In this study, 19 ecosystem services (biological control of pests, soil formation, mineralisation of plant nutrients, pollination, services provided by shelterbelts and hedges, hydrological flow, aesthetics, carbon accumulation, nitrogen fixation, etc.) were evaluated and quantified on arable farmland using this novel, experimental approach. The total economic value and non-market value (2005 US \$) of ES for the conventional arable area (125,000ha) in Canterbury was \$500 million and \$100 million annually, respectively. If half of the arable area under conventional farming shifted to organic practices, the total economic value of ES would be \$285 million and \$240 million annually for organic and conventional arable area, respectively. In this case, the non-market value of ES for the organic area was \$90 million and that for the conventional area was \$50 million annually. The work showed that conventional New Zealand arable farming practices can severely reduce the financial contribution of some of these services to agriculture whereas organic agricultural practices enhances this economic

value. However, the change in ES as farms convert to organic practices is very slow, as conventional farming practices have reduced these services to a large extent and organic practices are slow to respond to repair them.

This economic valuation will help in redesigning agricultural landscapes using new eco-technologies based on novel and sound ecological knowledge to enhance ES. This will improve farm incomes by replacing unsustainable inputs and by managing natural resources. This helps to ensure long-term sustainability of farms in the face of very rapid human population growth.

Keywords: arable land, avoided cost, economic value, ecosystem services, engineered ecosystems, organic farming.

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Chapter 1 Introduction

Modern agriculture in the last century and currently is the most advanced form of farming that humans have ever practised (Federico, 2005). This has potentially offered to banish hunger. However, at present, the world population is nearly 6.3 billion (with 800 million malnourished; UN, 2005) and is projected to grow to 9 billion by 2050 (Pimentel & Wilson, 2004). All the nations of the world have pledged to achieve Millennium Development Goals by 2015 that include the eradication of hunger (UN, 2005).

Modern agriculture made it possible to grow more food per unit area. However, these practices made agriculture a major driver of land use change (Vitousek *et al.*, 1997; Goldewijk & Ramankutty, 2004; UNEP, 2005), leading to environmental damage and loss of ecosystem services (ES) (Heywood, 1995; Costanza et al., 1997; Daily, 1997; Krebs *et al.*, 1999; Tilman *et al.*, 2001). The current trends, if continued unabated, threaten to alter radically not only the capabilities to produce food and fibre but also the delivery of ES by these 'engineered ecosystems' (Pretty, 2002). ES are the benefits people obtain either directly or indirectly from functioning ecological systems (Daily, 1997; Millennium Ecosystem Assessment, 2003; Reid *et al.*, 2005). They include products such as food, fuel, and fiber; regulating services such as climate and water regulation and flood control; and nonmaterial assets such as recreational or aesthetic benefits (de Groot *et al.*, 2002). These nature's services or ES support life on earth through a wide range of processes and functions (Myers, 1996; Daily, 1997; Daily *et al.*, 1997).

The above global trends have led to world-wide concerns about the environmental consequences of modern agriculture (Reid *et al.*, 2005). There is also an additional concern that as the world approaches 'peak oil', agriculture may no longer be able to depend so heavily on oil-derived 'substitution' inputs (Pimentel & Giampietro, 1994). Such a grave situation does not detract from the responsibility of agriculture to meet the food demands of a growing population but it does question its ability to increase yields without further ecosystem damage (Escudero, 1998; Tilman, 1999; Pimentel & Wilson, 2004).

The key challenge is to meet the food demands of a growing population and yet maintain and enhance the productivity of agricultural systems (UN, 1992). There is therefore currently an increasing interest in the services provided by nature. As the economic value of the direct and indirect benefits of ES are substantial (Costanza *et al.*, 1997; Daily *et al.*, 1997; Sandhu *et al.*, 2005), there is growing awareness of the importance of the utilization of these services for the long-term sustainability of agro-ecosystems and their ability to provide increased production while maintaining ES (Pretty & Hine, 2001; Gurr *et al.*, 2004).

1.1 Background to the current work

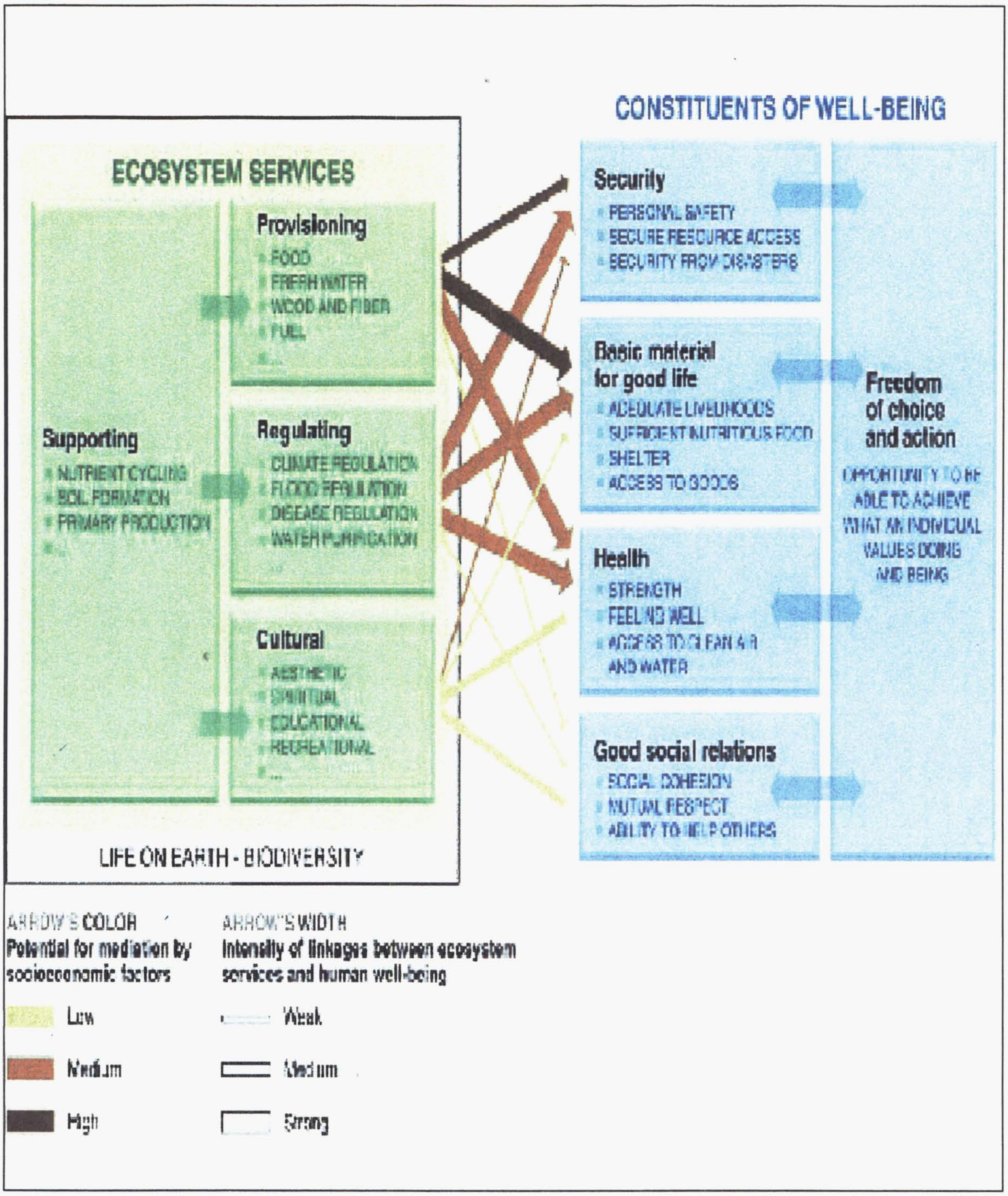
It is currently recognized that not only natural but also modified ecosystems significantly impact the delivery of ecosystem goods and services that contribute to human welfare (Palmer *et. al.*, 2004; Farber *et. al.*, 2006). In recent years, the concept of ES has gained wide acceptance within the international scientific community (Costanza *et al.*, 1997; Daily, 1997; Tilman *et al.*, 2002; Palmer et al., 2004; Robertson & Swinton, 2005). Extensive international peer review resulted in the adoption of the ES concept by the United Nations' sponsored Millennium Ecosystem Assessment (MA) program (www.millenniumassessement.org). It was designed to meet the needs of decision makers and the public for scientific information concerning the consequences of ecosystem change for human well-being and options for responding to those changes (Figures 1.1 and 1.2).

The ES framework used in this work synthesizes important ecological and economic concepts, so farmers, business leaders and environmental decision makers can use to classify and evaluate potential economic costs and benefits associated with different arable land management practices and evaluate potential remediation efforts.

The focus of this study is on one sector of an engineered ecosystem (arable farming) and since the province of Canterbury is the major arable area in New Zealand, this work addresses and quantifies the economic value of ES in both conventional and organic systems in Canterbury (more details in section 1.4).

1.2 New Zealand agriculture

New Zealand is situated in the temperate zone of the Southern Hemisphere. Its landforms are mainly mountainous and hilly. The total land area is 270,500 sq km (www.stats.govt.nz). About 24% of that land area is covered in natural forest. Approximately 118,130 sq km is used for agriculture and horticulture while a further 1,835 km^2 is planted with exotic timber species.



(Source: Reid *et al.*, 2005)

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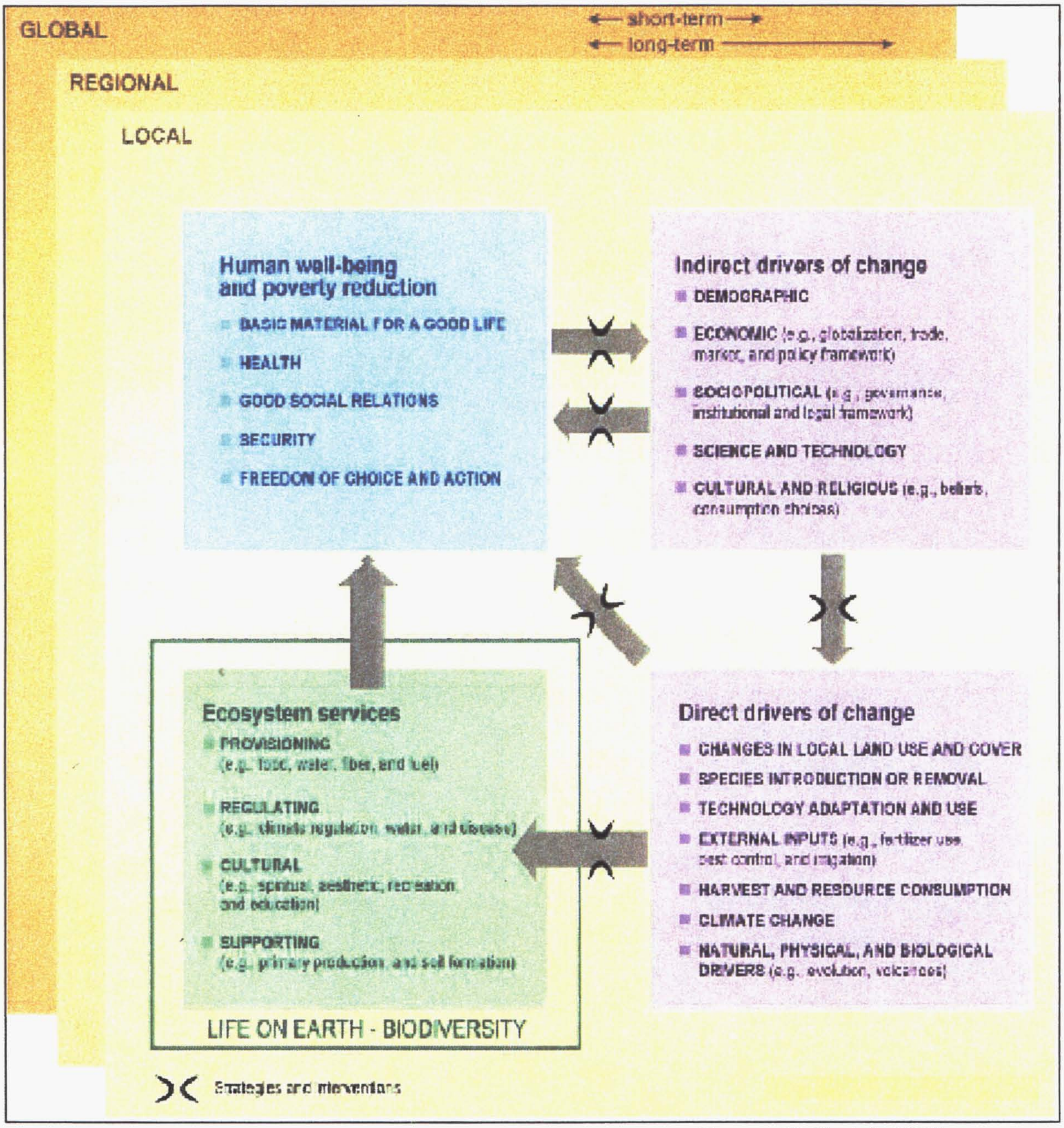

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About half of the total land area is in agricultural-pastoral and arable production. Farming is a major industry in New Zealand with a total farming area of 15,640,348 ha and 70,000 farms (www.stats.govt.nz). In the Canterbury region there are 10,000 farms with a farming area of 3,150,891 ha, of which 205,724 ha is under arable cropland, fodder cropland and fallow land, comprising 2900 farms. The remainder consists of land in horticulture, grasslands, forest plantation, etc.

Pastoral farming is the dominant type of agriculture in New Zealand and livestock numbers are very high compared with the human population. Arable farming occupies a small and declining percentage of total New Zealand land area. For example, on the South Island in Canterbury, the region with most arable farming, dairy farming has increased in area while arable farming has decreased over the last two decades. Horticulture is increasing in importance and wine production has increased rapidly in the last twenty years, but horticulture occupies less than 0.1 % of the total land area (MAF, 2006).

New Zealand agriculture is highly productive, and the volume of production is much greater than is needed to sustain the domestic population of 4.1 million people. Agricultural, forestry and horticultural exports comprised 65% of New Zealand's total exports in 2004. Despite its modest size and distant location relative to major world markets, New Zealand is a leading exporter of dairy and meat products, and has significant global market share in those sectors (MAF, 2005).

New Zealand also has a global image of being 'clean and green' (MfE, 2000)-see Fig. 1.3. That image has arisen because of the low human population density, the small amount of industrial activity and its heavy reliance upon pastoral agriculture. More recently, this image has been tarnished by a worsening environmental record, particularly associated with agriculture. Agricultural intensification is increasingly linked to eutrophication of lakes, increased demands for irrigation water and subsequent reduction in groundwater and stream water availability, nitrates leaching to waterways, reduction in amounts of natural biodiversity on farms and increasing greenhouse gas emissions, particularly of methane from livestock (PCE, 2004). These effects indicate that significant tradeoffs may exist between increasing production of some ES (food and fibre) in favour of other non-marketed ES (soil formation, biological control etc.).

Fig. 1.3 New Zealand at London wine trade fair

1.3 Ecosystem services

Natural and modified ecosystems support human life through ES (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. These ES are worth many trillions of dollars annually (Costanza *et al.,* 1997). Yet because most of these benefits are not traded in economic markets, they carry no 'price tags' (no exchange value in spite of their high use value) that could alert society to changes in their supply or deterioration of underlying ecological systems that generate them. Value-in-exchange and value-in-use has been explained by many economists using the diamond-water paradox (Smith, 1869), the exchange value of diamonds is very high but low use value as compared with water, which has high use value but low exchange value. Because the threats to ES are increasing, there is a critical need for identification, monitoring and enhancement of ES both locally and globally, and for the incorporation of their value into decision-making processes (Daily *et al.*, 1997).

1.3.1 Ecosystem functions, goods and services

Ecosystem functions can be defined as 'the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly' (de Groot, 1992). Using this definition, ecosystem functions are best conceived as a subset of ecological processes and ecosystem structures. Each function is the result of the natural processes of the total ecological sub-system of which it is a part. Natural processes, in turn, are the result of complex interactions between biotic (living) and abiotic (chemical and physical) components of ecosystems through the universal driving forces of matter and energy (de Groot *et al.*, 2002).

One of the key insights provided by Reid *et al.* (2005) is that not all ecosystem services are equal - there is no one single category that captures the diversity of what fully functioning ecological systems provide humans. Rather, researchers in the field must recognize that ecosystem services occur at multiple scales, from climate regulation and carbon sequestration at the global scale, to soil formation and nutrient cycling more locally. To capture the diversity of ES, Reid *et al.* (2005) groups them into four basic services based on their functional characteristics:

1. *Regulating Services*: ecosystems regulate essential ecological processes and life support systems through bio-geochemical cycles and other biospheric processes. These include climate regulation, disturbance moderation and waste treatment.
2. *Provisioning Services:* the provisioning function of ecosystems supplies a large variety of ecosystem goods and other services for human consumption, ranging from food in agricultural systems, raw materials and energy resources.
3. *Cultural Services:* ecosystems provide an essential 'reference function' and contribute to the maintenance of human health and wellbeing by providing spiritual fulfilment, historical integrity, recreation and aesthetics.
4. *Supporting Services:* ecosystems also provide a range of services that are necessary for the production of the other three service categories. These include nutrient cycling, soil formation and soil retention.

This typology provides the organizing principle for assessment of ES associated with New Zealand arable land in this work. Arable landscapes are intensively 'engineered' systems, designed to maximize the delivery of socially valued goods and services (Cullen *et al.*, 2004;

Cullen *et al.*, 2006; Sandhu *et al.*, 2005). As is the case worldwide, some New Zealand arable farming practices can reduce the ability of the ecosystem to provide goods and services while others may enhance the latter (Sandhu *et al.*, 2005; Takatsuka *et al.*, 2005a). The current research is therefore based on the premise that developing a deeper scientific understanding of the complex relationships between '*engineered*' *eco*systems and the types of ES they affect will provide a better informed basis for ecosystem service management in New Zealand (Farber *et al.*, 2006).

1.3.3 Economic valuation techniques

Economic valuation methods fall into four basic types (de Groot *et al.*, 2002), each with its own repertoire of associated measurement issues: (1) direct market valuation, (2) indirect market valuation, (3) contingent valuation, (4) group valuation. Table 1.2 gives an overview of the link between these valuation methods and the ES described in Table 1.1 based on a synthesis by Costanza *et al.* (1997). It shows that for each ecosystem function usually several valuation methods can be used.

1) Direct market valuation: This is the exchange value that ES have in trade, mainly applicable to the 'goods' (i.e., production functions). Value of food produced is an example.

2) Indirect market valuation: When there are no explicit markets for services, we must resort to more indirect means of assessing values are needed. A variety of valuation techniques can be used to establish the (revealed) Willingness-to-Pay (WTP) or Willingness-to-Accept compensation (WTA) for the availability or loss of these services.

- Avoided Cost (AC): services allow society to avoid costs that would have been incurred in the absence of those services. Examples are flood control (which avoids property damages), waste treatment (which avoids health costs) by wetlands and biological control (which can lead to lower pesticide costs).

Table 1.1. Definitions and Examples of Ecosystem Services*

	Ecosystem Services	Definitions	Examples
1	Gas regulation	Regulation of atmospheric chemical composition	CO_2/O_2 balance, O_2 for UVB, SOx levels
2	Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels	Greenhouse gas regulation, DMS production affecting cloud formation
3	Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations	Storm protection, flood control, drought recovery
4	Water regulation	Regulation of hydrological flows	Irrigation, milling, transportation
5	Water Supply	Storage and retention of water	Watersheds, reservoirs, aquifers
6	Erosion control and sediment retention	Retention of soil within an ecosystem	Erosion control, reduction of runoff
7	Soil formation	Soil formation processes	Accumulation of organic material, weathering of rock
8	Nutrient cycling	Storage , internal cycling, processing and acquisition of nutrients	Nitrogen fixation
9	Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds	Waste treatment, pollution control detoxification
10	Pollination	Movement of floral gametes	Reproduction of plant populations
11	Biological control	Trophic-dynamic regulations of population	Reduction of herbivory by top predators, control of prey species
12	Refugia	Habitat for resident and transient production	Nurseries, habitat for migratory species, regional habitats for locally harvested species
13	Food production	That portion of gross primary production extractable as food	Production of fish, crops, nuts, fruits
14	Raw material	That portion of gross primary production extractable as raw materials	Production of lumber, fuel , or fodder
15	Genetic resources	Sources of unique biological materials and products	Medicine, products for materials science, resistance to plant pathogens and crop pests
16	Recreation	Providing opportunities for recreational activities	Eco-tourism, sport fishing, outdoor activities
17	Cultural	Providing opportunities for non-commercial uses	Aesthetic, artistic, education, spiritual, and/or scientific values

* From Costanza *et al.* (1997).

Table 1.2 Relationship between ecosystem functions and monetary valuation techniques

	Ecosystem functions (and associated goods and services)	Range of monetary values in US$/ha year[a]	Direct market Pricing[b]	Indirect market pricing					Contingent valuation	Group valuation
				Avoided cost	Replacement cost	Factor income	Travel cost	Hedonic pricing		
	Regulation Functions									
1	Gas regulation	7-265		+++	0	0			0	0
2	Climate regulation	88-223		+++	0	0			0	0
3	Disturbance prevention	2-7240		+++	++	0			0	0
4	Water regulation	2-5445	+	++	0	+++		0	+	0
5	Water supply	3-7600	+++	0	++	0	0	0	0	0
6	Soil retention	29-245		+++	++	0		0	0	0
7	Soil formation	1-10		+++	0	0			0	0
8	Nutrient regulation	87-21100		0	+++	0			0	0
9	Waste treatment	58-6696		0	+++	0		0	++	0
10	Pollination	14-25	0	+	+++	++			0	0
11	Biological control	2-78	+	0	+++	++			0	0
	Habitat Functions									
12	Refugium function	3-1523	+++		0	0		0	++	0
13	Nursery function	142-195	+++	0	0	0		0	0	0

Table 1.2 continued

	Ecosystem functions (and associated goods and services)	Range of monetary values in US$/ha year[a]	Direct market Pricing[b]	Indirect market pricing					Contingent valuation	Group valuation
				Avoided cost	Replacement cost	Factor income	Travel cost	Hedonic pricing		
	Production Functions									
14	Food	6-2761	+++		0	++			+	0
15	Raw materials	6-1014	+++		0	++			+	0
16	Genetic resources	6-112	+++		0	++			0	0
17	Medicinal resources		+++	0	0	++			0	0
18	Ornamental resources	3-145	+++		0	++		0	0	0
	Information Functions									
19	Aesthetic information	7-1760			0		0	+++	0	0
20	Recreation	2-6000	+++		0	++	++	+	+++	
21	Cultural and artistic information		0			0	0	0	+++	0
22	Spiritual and historic information	1-25					0	0	+++	0
23	Science and education		+++			0	0		0	0

[a] Dollar values are based on Costanza et al. 1997 and apply to different ecosystems (e.g. waste treatment is mainly provided by wetlands and recreational benefits are, on a per hectare basis, highest in coral reefs). In the columns, the most used method on which the calculations was based is indicated with +++, the second most with ++, etc.; open circles indicate that that method was not used in the Costanza study but could potentially also be applied to that function.

[b] Based on added value only (i.e. market price minus capital and labor costs (typically about 80%).

- Replacement Cost (RC): services could be replaced with human-made systems; an example is natural waste treatment by marshes, which can be (partly) replaced with costly artificial treatment systems.
- Factor Income (FI): many ES enhance incomes, An example is natural water quality improvements which increase commercial fisheries catch and thereby incomes of fishermen. In one of the recent reports of the Department of Conservation (DOC) New Zealand, total economic impact on the West Coast region associated with DOC and Public Conservation Lands is NZ $ 222 million per year.
- Travel Cost (TC): Use of ES may require travel. The travel costs can be seen as a reflection of the implied value of the service. An example is recreation areas that attract distant visitors whose value placed on that area must be at least what they were willing to pay to travel to it.
- Hedonic Pricing (HP): Service demand may be reflected in the prices people will pay for associated goods; an example is that housing prices at beaches usually exceed prices of identical inland homes near less attractive scenery.

3) Contingent valuation (CV): Service demand may be elicited by posing hypothetical scenarios that involve the description of alternatives in a social survey questionnaire. For example, such a questionnaire might ask respondents to express their willingness to pay (i.e. their stated preference as opposed to revealed preference) to increase the level of water quality in a stream, lake or river so that they might enjoy activities such as swimming, boating or fishing (Wilson & Carpenter 1999).

4) Group valuation: Another approach to ecosystem service valuation that has gained increasing attention recently involves group valuation (Sagoff, 1998; Wilson & Howarth, 2002). Derived from social and political theory, this valuation approach is based on the principles of deliberative democracy and the assumption that public decision making should result, not from the aggregation of separately measured individual preferences, but from open public debate.

1.4 Objectives

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 yr^{-1}, with an annual mean of US \$33 trillion. This assessment was based on published studies and used 'value transfer' techniques (Wilson *et al.*, 2004), supported by a few original calculations. This study provoked meaningful debate about appropriate ways to value ES (Toman, 1998; Turner *et al.*, 1998; Farber *et al.*, 2002). Some contributors to the debate have argued that attempts to provide estimates of the value of global ES are misguided as there is no potential purchaser of the total ES (Dasgupta, *et al.*, 2000). In contrast, some authors argue there is merit in estimating the incremental changes of values in ES at specific sites and locations (Turner *et al.*, 1998).

Pimentel *et al.* (1997) estimated the annual economic and environmental benefits of biodiversity in the world to be about US \$3 trillion yr^{-1}, while in New Zealand, Patterson & 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 & Swinton, 2005) and a more experimental approach to evaluating ES in this sector may give more reliable results which may be amenable to interpretation. Methodologies for improving ES may also be more apparent when such approaches are used.

Therefore, in contrast to the above methods for the valuation of ES, this work quantified the economic value of ES in highly modified and productive farming landscapes ('engineered systems') in New Zealand using a 'bottom-up' approach. It demonstrates the value in the arable sector for the maintenance of profit and sustainable practices by addressing both conventional as well as organic systems.

The present study was therefore planned with the following objectives.

1. To identify and describe ES on arable farmland.
2. In Canterbury, New Zealand, to assess the extent of ES on arable farmland in organic and conventional systems.
3. To estimate the economic value of ES in arable land at the field level.

4. To estimate the change in ES value when arable farming shifts from a conventional to organic system.
5. To analyse prospects for enhancing ES in the arable sector.

Thesis structure

This thesis is written as a series of self contained chapters connected by the overall aim of the thesis.

Chapter 1 General introduction, concept of ecosystem services, importance of ecosystem services in agriculture, valuation methods and new approach.

Chapter 2 The aim of this chapter is to identify and describe ecosystem services associated with arable farming. Ecosystem services associated with arable farming in Canterbury, New Zealand are identified and described. Although these types of ES have been defined and explained in the economics literature, they are dealt with here, specifically for a biological/agricultural readership. It also studied the perceptions of conventional and organic farmers towards these services and concluded that farmers' attitudes change as conventional producers shift to organic farming and as conventional growers become increasingly aware of environmentally-based market pressures.

Chapter 3 In this chapter a novel, experimental 'bottom-up' approach is used to quantify three key ecosystem services associated with highly modified arable landscapes in New Zealand. This study was designed to assess the effects of arable farming on the provision of ES at the field level. It estimated the economic value of these services using experimental data, in contrast with 'value transfer' approaches used in previous studies.

Chapter 4 In this chapter, the role of land management practices in the maintenance and enhancement of ES in agricultural land was investigated by quantifying the economic value of ES at the field level based on an experimental approach. The total economic value of ES for Canterbury arable land was calculated by extrapolating ES values compiled for the fields to the total arable area in the Canterbury province. It also calculated the economic value of ecosystem services under the scenario that half the arable area of Canterbury was converted to an organic regime. Based on this scenario, the predicted change in the economic value of ecosystem services for the whole province was estimated using market and non market values for each organic field, by crop type. Next, total and non-market values of ecosystem services for both the full conventional and half conventional/half-organic scenarios were spatially extrapolated and mapped across Canterbury using Geographic Information System.

Chapter 5 The aim of this chapter was to study one of the key ecosystem services, i.e., biological control of pests using infra-red digital video analysis. Since natural enemy species vary in their impact on pest populations, it is crucial to identify which predators are effective at reducing pest abundance. Leafrollers, a ubiquitous pest, spend part of their life on the ground and part in the canopy of vineyards. In this study, predation of tethered leafrollers on the ground and in the vine canopy was compared in a New Zealand vineyard. It demonstrates the value of video recording in biological control research, as it permits identification of the predators contributing to pest reduction. In addition, it highlights the need to understand the contributions of individual predator taxa to biological control to better conserve the 'right diversity' in agricultural systems and benefit from this ecosystem service.

Chapter 6 General discussion

References

Bjorklund, J., Limburg, K.E. and Rydberg, T. (1999) Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: an example from Sweden. *Ecological Economics* 29, 269-291.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., and van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. *Nature*, 387, 253-260.

Cullen, R., Takatsuka, Y., Wilson, M. and Wratten, S. (2004) Ecosystem services on New Zealand arable farms. Agribusiness and Economics Research Unit, Lincoln University, Discussion Paper 151, 84–91.

Daily, G.C., (ed.) (1997) *Nature's Services: Societal Dependence on Natural Ecosystems.* Island Press, Washington, D.C.

Daily, G.C., Alexander, S., Ehrlich, P.R., Goulder, L., Lubchenco, J., Matson, P.A., Mooney, H.A., Postel, S., Schneider, S.H., Tilman, D. and Woodwell, G.M. (1997) Ecosystem services: benefits supplied to human societies by natural ecosystems. *Issues in Ecology* 2, pp. 18.

Dasgupta, P., Levin, S. and Lubchenco, J. (2000) Economic pathways to ecological sustainability. *BioScience* 50, 339-345.

de Groot, R.S. (1992) *Functions of Nature: Evaluation of Nature in Environment Planning, Management and Decision Making.* Wolters-Noordhoff, Gröningen.

de Groot, R.S. (2000) Ecological functions and socio-economic values of critical natural capital as a measure for ecological integrity and environmental health. In: Crabbe, P., Holland, A., Ryszkowski, L. and Westra, L. (eds) *Implementing Ecological integrity: Restoring Regional and Global Environmental and Human Health* (pp. 191-214). Kluwer Academic Publishers, Dordrecht/Boston/London.

de Groot, R.S., Wilson, M.A. and Boumans, R.M.J. (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41, 393-408.

Edwards, P.J., and Abivardi, C. (1998) The value of biodiversity: where ecology and economy blend. *Biological Conservation* 83, 239-246.

Ehrlich, P.E. and Ehrlich, A.H. (1990) *The Population Explosion.* Simon and Schuster, New York.

Escudero, G. (1998) The vision and mission of agriculture in the year 2020: towards a focus that values agriculture and the rural environment *Agricultura, medio ambiente y pobreza rural en America Latina* 21-54.

Farber, S.C., Constanza, R. and Wilson, M.A. (2002) Economic and ecological concepts for valuing ecosystem services. *Ecological Economics* 41, 3, 375-392.

Farber, S., Costanza, R., Childers, D.L., Erickson, J., Gross, K., Grove, M., Hopkinson, C., Kahn, J., Pincetl, S., Troy, A., Warren, P. and Wilson, M.A. (2006) An ecosystem services framework that links science, values, and environmental decision making. *Bioscience* 56, 121-133.

Federico, G. (2005) *Feeding the World: An Economic History of Agriculture, 1800-2000.* Princeton University Press, Princeton.

Firbank, L.G. (2005) Striking a new balance between agricultural production and biodiversity. *Annals of Applied Biology* 146, 163-175.

Goldewijk, K.K. and Ramankutty, N. (2004) Land cover change over the last three centuries due to human activities: the availability of new global data sets. *GeoJournal* 61, 335-344.

Gurr, G. M., Wratten, S. D. and Altieri, M. A. (eds) (2004) *Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods*. CSIRO, Victoria.

Heal, G.M. and Small, A.A. (2002) Agriculture and ecosystem services. In: Gardner, B.L. and Rausser, G.C. (eds) *Handbook of Agricultural Economics Vol. 2a* (pp. 1341-1369). Elsevier, Amsterdam.

Heywood, V.H. (ed.) (1995) *United Nations Environment Program, Global Biodiversity Assessment*. Cambridge University Press, Cambridge.

Krebs, J.R., Wilson, J.D., Bradbury, R.B. and Siriwardena, G.M. (1999) The second silent spring? *Nature* 400, 611-612.

Kremen, C. (2005) Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters* 8, 469–479.

MAF (2005) *Situation and outlook for New Zealand agriculture and forestry*. Ministry of Agriculture and Forestry, Wellington.

MAF (2006) *Agriculture, forestry, horticulture in brief.* Ministry of Agriculture and Forestry, Wellington.

Matson, P.A., Parton, W.J, Power, A.G, and Swift, M.J. (1997) Agricultural intensification and ecosystem properties. *Science* 277, 504-509.

MfE (2000) *Valuing New Zealand's Clean Green Image*, Ministry for the Environment, Wellington.

Millennium Ecosystem Assessment (2003) *Ecosystems and Human Well-Being: Framework for Assessment.* Island Press, Washington DC.

Myers, N. (1996) Environmental services of biodiversity. *Proceedings of the National Academy of Sciences* 93, 2764-2769.

Palmer, M., Bernhardt, E., Chornesky, E., Collins, S., Dobson, A., Duke, C., Gold, B., Jacobson, R., Kingsland, S., Kranz, R., Mappin, M., Martinez, M. L., Michell, F., Morse, J., Pace, M., Pascual, M., Palumbi, S., Reichman, O. J., Simons, A., Townsend, A. and Turner, M. (2004) Ecology for a Crowded Planet. *Science* 304: 1251-2.

Patterson, M. and Cole, A. (1999). Assessing the value of New Zealand's biodiversity. Massey University, Palmerston North, New Zealand.

Patterson, M. and Cole, A. (1999) Estimation of the value of ecosystem services in the Waikato region. Environment Waikato, Hamilton.

PCE (2004) *Growing for Good: Intensive Farming, Sustainability and New Zealand's Environment.* Parliamentary Commissioner for the Environment, Wellington.

Pimentel, D. and Giampietro, M. (1994). *Food, Land, Population and the U.S. Economy.* Carrying Capacity Network, Washington, DC.

Pimentel, D. and Wilson, A. (2004) World population, agriculture and malnutrition. *World Watch* 17, 22–25.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T., and Cliff, B. (1997) Economic and environmental benefits of biodiversity. *BioScience* 47, 747-758.

Pretty. J.N. (2002) *Agri-Culture: Reconnecting People, Land and Nature.* Earthscan Publishing Ltd., London.

Pretty, J. and Hine, R. (2001) *Reducing Food Poverty with Sustainable Agriculture: Summary of New Evidence.* Final Report from the "SAFE - World" (The Potential of Sustainable Agriculture to Feed the World) Research Project, University of Essex Commissioned by UK Department for International Development. On WWW at ttp://www2.essex.ac.uk/ces/ ResearchProgrammes/CESOccasionalPapers/SAFErepSUBHEADS. htm

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar, P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell, J. and Zurek, N.B. (2005) *Millennium Ecosystem Assessment Synthesis Report.* Island Press, Washington DC.

Robertson, G.P. and Swinton, S.M. (2005) Reconciling agricultural productivity and environmental integrity: a grand challenge for agriculture. *Frontiers in Ecology and Environment* 3, 38–46.

Sagoff, M. (1998) Aggregation and deliberation in valuing environmental public goods: a look beyond contingent valuation. *Ecological Economics* 24, 213-230.

Sandhu, H.S., Wratten, S.D. and Cullen, R. (2005) Evaluating ecosystem services on farmland: a novel, experimental, 'bottom-up' approach. In: Proceedings of the 15th International Federation of Organic Agriculture Movements (IFOAM) Organic World Congress, Adelaide, Australia.

Smith, A. (1869) An Inquiry into the Nature and Causes of the Wealth of Nations. Clarendon Press, Oxford.

Takatsuka, Y., Cullen, R., Wilson, M. and Wratten, S. (2005a) Using choice modelling to value ecosystem services on arable land. In: proceedings of the 49th Australian Agricultural and Resource Economics Society (AARES) Annual Conference, Coffs Harbour, Australia.

Takatsuka, Y., Cullen, R., Wilson, M.A. and Wratten, S. (2005b) Analysis of choice modeling data with various choice sets. In: proceedings of the New Zealand Association of Economists Conference, Christchurch.

Takatsuka, Y., Cullen, R., Wilson, M. and Wratten, S. (2005b) Values of ecosystem services on arable land and the role of organic farming. In: Proceedings of the New Zealand Agricultural and Resource Economics Society (NZARES) 11th annual conference, Nelson, New Zealand.

Tilman, D. (1999) Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. *Proceedings of the National Academy of Sciences USA* 96, 5995-6000.

Tilman, D., Cassman, G., Matson, P.A., Naylor, R., and Polasky, S. (2002) Agricultural sustainability and intensive production practices. *Nature* 418, 671-677.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., and Swackhamer, D. (2001) Forecasting agriculturally driven global environmental change. *Science* 292, 281-284.

Toman, M, 1998. Why not to calculate the value of the world's ecosystem services and natural capital. *Ecological Economics* 25, 1, 57-60.

Turner, R. K., Adger, W.N. and Brouwer, R. 1998. Ecosystem services value, research needs, and policy relevancy: a commentary. *Ecological Economics* 25, 1, 61-66.

UN (1992) *Promoting sustainable agriculture and rural development. United Nations Conference on Environment & Development.* Rio de Janerio, Brazil, 3 to 14 June. Agenda 21, 14.1-14.104. On WWW at http://www.un.org/esa/sustdev/agenda21.htm

UN, 2005. The Millennium Development Goals report, United Nations, New York.

UNEP (2005) *One Planet, Many People: Atlas of Our Changing Environment.* UN, New York.

Vitousek, P.M., Mooney, H.A., Lubchenco, J. and Melillo, J.M. (1997) Human domination of earth's ecosystems. *Science* 277, 494-499.

Wackernagel, M. and Rees, W. (1996) *Our Ecological Footprint: Reducing Human Impact on the Earth.* New Society Publishers, Gabriola Island, B.C.

Wilson, M.A., and Carpenter, S. R. (1999) Economic valuation of freshwater ecosystem services in United States 1971-1997. *Ecological Applications* 9, 772-783.

Wilson, M.A., and Howarth, R. (2002) Discourse-based valuation of ecosystem services: establishing fair outcomes through group delibration. *Ecological Economics* 41, 431-443.

Wilson, M., Troy, M. and Costanza, R. (2004) The economic geography of ecosystem goods and services: revealing the monetary value of landscapes through transfer methods and geographic information systems. In: Dieterich, M., van der Straaten, J. (Eds.), Cultural Landscapes and Land Use: the Nature Conservation–Society Interface (pp. 69–94). Kluwer Academic Publishers, Dordrecht.

Chapter 2 From Poachers to Gamekeepers: Perceptions of Farmers Towards Ecosystem Services on Arable Farmland[1]

Abstract

Management of ecosystem services (ES) is vital to maintain and improve the productivity of agricultural systems in order to meet the food demands of a growing human population. However, some land management practices can severely reduce the ecological and financial contribution of some of these services to agriculture, which in the longer term can offset the ability of farming to produce large amounts of food and fibre. Therefore, to improve the understanding and enhancement of these services, it is crucial to know the opinions of farmers who manage ES on their land. Being in close contact with the land provides them with an opportunity to understand its natural processes and functions as well as to act as its stewards. This paper describes ES associated with arable farming in Canterbury, New Zealand and analyses the results of a survey of farmers' perceptions of these services. There was no difference between the measured perceptions of these services by organic and conventional farmers except in the case of biological control. However, organic farmers gave a higher score to 16 individual services compared with conventional farmers. Also, for organic farmers, the importance of some of these services increased significantly with the number of years the farmers had been operating under an organic regime.

2.1 Introduction

Agriculture is the major cause of land use change (Vitousek *et al.*, 1997; Goldewijk & Ramankutty, 2004; UNEP, 2005), leading to environmental destruction and associated loss of ecosystem services (ES) (Heywood, 1995; Krebs *et al.*, 1999; Tilman *et al.*, 2001). Therefore, a growing human population and associated increasing food demands make the challenge to maintain and enhance ES in agriculture greater than in other ecosystems (UN, 1992; Pinstrup-Andersen, 1998).

Agricultural activities before the twentieth century were dependent mainly on crop rotation and the reduction of pests and diseases through diverse agro-ecosystems (Ernle, 1961). Farmers were able to meet the food requirements of human populations without being

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highly dependent on external chemical inputs. They had an instinctive, if not scientific understanding of nature and its services (Pretty, 2002). In New Zealand, Maori (and other 'first people' cultures elsewhere) often have a profound understanding of inter-generational sustainability issues. This is expressed among the largely oral Maori culture as *kaitiakitanga*.

However, since the onset of the industrial revolution, and especially more recently, farmers are becoming very susceptible to pressures imposed by expanding international food markets (Aksoy & Beghin, 2005). These markets demand higher production and year-round availability of many products. This has led to massive expansion and intensification of agriculture (Tilman *et al.*, 2002), which is heavily dependent on fossil fuels, chemical fertilizers and pesticides. This 'substitution agriculture' has resulted in the loss of valuable ES (Daily, 1997; Reid *et al.*, 2005) as well as leading to other detrimental effects (Tilman, 1998; National Academy of Sciences, 2001; Tilman & Lehman, 2001) and high 'external costs' (Pretty *et al.*, 2000; Pretty *et al.*, 2001; Pretty, 2005; Tait *et al.*, 2006; Tegtmeier & Duffy, 2004). These 'external costs' of chemical-dependent, intensive agricultural practices include severe damage to soil fertility, water, biodiversity and human health.

This has led to world-wide concerns about the environmental consequences of modern agriculture (Reid *et al.*, 2005). There is also the additional concern that as the world approaches 'peak oil', agriculture may no longer be able to depend so heavily on oil-derived 'substitution' inputs (Pimentel & Giampietro, 1994). Such a grave situation does not detract from the responsibility of agriculture to meet the food demands of a growing population but it does question its ability to increase yields without further ecosystem damage (Escudero, 1998; Tilman, 1999; Pimentel & Wilson, 2004;).

The key challenge is to meet the food demands of a growing population and yet maintain and enhance the productivity of agricultural systems (UN, 1992). There is therefore currently an increasing interest in the services provided by nature (Heal *et al.*, 2005). As the economic value of the direct and indirect benefits of ES are substantial (Costanza *et al.*, 1997; Daily *et al.*, 1997b; Sandhu *et al.*, 2005), there is growing awareness of the utilisation of these services for the long-term sustainability of agro-ecosystems and their ability to provide increased production while maintaining ES (Pretty & Hine, 2001; Gurr *et al.*, 2004; Tilman *et al.*, 2006).

2.2 Background to the current work

Agriculture is both a consumer and a producer of ES (Heal & Small, 2002; Sandhu *et al.*, 2005; Takatsuka *et al.*, 2005a). A number of ES are utilised to produce others such as food, which is supported by the maintenance of soil fertility, plant protection, water regulation and many other services (Daily *et al.*, 1997b). Food and fibre production are valued in commercial markets and the foremost objective of modern agriculture is to maximise commercial gains. However, doing so usually results in the decline of other valuable ES. However, the concept of using ES to enhance farm sustainability is growing worldwide (Matson *et al.*, 1997; Gurr *et al.*, 2004; Kremen, 2005; Robertson & Swinton, 2005). Researchers and practitioners aspire to strike a balance between production and consumption of ES in agriculture for long-term farm sustainability (Bjorklund *et al.*, 1999; Firbank, 2005).

Sustainable agriculture involves the use of agricultural technologies and practices that maximise the productivity of the land after considering all the costs and benefits (Altieri, 1995; Pretty, 1995; Thrupp, 1996; Pretty & Hine, 2001; Tilman *et al.*, 2002). Organic agriculture is considered to be one of the production systems that aim to achieve sustainability (Reganold *et al.*, 1990; Lampkin & Measures, 2001; Mäder *et al.*, 2002). The estimated magnitude of ES is very high in organic agriculture compared with high-input substitution agriculture (Takatsuka *et al.*, 2005a). It is well established that organic farming delivers more environmental benefits compared with conventional practices (Mäder *et al.*, 2002; Pacini *et al.*, 2003; Swift *et al.*, 2004; Pimentel *et al.*, 2005). The provision of ES is higher in organic than in conventional farms (Sandhu *et al.*, 2005). Organic farmers are more dependent on ES because most chemical inputs are prohibited.

They are also more concerned about the environment than are those who farm conventionally (Egri, 1999; Fairweather & Campbell, 2003). However, information on the importance of ES on farmland and the perceptions of farmers who manage ES (Edling, 2003) is limited. Farmers have deep ties to the land as they earn their livelihood from it and this can provide them with an opportunity to have an appreciation of natural processes and functions as well as to act as stewards of their land (McCann, 1997). Also, by understanding the perceptions of arable farmers, new eco-technologies based on the novel application of sound ecological knowledge can be targeted to design efficient farming systems by involving the 'end-user' at the conceptual stage, not through 'end-of-project' attempts to sell research results to hitherto previously un-involved farmers (Chambers, 1990; Pretty, 1995; Warner, 2006). The research in this paper aims to explore the extent of appreciation of on-farm ES by farmers in relation to within- and off- farm benefits. It surveyed organic and conventional farmers in Canterbury, New Zealand in 2005.

2.3 Aim of the study

Agriculture contributes 16% of the annual Gross Domestic Product (GDP) in New Zealand (Statistics New Zealand, 2003). About half of the New Zealand land area is under pastoral or arable agricultural production. Arable landscapes are intensively 'engineered' systems, designed to maximize the delivery of socially valued goods and services (Cullen *et al.*, 2004; Sandhu *et al.*, 2005; Cullen *et al.*, 2006). As is the case worldwide, some New Zealand arable farming practices can reduce the ability of the ecosystem to provide goods and services while others may enhance the latter (Sandhu *et al.*, 2005; Takatsuka *et al.*, 2005a).

The focus of this study is on one sector of an engineered ecosystem (arable farming) and since the province of Canterbury is the major arable area in New Zealand, this work addresses the perceptions of arable farmers in that province towards ES in both conventional and organic systems. A conceptual model depicting the perceptions of farmers of ES is outlined in Fig. 2.1.

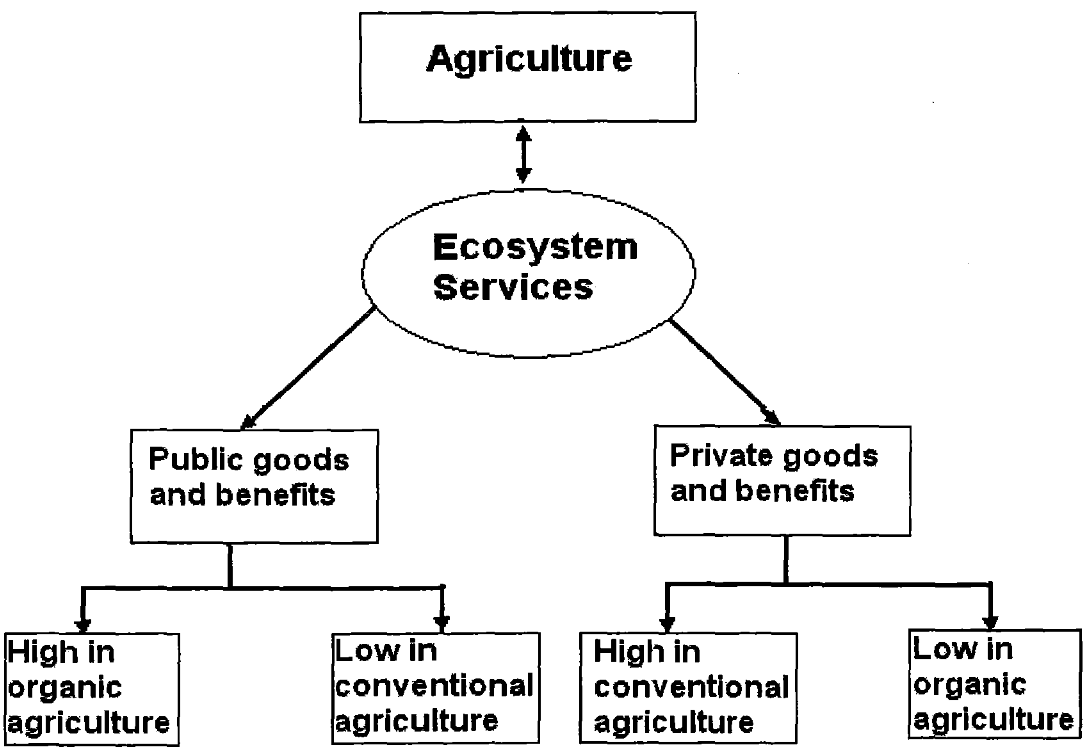

Fig. 2.1 Conceptual model depicting perceptions of ecosystem services in organic and conventional agriculture.

2.4 Ecosystem services in agriculture

ES associated with farming are classified into four groups, as explained by Reid *et al.* (2005). Based on the ES literature and discussion with experts, several ES have been identified in agriculture (Cullen *et al.*, 2004; Reid *et al.*, 2005; Takatsuka *et al.*, 2005b). These are summarised in Table 2.1. Although these types of ES have been defined and explained in the economics literature, they are dealt with here, specifically for a biological/agricultural readership. Each of the ES is defined below with special reference to Canterbury, New Zealand arable land.

Table 2.1 Ecosystem services associated with arable farming (adapted from Cullen *et al.*, 2004 and Takatsuka *et al.*, 2005).

Provisioning services	*Regulating services*	Cultural services
Food	Hydrological flow	Aesthetic
Raw materials		Recreation
Fuel wood		Science and education
Conservation of species		
Maintenance of genetic resources		
	Supporting services	
Pollination	Mineralization of plant nutrients	Support to plants
Biological control	Soil fertility	Soil formation
Carbon accumulation	Soil erosion control	Nitrogen fixation
		Services provided by shelterbelts

(1) Supporting services

These are the services that are required to support the production of other ecosystem goods and services. In this case they support food goods. Suppression of these services can lead to their substitution with external inputs. Key supporting ES associated with arable farming are described below.

(1a) Pollination

The transfer of pollen grains from anthers to stigmas is pollination (Free, 1970). Of the 1330 crop species, two thirds require animal pollinators (Roubik, 1995). Of the 100 crop species that provide 90 percent of human food supplies, 71 are bee pollinated (Prescott-Allen & Prescott-Allen, 1990). The dependence of important food crops on pollination makes this service crucial in agriculture. Earlier work provides information about the value of pollination services (Matheson, 1987; Pimentel *et al.*, 1997; Kremen *et al.*, 2002; Gordon & Davis, 2003; Ricketts, 2004; Ricketts *et al.*, 2004). Extensive use of insecticides in agriculture is leading to a decline of this ES (Nabhan & Buchmann, 1997, 1998) which is worth US $200 billion annually in cropland worldwide (Pimentel *et al.*, 1997). The value to New Zealand is estimated to be in the range of US $1.4-2 billion annually (Matheson, 1987; Matheson & Schrader, 1987). New Zealand arable.land produces high-value seed crops including clovers that fix atmospheric nitrogen and require bees for pollination. The grain and seed industry in New Zealand is worth US $300 million annually (www.maf.govt.nz/mafnet/rural-nz/overview/nzoverview012.htm). To provide increased pollination services for this industry, farmers rent honey-bee hives every year, adding to the costs of production. Any major reduction in populations of pollinators will lead to severe losses to the seed industry. This ES therefore plays a vital role in the economy of Canterbury, New Zealand.

(1b) Biological control

Biological control of pests, diseases and weeds is crucial to the production of crops. 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). The provisions of this ES are higher in organic compared with conventional agriculture (Sandhu *et al.*, 2005).

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 (such as damage to human health) from increasing pesticide applications in agriculture are also well documented (Pretty, 2005). High environmental and economic costs of pesticide use worldwide are also evident (Pimentel *et al.*, 1992; Pretty, 2005). It is estimated that 2.5 million tonnes (active ingredients) of pesticides are used worldwide in crop production (Pimentel *et al.*, 1992). In New Zealand, 3200 tonnes (active ingredients) of pesticides that includes fungicides and herbicides are applied yearly to soils (Holland & Rahman, 1999). There has recently been an increase of 27% in pesticides use over a period of four years in New Zealand (Manktelow *et al.*, 2005). Biological control, if properly utilised on farmland can result in annual savings worth billions of dollars and these services can be enhanced using 'ecological engineering' principles (Gurr *et al.*, 2004).

(1c) Services provided by the soil

Soil supports crops by providing shelter to seeds, aeration, plant support, nutrients, water, accumulation of carbon and fixing atmospheric nitrogen (Brady, 1990; Daily *et al.*, 1997b; de Groot *et al.*, 2002). Each of these services is vital for the growth of plants. For successful farming, healthy soils are a prerequisite. The economic value of the services provided by soil was estimated by Pimentel *et al.* (1997) to be $1.2 trillion per year worldwide. Carbon accumulation in soils was considered by Garcia-Torres *et al.* (2003) as an important alternative to offset the emissions of CO_2 in the atmosphere by industry and other human activities. Practices such as crop residue management, zero or minimum tillage or conservation agriculture can increase carbon accumulation in soils (Garcia-Torres *et al.*, 2003; Magdoff & Weil, 2004). Nutrient mineralisation in the soil provides minerals to plants. Soil fungi, bacteria and micro- and macro-fauna decompose organic matter to release these nutrients (Brady & Weil, 2004). This process can be enhanced by appropriate rotations of crops and by maintaining or increasing soil organic matter. Low-carbon, mineral and un-vegetated soils are more prone to erosion by wind and water. Also, improved activity of soil organisms in the soil by adding mulches or cover crops can decrease the incidence of plant diseases by accelerating the decomposition of overwintering life stages of plant diseases and improving plant vigour (Jacometti *et al.*, in press). Well-structured soils with ample cover protect against erosion. Annually, large quantities of nutrients are lost due to soil erosion by wind and water (McLaren & Cameron, 1996). Tall crops such as maize require well-structured soils to provide a good anchor for the roots to prevent lodging.

Soil formation is also an important ES provided by soil biota (Breemen & Buurman, 2002). Earthworms are the most important component of the soil biota in terms of this service and the maintenance of soil structure and fertility (Stockdill, 1982; Lee, 1985; Edwards, 2004). According to Pimentel *et al.* (1995), soil biota aid the formation of approximately 1 tonne $ha^{-1}yr^{-1}$ of topsoil. Earthworms also maintain soil nutrient levels by mixing the soil, providing nutrients in the plant root zone. Nitrogen fixation by growing legumes can provide all or some of the nitrogen required by the subsequent crop. In Canterbury, New Zealand, clovers are still used as a restorative phase in this way even though the use of urea has increased markedly over the last few decades (PCE, 2004).

(1d) Services provided by shelterbelts and hedges

Shelterbelts on farmland benefit crops and farm animals by improving yields and quality (Sturrock, 1969; Kort, 1988). This is because of reduced wind speed, minimising soil erosion, improving microclimate and giving higher levels of soil moisture (Kort *et al.*, 1988). They also provide shelter and pollen/nectar resources to pollinators (Norton, 1988) and to natural enemies that perform biological control of pests and diseases (Thomas *et al.*, 1991; Landis *et al.*, 2000; de Groot *et al.*, 2002; Heal & Small, 2002;). In Canterbury, New Zealand, good shelter can increase crop yield up to 35 per cent (Sturrock, 1981).

(2) Provisioning goods and services

These include food and services for human consumption, ranging from raw materials and fuel wood to the conservation of species and genetic material (de Groot *et al.*, 2002, Reid *et al.*, 2005). These goods and services are produced in agricultural landscapes by consuming some of the supporting and regulating services.

(2a) Food

Modern agriculture is feeding over 6 billion people worldwide and it is estimated that with an increase in population to 9 billion by 2050, global food demand will double (Pimentel & Wilson, 2004). Agriculture has played a major role in shaping the environment as well as the economy of the world. Although natural ecosystems are sources of a considerable amount of wild foods, including fish, the needs of the growing population will be largely fulfilled by agriculture.

(2b) Raw materials

Agriculture also produces raw materials in the form of fibre, fuel wood, pharmaceuticals and industrial products (Daily *et al.*, 1997b). Arable farming in Canterbury, New Zealand produces straw, fuel wood, medicinal plants etc., as well as food and seeds.

(2c) Conservation of species and genetic resources

Agriculture can provide for the maintenance of genetic material and conservation of species of plants and animals on farmland. Many species have been improved by using genetic resources from their wild relatives by cross-breeding. Further, these resources can be obtained from cultivated plants and domesticated animals in the absence of wild relatives (de Groot *et al.*, 2002). Hedges and shelterbelts around arable fields are major refugia for plants and animal species which are rare, transient or absent on the cultivated parts of the farm (Pollard *et al.*, 1974; Thomas *et al.*, 1991, 1992; MacLeod *et al.*, 2004).

(3) Regulating services

Ecosystems regulate essential ecological processes and life-support systems through bio-geochemical cycles and other biospheric processes (Daily, 1997; Costanza *et al.*, 1997). Hydrological flow in the plant-soil-atmosphere plays a critical role in arable farming. The hydrological cycle renews the earth's supply of water by distilling and distributing it (Gordon *et al.*, 2005). The earth's atmosphere contains approximately 1.3×10^{13} m^3 of water (which is 0.001% of the water in oceans) and is the source of the rainwater that falls on earth (Pimentel *et al.*, 1997). This rainfall is collected in lakes, rivers and oceans or seeps into the ground and eventually evaporates or transpires to the air from the leaves of plants; the latter is known as evapotranspiration. One rainforest tree can return at least 10 million litres of water to the atmosphere in 100 years (Myers, 1996). In contrast with this, maize crops occupying roughly the same area as taken up by a rainforest tree (but for only part of the year) transfer 50 million litres in 100 years (Myers, 1996). This rate of use of ground water would greatly exceed inputs, whereas that of the tree would not.

(4) Cultural services

Cultural services contribute to the maintenance of human health and well-being by providing recreation, aesthetics and education (Costanza *et al.*, 1997; de Groot *et al.*, 2002; Reid *et al.*, 2005). Agriculture provides these services as some farmers conserve field-boundary vegetation or enhance landscapes by planting hedgerows, shelterbelts or native trees. Arable farms in Canterbury are characterised by highly managed shelterbelts. Although there is a very well-travelled 'scenic route' in Canterbury, New Zealand (State Highway 72) which features farmland which is considered to be attractive by motorists, most of this vegetation comprises non-native species such as *Cupressus macrocarpa* (Hartw. ex Gordon).

Some farms provide accommodation and recreational activities for family members as well as for national and international visitors. 'Farm stays' are very common in Canterbury, especially on organic farms. Participation of farms in research and education enhances this cultural service (Warner, 2006).

However, the perceptions of, and attitudes to the provision of ES in Canterbury, New Zealand arable farmland by farmers in that province have not been quantified. This knowledge is important in the development of statutory policies and voluntary practices to enhance functional diversity on arable land. This paper quantified Canterbury arable farmers' attitudes to the provision of ES by conventional and organic farming practices in that province.

2.5 Materials and methods

2.5.1 Site description

The province of Canterbury is the major arable area of New Zealand, comprising 125,000 ha of arable land. Fifteen arable farmers were selected in September 2004 from throughout the Canterbury Plains, New Zealand and seven of these were practising organic agriculture while eight used conventional methods. Of the seven organic farms, three were certified by AgriQuality (www.agriquality.co.nz), New Zealand and four by BIO-GRO (www.bio-gro.co.nz), New Zealand. Both certifiers are accredited with IFOAM, the International Federation of Organic Agriculture Movements (www.ifoam.org).

A list of arable farmers in Canterbury was obtained from the Foundation for Arable Research (www.far.org.nz), Lincoln and OPENZ (Organic Products Exporters of New Zealand; www.organicsnewzealand.org.nz) provided the contacts for all organic farmers. The latter were contacted first by sending a letter, followed by a telephone call and a meeting to collect detailed information about the farming practices such as crop rotation and the crops grown, as well as soil type. After this, conventional arable farmers within 5 km of the selected organic farms were contacted. These were selected within this radius because they were growing similar crops on similar soil types.

2.5.2 Survey methodology

First, a Delphi panel of experts (Brooks, 1979; Angus *et al.*, 2003; Curtis, 2004) was used to place all the ES identified in this work into one of five categories in terms of whether the perceived benefits were attributable mainly to private or public entities. The panel comprised three ecologists and two resource economists.

The five categories allocated for ES were: (1) purely private, (2) mostly private, (3) in between the two, (4) mostly public and (5) purely public. Each of the identified ES was considered once as a good and then as a benefit. Goods are those articles that can be traded whereas benefits are those that promote or enhance human well-being but which are not usually traded (McTaggart *et al.*, 2003). Members of the panel were requested to provide one rating for each ES. In the first round, each member provided a rating for each ES. In the next round, the initial results were sent to the members such that they could reconsider and modify their initial estimations in the light of the first round estimations. The final results were presented after the panel came to a consensus over the allocation of ES into different categories.

Next, data were collected by face-to-face surveys of each selected farmer. A survey questionnaire was prepared, covering the demographic details of farms, farm management practices and perceptions of ES. Each farmer was asked to rank the importance of the listed ES (Abeyasekera *et al.*, 2001). The rankings were on a score of 1-5, one being least important, 3 being moderately important and five being highly important for their farming. Fisher's exact test was used to compare the perceptions of individual ES by organic and conventional farmers.

2.6 Results

The Delphi exercise resulted in categorizing the identified ES as different categories of goods and benefits (Table 2.2). When all the ES were considered as goods, 14 were identified as private, two in between (soil erosion control and aesthetics) and three as public goods (conservation of species, maintenance of genetic resources and science/education). For benefits, 11 were identified to be purely private, five in between (pollination, soil erosion control, nitrogen fixation, hydrological flow and aesthetics) and three purely public (conservation of species, maintenance of genetic resources and science/education). The mean values for perceptions of the importance of ES to organic and conventional farmers obtained by the scoring exercise are presented in Table 2.2. It is noteworthy that two ES (pollination and soil fertility) were ranked as most important by organic as well as conventional farmers (Figures 2.2 & 2.3). Conventional farmers rated 11 ES at a score of 3 or more. This includes seven supporting, three provisioning, one regulating and none of the cultural services. Eight ES were given scores lower than 3 by these conventional farmers. In contrast, organic farmers rated 16 ES at 3 or more; these included nine supporting, four provisioning, one regulating and two cultural services. Only three ES were ranked below 3.

Organic farmers considered most of the supporting services (which provide private goods and benefits) as highly valuable for their farming systems and also ranked the cultural services (which provide public goods and benefits) higher than some of the provisioning and regulating services (Fig. 2.2). However, conventional farmers rated only the provisioning services, such as food production (which have high economic value) as highly important (Fig. 2.3). The responses of conventional farmers indicated that they also considered some of the supporting services to be important, as demonstrated by mean values of 3 or more for these ES (Table 2.2).

Table 2.2 Perceived importance of ES by organic and conventional farmers on a scale of 1-5.

	Ecosystem services	Organic farmers' responses (mean)	Conventional farmers' responses (mean)
	Supporting services		
1	Pollination	4.8	4.7
2	Biological control	3.7	2.6
3	Carbon accumulation	3.2	2.6
4	Mineralization of plant nutrients	3.7	3
5	Soil fertility	4.8	4.5
6	Soil erosion control	4	3.8
7	Support to plants	2.5	2.8
8	Soil formation	3.8	3.6
9	Nitrogen fixation	4	3.6
10	Services provided by shelterbelts	3	3.6
	Provisioning services		
11	Food	3.7	4.2
12	Raw materials	3.2	2.7
13	Fuel wood	2.1	2.3
14	Conservation of species	3.5	3.3
15	Maintenance of genetic resources	4	3.5
	Regulating services		
16	Hydrological flow	3.7	3.7
	Cultural services		
17	Aesthetic	3.5	2.7
18	Recreation	2.5	2.1
19	Science and education	3	2.7

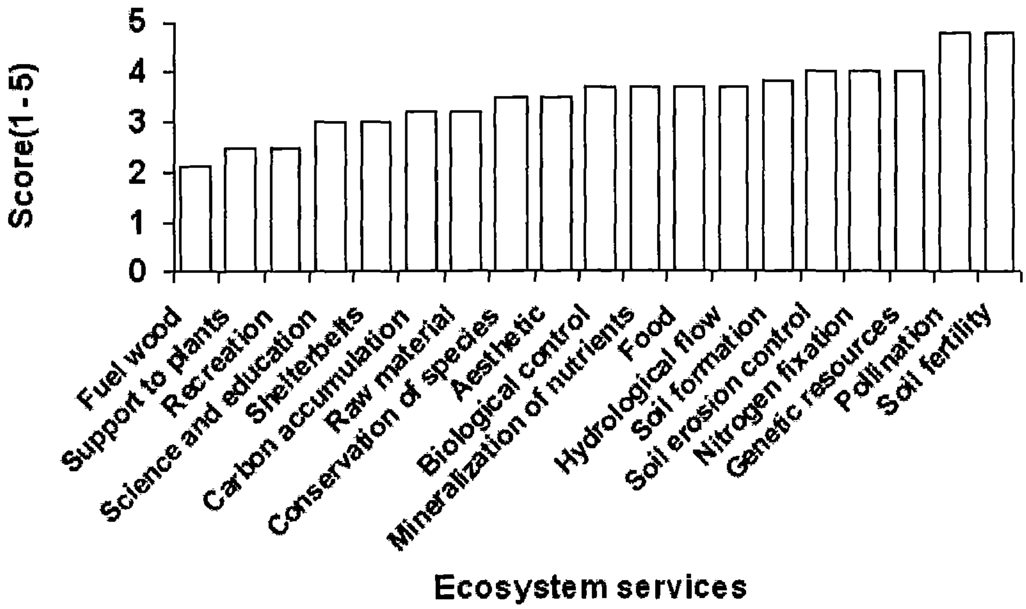

Fig. 2.2 Ranking based on the perceptions of organic farmers regarding the importance of each ES.

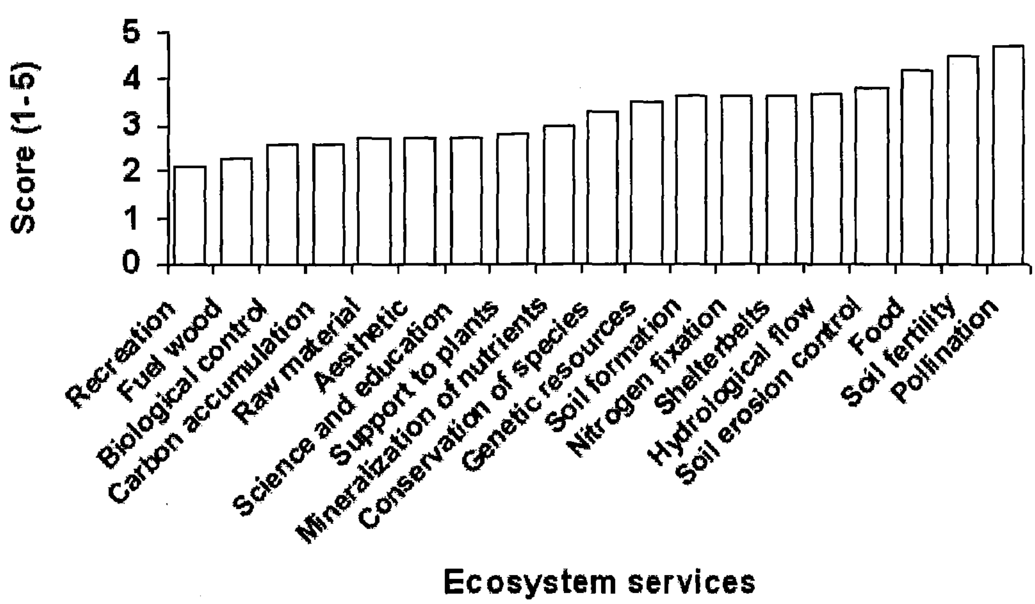

Fig. 2.3 Ranking based on the perceptions of conventional farmers regarding the importance of each ES.

Organic and conventional farmers did not differ significantly for their perceptions of ES except for biological control ($p<0.05$). When the responses of organic farmers were analysed in relation to the number of years their land had been certified organic, there was a significant ($y = 0.0673x + 3.1224$; $R^2 = 0.61$; $p<0.05$) relationship with time for supporting services. However, in terms of their perception of provisioning, cultural and regulating services there was no significant change with time.

Organic farmers depend on nature's services for production, therefore there is increasing importance of these ES, particularly supporting services. Farmers can achieve desired outcomes only by utilising these nature's services in the absence of most external chemical inputs.

2.7 Discussion

2.7.1 Ecosystem services in agriculture

In Canterbury, New Zealand, arable farms comprise highly modified landscapes designed to generate revenue for farmers. Farmers use chemical as well as natural inputs to produce food and fibre. The latter are the ES that have been identified and classified here. Intensive agriculture largely replaces these ES with chemical inputs, resulting in a decrease in their value and importance on farmland (Sandhu *et al.*, 2005). This 'substitution agriculture' has also to a large extent replaced these ES worldwide in the 20th century. Severe environmental destruction, increasing fuel prices and the external costs of modern agriculture have resulted in increased interest among researchers and farmers in using ES for the production of food and fibre (Daily, 1997; Costanza *et al.*, 1997; Tilman, 1999; Cullen *et al.*, 2004; Gurr *et al.*, 2004; Robertson & Swinton, 2005; Tilman *et al.*, 2006).

Increasing concerns about intensive agriculture and its detrimental effects have led to the development of sustainable agricultural practices such as organic farming (Anon., 1994). At present, this is practised on 31 million ha worldwide with a global market of US $26.8 billion, which is increasing at 20% per year (Willer & Yussefi, 2006).

Previous studies have classified and described various ES at a regional or global level (Daily, 1997; Costanza *et al.*, 1997; de Groot *et al.*, 2002; Wilson *et al.*, 2004; Takatsuka *et al.*, 2005a). However, this study focuses on one sector of an 'engineered ecosystem' (arable farming) and addresses both conventional and organic systems in Canterbury, New Zealand. ES operating on arable farmland have been classified as goods as well as benefits using the

Delphi technique (Brooks, 1979) in this study. These ES have been described individually as private or public goods and benefits. Individual farmers derive more immediate advantages from these ES compared with the benefits to the general public (Daily *et al.*, 1997a; Heal and Small, 2002). However, the public also derives aesthetic and other advantages from these ES which are maintained and enhanced on farmland (Anon., 2001; Takatsuka *et al.*, 2005a). Further research is required to study the net private and public benefits of ES on farmland. Better understanding of the importance of ES by farmers and the public is required to enable the inclusion of this natural, social and cultural capital into assessments of gross national product (GNP) (Williams, 2004).

2.7.2 Perceptions of ES by farmers

To ensure the sustainability of agriculture and to minimize associated detrimental effects, it is imperative to evaluate and enhance ES on farmland (Tilman *et al.*, 2002). In the present work, although a larger sample size would be required for a full understanding of the importance of ES on New Zealand farmland, that used here is not atypical of studies using this type of scoring exercise (Abeyasekera *et al.*, 2001; Silvano *et al.*, 2005). The literature provides information on farmers' perceptions of single ES (Johns, 1999; Quansah *et al.*, 2004; Leenders *et al.*, 2005; Silvano *et al.*, 2005) or on farmers' general environmental awareness (McCann, 1997; Fairweather & Campbell, 2002). To date, no study has evaluated the perceptions of farmers towards ES in arable farming.

Intensive agriculture in the past has made some unprecedented changes to agroecosystems, resulting in declines in ES (Reid *et al.*, 2005). As farmers became more dependent on 'substitution' agriculture in the last 50 years, they ignored the importance of ES. However, this study confirmed that there is moderate to high awareness of the importance of these services among two groups of arable farmers, irrespective of whether they intended to utilize these services or not.

Perceptions of ES by conventional farmers

Although conventional farmers in this study depend heavily on external chemical inputs they also rated certain key ES as very important for their farming. The top five were pollination, soil fertility, food production, soil erosion control and hydrological flow. A better understanding of the detrimental effects of current conventional farming practices has made these farmers more aware of the role of ES on their farmland (Fairweather, 1999; Storstad &

Bjørkhaug, 2002). While intensive agricultural practices are associated with a decline in pollination and soil fertility (Daily *et al.*, 1997a; Nabhan & Buchmann, 1997; Kremen *et al.*, 2004), these were the top two services identified by conventional farmers to be highly important. It could be inferred that the recognition of the importance of ES by conventional farmers provides an opportunity for researchers and policy makers to offer alternative tools, techniques and incentives to incorporate new thinking into practice (Silvano *et al.*, 2005). There is a need for practical advice on how to capture ES in agriculture; defining the SPU (Service Providing Unit; Luck *et al.*, 2003) is a key step in this process. An SPU is a characterization of which species provide(s) the service, how many individuals are needed and how to deploy this provider of ES in the agricultural landscape. A good example in which this has been done is "beetle banks' (Sotherton, 1995; Thomas, 2000); the plant type, where and when to use it and its benefits (for pest biological control in this case) have all been quantified and the practice has been widely adopted (Collins *et al.*, 1997; Bowie *et al.*, 2003; MacLeod *et al.*, 2004). More examples of this type will help to ameliorate some of the profound negative effects of 'substitution' farming. Higher food production per unit area per unit time is the goal of arable farmers to maximise their profits. This is very important but surprisingly its score for conventional farmers was below the scores for pollination and soil fertility. This suggests that an awareness of long-term sustainability may sometimes over-ride short-term profit motives (Andreoli & Tellarini, 2000; Freyenberger *et al.*, 2001) and that the associated need for clearly-defined SPU, is high.

Perceptions of ES by organic farmers

Organic farmers are more dependent then are conventional ones on nature's services to support production of food and fibre. Not surprisingly, they ranked key (soil fertility, pollination) ES as most important. Organic farmers utilize appropriate crop rotations and practise sustainable land management to grow food (Lampkin & Measures, 2001). It became clear in this study that this category of farmers adopts those practices that maintain and enhance ES on farmland. There is strong motivation amongst this group to regard ES other than as a provider of premium profits for their produce (Fairweather, 1999). Recognition of some of the ES as highly important provides opportunities to researchers to target the improvement of these services in future (Gurr *et al.*, 2004; Swift *et al.*, 2004).

This study described various ES as goods and benefits and showed the importance of ES by organic and conventional arable farmers. Two hypotheses put forward in Fig. 2.1 were rejected: these were that the importance of public goods and benefits is low for conventional practitioners and that the importance of private goods and benefits is low for organic practitioners. Results suggests that conventional farmers also consider ES as important in farming but unlike organic farmers do not utilize these services as much because there are no direct incentives for them in the markets (Kumar, 2005). However, organic farmers have limited choices on the use of external inputs and obtain premium prices for their produce, so they are increasingly using these services in farming (Sandhu *et al.*, 2005; Kasperczyk & Knickel, 2006). The awareness of consumers towards environmental change and factory farming-techniques driven by supermarkets (Lyon *et al.*, 2003) are putting more pressures on these markets to provide environmentally safe food (e.g., www.waiparawine.co.nz). Conventional food producers which export their produce need to respond to the increased global trade which may nevertheless include non-tariff trade barriers (Anderson & Josling, 2005) and increasingly need to provide pesticide free food (Cranfield & Magnusson, 2003) to distant sophisticated markets.

Information on the vital role played by ES on farmland can be used by researchers and policy makers to increase ecological and economic wealth in a sustainable way. This can 'future-proof' agriculture in an increasingly uncertain food-production environment (Kristiansen *et al.*, 2006). Further research is required to study those ES which are of more interest to different group of farmers, based on their land management practices. Increased use of ES on farmland is possible only if the farmers are given ownership of them, share the benefits of maintaining them on their farmlands and are involved in decisions to safeguard them at regional and national level (Vos, 2000; Pretty, 2002; Warner, 2006).

It is concluded that 'poachers' can indeed turn into 'gamekeepers' as farmers' attitudes change as conventional producers shift to organic farming and as conventional growers become increasingly aware of environmentally-based market pressures.. Also, organic farmers increasingly appreciate the importance of ES for sustainable food and fibre production, minimising the social and environmental risks associated with the 'poaching' of resources in high-input, fossil-fuel-based agriculture.

References

Abeyasekera, S., Ritchie, J.M. and Lawson-McDowall, J. (2001) Combining ranks and scores to determine farmer's preferences for bean varieties in southern Malawi. *Experimental Agriculture* 38, 97-109.

Aksoy, M.A. and Beghin, J.C. (2005) *Global Agricultural Trade and Developing Countries*. World Bank, Washington DC.

Altieri, M. (1995) *Agroecology: The Science of Sustainable Agriculture.* Westview Press, Colorado.

Anderson, K. and Josling, T. (2005) *The WTO and Agriculture*. Edward Elgar Publishing Ltd., UK.

Andreoli, M. and Tellarini, V. (2000) Farm sustainability evaluation: methodology and practice. *Agriculture, Ecosystems and Environment* 77, 43-52.

Angus, A., Hodge, I., McNally, S. and Sutton, M. (2003) The setting of standards for agricultural nitrogen emissions: a case of the Delphi technique. *Journal of Environmental Management* 69, 323-337.

Anonymous (1994) *Certified BIO-GRO Organic Production Standards*. Biological Producers and Consumers Council (Inc.), Auckland, New Zealand.

Anonymous (2001) *Private Lands, Public Benefits: Principles for Advancing Working Lands Conservation.* National Governors Association/ Center for Best Practices, Washington. On WWW at www.nga.org

Bjorklund, J., Limburg, K.E. and Rydberg, T. (1999) Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: an example from Sweden. *Ecological Economics* 29, 269-291.

Bowie, M., Wratten, S. and Tylianakis, J. (2003) An introduction to entomological research on Kowhai Farm - The Heinz Wattie's organic farm at Lincoln University. *Weta* 25, 18-23.

Brady, N.C. (1990) *The Nature and Properties of Soils*. Macmillan Publishing Company, New York.

Brady, N.C. and Weil, R.R. (2004) *Elements of the Nature and Properties of Soils*. Prentice Hall, New Jersey.

Breemen, N.V. and Buurman, P. (2002) *Soil Formation.* Kluwer Academic Publishers, Dordrecht.

Brooks, K.W. (1979) Delphi technique: expanding applications. *North Central Association Quarterly* 54, 377-385.

Chambers, R. (1990) Farmer-first: a practical paradigm for the third agriculture. In: Altieri, M.A. and Hecht, S.B. (eds) *Agroecology and Small Farm Development* (pp. 237-244). CRC Press, Florida.

Collins, K.L., Wilcox, A., Chaney, K., Boatman, N.D. and Holland, J.M. (1997) The influence of beetle banks on aphid population predation in winter wheat. *Aspects of Applied Biology* 50, 341-346.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. *Nature* 387, 253–260.

Cranfield J.A.L. and Magnusson, E. (2003) Canadian consumer's willingness-to-pay for pesticide free food products: an ordered probit analysist. *International Food and Agribusiness Management Review* 6, 13-30.

Cullen, R., Takatsuka, Y., Wilson, M. and Wratten, S. (2004) Ecosystem services on New Zealand arable farms. Agribusiness and Economics Research Unit, Lincoln University, Discussion Paper 151, 84–91.

Cullen, R., Wilson, M., Wratten, S., Takatsuka, Y. Sandhu, H. and Tait, P. (2006) Accounting for ecosystem services associated with agricultural production in New Zealand. *Ecological Economics* (in press).

Curtis, I. (2004) Valuing ecosystem goods and services: a new approach using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes. *Ecological Economics* 50, 29-44.

Daily, G.C. (1997) Introduction: what are ecosystem services? In: Daily, G.C. (ed.) *Nature's Services: Societal Dependence on Natural Ecosystems* (pp. 1-10). Island Press, Washington DC.

Daily, G.C., Matson, P. and Vitousek, P. (1997a) Ecosystem services supplied by soil. In G.C. Daily (ed.) *Nature's Services: Societal Dependence on Natural Ecosystems* (pp. 113-132). Island Press, Washington DC.

Daily, G.C., Alexander, S., Ehrlich, P.R., Goulder, L., Lubchenco, J., Matson, P.A., Mooney, H.A., Postel, S., Schneider, S.H., Tilman, D. and Woodwell, G.M. (1997b) Ecosystem services: benefits supplied to human societies by natural ecosystems. *Issues in Ecology* 2, pp. 18.

de Bach, P. (1974) *Biological Control by Natural Enemies.* Cambridge University Press, London.

de Groot, R.S., Wilson, M. and Boumans, R.M. J. (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41, 393-408.

Edling, P. (2003) A farmer's view of ecosystem services. In: Proceedings of the International conference on ecosystem services in European agriculture – theory and practice, Falkenberg, Sweden.

Edwards, C.A. (2004) The importance of earthworms as key representatives of the soil fauna. In: Edwards, C.A. (ed.), *Earthworm Ecology* (pp. 3-11). CRC Press, Florida.

Egri, C.P. (1999) Attitudes, background and information preferences for Canadian organic farmers: implementation for organic farming advocacy and extension. *Journal of Sustainable Agriculture* 13, 45-72.

Ernle, L. (1961) *English Farming, Past and Present.* Heinemann, London.

Escudero, G. (1998) The vision and mission of agriculture in the year 2020: towards a focus that values agriculture and the rural environment *Agricultura, medio ambiente y pobreza rural en America Latina* 21-54.

Fairweather, J.R. (1999) Understanding how farmers choose between organic and conventional production: results from New Zealand and policy implications. *Agriculture and Human Values* 16, 51-63.

Fairweather, J.R. and Campbell, H.R. (2003) Environmental beliefs and farm practices of New Zealand farmers; contrasting pathways to sustainability. *Agriculture and Human Values* 20, 287-300.

Firbank, L.G. (2005) Striking a new balance between agricultural production and biodiversity. *Annals of Applied Biology* 146, 163-175.

Free, J.B. (1970) *Insect Pollination of Crops.* Academic Press, London.

Freyenberger, S., Levins, R., Norman, D. and Rumsey, D. (2001) Beyond profitability: using economic indicators to measure farm sustainability. *American Journal of Alternative Agriculture* 16, 31-34.

Garcia-Torres, L., Benites, J., Martinez-Vilela, A. and Holgado-Cabera, A. (eds) (2003) *Conservation Agriculture.* Kluwer Academic Publishers, Dordrecht.

Goldewijk, K.K. and Ramankutty, N. (2004) Land cover change over the last three centuries due to human activities: the availability of new global data sets. *GeoJournal* 61, 335-344.

Gordon, J. and Davis, L. (2003) *Valuing Honeybee Pollination*. Rural Industries Research and Development Corporation, Canberra.

Gordon, L.J., Steffen, W., Jonsson, B.F., Folke, C., Falkenmark, M. and Johannessen, A. (2005) Human modification of global water vapour flows from the land surface. *Proceedings of the National Academy of Sciences USA* 102, 7612-7617.

Gurr, G. M., Wratten, S. D. and Altieri, M. A. (eds) (2004) *Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods*. CSIRO, Victoria.

Heal, G.M. and Small, A.A. (2002) Agriculture and ecosystem services. In: Gardner, B.L. and Rausser, G.C. (eds) *Handbook of Agricultural Economics Vol. 2a* (pp. 1341-1369). Elsevier, Amsterdam.

Heal, G.M., Barbier, E.B., Boyle, K.J., Covich, A.P., Gloss, S.P., Hershner, C.H., Hoehn, J.P., Pringle, C.M., Polasky, S., Segerson, K. and Schrader-Frechette, K. (2005) *Valuing Ecosystem Services: Towards Better Environmental Decision-Making*. The National Academic Press, Washington DC.

Heywood, V.H. (ed.) (1995) *United Nations Environment Program, Global Biodiversity Assessment*. Cambridge University Press, Cambridge.

Holland, P. and Rahman, A. (1999) Review of trends in agricultural pesticide use in New Zealand. *MAF Policy Technical Paper* pp. 54. On WWW at http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/resource-management/pesticide-use-trends/PesticideTrends.PDF

Jacometti, M.A., Wratten, S.D., Walter, M. and Jaspers, M.V. (2006) Enhancing ecosystem services in vineyards: understorey management to reduce *Botrytis cinerea* primary inoculum. *Biological Control* (in press).

Johns, N.D. (1999) Conservation in Brazil's chocolate forest: the unlikely persistence of traditional cocoa agroecosystems. *Environmental Management* 23, 31-47.

Kasperczyk, N. and Knickel, K. (2006) Environmental impacts of organic farming. In: Kristiansen, P., Taji, A. and Reganold, J. (eds) *Organic Agriculture: A Global Perspective* (pp. 259-294). CSIRO Publishing, Australia.

Kort, J. (1988) Benefits of windbreaks to field and forage crops. *Agriculture, Ecosystems and Environment* 22/23, 165-190.

Kort, J. Collins, M. and Ditsch, D. (1988) A review of soil erosion potential associated with biomass crops. *Biomass and Bioenergy* 14, 351-359.

Krebs, J.R., Wilson, J.D., Bradbury, R.B. and Siriwardena, G.M. (1999) The second silent spring? *Nature* 400, 611-612.

Kremen, C. (2005) Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters* 8, 469–479.

Kremen, C., Williams, N.M., Bugg, R.L., Fay, J.P. and Thorp, R.W. (2004) The area requirements of an ecosystem service: crop pollination by native bee communities in California. *Ecology Letters* 7, 1109-1119.

Kremen, C., Williams, N.M. and Thorp, R.W. (2002) Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences USA* 99, 16812-16816.

Kristiansen, P., Taji, A. and Reganold, J. (2006) Organic agriculture: opportunities and challenges. In: Kristiansen, P., Taji, A. and Reganold, J. (eds) *OrganicAgriculture: A Global Perspective* (pp. 421-441). CSIRO Publishing, Australia.

Kumar, P. (2005) Market for ecosystem services. International Institute for Sustainable Development, Canada.

Lampkin, N. and Measures, M. (2001) *Organic Farm Management Handbook: Organic Farming Research Unit.* Aberystwyth: Institute of Rural Studies, University of Wales

Landis, D.A., Wratten, S.D. and Gurr, G.M. (2000) Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology* 45, 175-201.

Lee, K. E. (1985) *Earthworms: their Ecology and Relationships with Soils and Land Use.* Academic Press, Sydney.

Leenders, J.K., Visser, S.M. and Stroosnijder, L. (2005) Farmers' perceptions of the role of scattered vegetation in wind erosion control on arable land in Burkina Faso. *Land Degradation and Development* 16, 327-337.

Luck, G.W., Daily, G.C. and Ehrlich, P.R. (2003) Population diversity and ecosystem services. *Trends in Ecology and Evolution* 18, 331–336.

Lyon, P., Colquhoun, A. and Janhonen-Abruquah, H. (2003) Consumer confidence and UK food retailing: why does local food matter? *Food, Agriculture and Environment.*1, 12-21

MacLeod, A., Wratten, S.D., Sotherton, N.W. and Thomas, M.B. (2004) 'Beetle banks' as refuges for beneficial arthropods in farmland: long-term changes in predator communities and habitat. *Agricultural and ForestEntomology* 6, 147-154.

Manktelow, D., Stevens, P., Walker, J., Gurnsey, S., Park, N., Zabkiewicz, J., Teulon, D. and Rahman, A. (2005) *Trends in pesticides use in New Zealand: 2004.* Ministry for the Environment, New Zealand. On WWW at http://www.hortresearch.co.nz/files/science /ifp/nz-pesticide-trends.pdf

McCann, E. (1997) Environmental awareness, economic orientation, and farming practices: a comparison of organic and conventional farmers. *Environmental Management* 21, 747-758.

McTaggart, D., Findlay, C. and Parkin, M. (2003) *Economics*. Pearson Education, Australia.

Mäder, P., Fließbach, A., Dubois, D., Gunst, L., Fried, P., and Niggli, U. (2002) Soil fertility and biodiversity in organic farming. *Science* 296, 1694-1697.

Magdoff, F. and Weil, R.R. (eds) (2004) *Soil Organic Matter in Sustainable Agriculture*. CRC press, Florida.

Matheson, A. (1987) The value of honey bees to New Zealand. *The New Zealand Beekeeper* 194, 29.

Matheson, A. and Schrader, M. (1987) *The value of honey bees to New Zealand's primary production*. New Zealand: Ministry of Agriculture and Fisheries.

Matson, P.A., Parton, W.J., Power, A.G. and Swift, M.J. (1997) Agricultural intensification and ecosystem properties. *Science* 277, 504–509.

McCann, E. (1997) Environmental awareness, economic orientation, and farming practices: a comparison of organic and conventional farmers. *Environmental Management* 21, 747-758.

McLaren, R.G. and Cameron, K.C. (1996) *Soil Science*. Oxford University Press, Auckland.

Myers, N. (1996) Environmental services of biodiversity. *Proceedings of the National Academy of Sciences USA* 93, 2764–2769.

Nabhan, G.P. and Buchmann, S.L. (1997) Services provided by pollinators. In: G. C. Daily (ed.) *Nature's Services: Societal Dependence on Natural Ecosystems* (pp. 133-150). Island Press, Washington.

Nabhan, G.P. and Buchmann, S.L. (1998) *Forgotten Pollinators*. Island Press, Washington.

National Academy of Sciences (2001) *Growing Populations, Changing Landscapes: Studies from India, China, and the United States*. National Academy Press, Washington, DC.

Norton, R.L. (1988) Windbreaks: benefits to orchard and vineyard crops. *Agriculture, Ecosystems and Environment* 22/23, 205-213.

Pacini, C., Wossink, A., Giesen, G., Vazzana, C. and Huirne, R. (2003) Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis. *Agriculture, Ecosystems andEnvironment* 95, 273-288.

PCE (2004) Growing for good: intensive farming, sustainability and New Zealand's environment. Parliamentary Commissioner for the Environment, Wellington, New Zealand. On WWW at http:// www.pce.govt.nz /reports/allreports/1_877274_45_3.pdf

Pimentel, D., Acquay, H., Biltonen, M., Rice, P., Silva, M., Nelson, J., Lipner, V., Giordano, S., Horowitz, A. and D'Amore, M. (1992) Environmental and economic costs of pesticide use. *BioScience* 42, 750–760.

Pimentel, D. and Giampietro, M. (1994). *Food, Land, Population and the U.S. Economy.* Carrying Capacity Network, Washington, DC.

Pimentel, D. and Wilson, A. (2004) World population, agriculture and malnutrition. *World Watch* 17, 22-25.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R, and Blair, R. (1995) Environmental and economic costs of soil erosion and conservation benefits. *Science* 267, 1117–1125.

Pimentel, D., Hepperly, P., Hanson, J., Douds, D. and Seidael, R. (2005) Environmental, energetic, and economic comparisons of organic and conventional farming systems. *BioScience* 55, 573-582.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T. and Cliff, B. (1997) Economic and environmental benefits of biodiversity. *BioScience* 47, 747–758.

Pinstrup-Andersen, P. (1998) A global vision of agriculture, food and the environment *Agricultura, medio ambiente y pobreza rural en America Latina* 3-20.

Pollard, E., Hooper, M. and Moore, N. (1974) *Hedges*. Collins New Naturalist Series, London.

Prescott-Allen, R. and Prescott-Allen, C. (1990) How many plants feed the world? *Conservation Biology* 4, 365-374.

Pretty, J. (2002) *Agri-Culture: Reconnecting People, Land and Nature*. Earthscan, London.

Pretty, J. N. (2005) *The Pesticide Detox: Towards a More Sustainable Agriculture*. Earthscan, London.

Pretty, J.N., Brett, C., Gee, D., Hine, R.E., Mason, C.F., Morison, J.I.L., Raven, H., Raymant, M.D. and van der Bijl, G. (2000) An assessment of the total external costs of UK agriculture. *Agricultural Systems* 65, 113-136.

Pretty, J., Brett, C., Gee, D., Hine, R., Mason, C., Morison, J., Rayment, M., van der Bijl, G. and Dobbs, T. (2001) Policy challenges and priorities for internalizing the externalities of modern agriculture. *Journal of Environmental Planning and Management* 44, 263 – 283.

Pretty, J. and Hine, R. (2001) *Reducing Food Poverty with Sustainable Agriculture: a Summary of New Evidence*. Final Report from the "SAFE-World" (The Potential of Sustainable Agriculture to Feed the World) Research Project, University of Essex

Commissioned by UK Department for International Development. On WWW at http://www2.essex.ac.uk/ces/ResearchProgrammes/CESOccasionalPapers/SAFErepSUBHEADS.htm

Pretty, J. N. (1995) *Regenerating Agriculture: Policies and Practice for Sustainability and Self-Reliance.* Earthscan Publications, London.

Quansah, C., Drechsel, P., Yirenkyi, B.B. and Asante-Mensah, S. (2004) Farmer's perceptions and management of soil organic matter – a case study from West Africa. *Nutrient Cycling in Agroecosystems* 61, 205-213.

Reganold, J.P., Papendick, R.I., and Parr, J.F. (1990) Sustainable agriculture. *Scientific American* 262, 112-120.

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar, P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell, J. and Zurek, N.B. (2005) *Millennium Ecosystem Assessment Synthesis report.* Island Press, Washington DC.

Ricketts, T.H. (2004) Tropical forest fragments enhance pollinator activity in nearby coffee crops. *Conservation Biology* 18, 1262-1271.

Ricketts, T.H., Daily, G.C., Ehrlich, P.R. and Michener, C.D. (2004) Economic value of tropical forest to coffee production. *Proceedings of the National Academy of Sciences USA* 101, 12579-12582.

Robertson, G.P. and Swinton, S.M. (2005) Reconciling agricultural productivity and environmental integrity: a grand challenge for agriculture. *Frontiers in Ecology and Environment* 3, 38–46.

Roubik, D.W. (1995) *Pollination of Cultivated Plants in the Tropics*. FAO, Rome.

Sandhu, H.S., Wratten, S.D. and Cullen, R. (2005) Evaluating ecosystem services on farmland: a novel, experimental, 'bottom-up' approach. In: Proceedings of the 15th International Federation of Organic Agriculture Movements (IFOAM) Organic World Congress, Adelaide, Australia.

Silvano, R.A.M., Udvardy, S., Ceroni, M. and Farley, J. (2005) An ecological integrity assessment of a Brazilian Atlantic Forest watershed based on surveys of stream health and local farmers' perceptions: implications for management. *Ecological Economics* 53, 369-385.

Sotherton, N.W. (1995) Beetle banks-helping nature to control pests. *Pesticide Outlook* 6, 13-17.

Statistics New Zealand (2003) *Agricultural Production Statistics*. Statistics New Zealand, Wellington.

Stockdill, S.M.J. (1982) Effects of introduced earthworms on the productivity of New Zealand pastures. *Pedobiologia* 24, 29–35.

Storstad, O. and Bjørkhaug, H. (2003) Foundations of production and consumption of organic food in Norway: common attitudes among farmers and consumers? *Agriculture and Human Values* 20, 151-163. .

Sturrock, J.W. (1969) Aerodynamic studies of shelterbelts in New Zealand-1. Low to medium height shelterbelts in mid-Canterbury. *New Zealand Journal of Science* 12, 754-756.

Sturrock, J.W. (1981) Shelter boosts crop yield by 35 per cent: also prevents lodging. *New Zealand Journal of Agriculture* 143, 18-19.

Swift, M.J., Izac, A.M.N. and van Noordwijk, M. (2004) Biodiversity and ecosystem services in agricultural landscapes – are we asking the right questions? *Agriculture, Ecosystems and Environment* 104, 113-134.

Tait, P. and Cullen, R. (2006) Some external costs of Dairy farming in Canterbury. In: Proceedings of the 50th Australian Agricultural and Resource Economics Society (AARES) Annual Conference, Manly, Australia.

Takatsuka, Y., Cullen, R., Wilson, M. and Wratten, S. (2005a) Using choice modelling to value ecosystem services on arable land. In: proceedings of the 49th Australian Agricultural and Resource Economics Society (AARES) Annual Conference, Coffs Harbour, Australia.

Takatsuka, Y., Cullen, R., Wilson, M. and Wratten, S. (2005b) Values of ecosystem services on arable land and the role of organic farming. In: Proceedings of the New Zealand Agricultural and Resource Economics Society (NZARES) 11th annual conference, Nelson, New Zealand.

Tegtmeier, E.M. and Duffy, M.D. (2004) External costs of agricultural production in the United States. *International Journal of Agricultural Sustainability* 2, 1-20.

Thomas, S. (2000) Progress on beetle banks in UK arable farming. *Pesticide Outlook* 11, 51-53.

Thomas M.B., Wratten, S.D. and Sotherton, N.W. (1991) Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: predator densities and emigration. *Journal of Applied Ecology* 28, 906-917.

Thomas M.B., Wratten, S.D. and Sotherton, N.W. (1992) Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: predator densities and species composition. *Journal of Applied Ecology* 29, 524-531.

Thrupp, L A. (1996) *Partnerships for Sustainable Agriculture.* World Resources Institute, Washington DC.

Tilman, D. (1998) The greening of the green revolution. *Nature* 396, 211-212.

Tilman, D. (1999) Global environmental impacts of agricultural expansion:The need for sustainable and efficient practices. *Proceedings of the National Academy of Sciences USA* 96, 5995-6000.

Tilman, D., Cassman, G., Matson, P.A., Naylor, R., and Polasky, S. 2002 Agricultural sustainability and intensive production practices. *Nature* 418, 671-677

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., and Swackhamer, D. (2001) Forecasting agriculturally driven global environmental change. *Science* 292, 281-284.

Tilman, D. and Lehman, C. (2001) Human-caused environmental change: impacts on plant diversity and evolution. *Proceedings of the National Academy of Sciences* 98, 5433-5440.

Tilman, D., Reich, P.B. and Knops, J.M.H. (2006) Biodiversity and ecosystem stability in a decade-long grassland experiment. *Nature* 441, 629-632.

UN (1992) *Promoting sustainable agriculture and rural development. United Nations Conference on Environment & Development.* Rio de Janerio, Brazil, 3 to 14 June. Agenda 21, 14.1-14.104. On WWW at http://www.un.org/esa/sustdev/agenda21.htm

UNEP (2005) *One Planet, Many People: Atlas of Our Changing Environment.* UN, New York.

Vitousek, P.M., Mooney, H.A., Lubchenco, J. and Melillo, J.M. (1997) Human domination of earth's ecosystems. *Science* 277, 494-499.

Vos, T. (2000) Visions of the middle landscape: organic farming and the politics of nature. *Agriculture and Human Values* 17, 245-256.

Warner, K.D. (2006) Extending agroecology: grower participation in partnerships is key to social learning. *Renewable Agriculture and FoodSystems* 21, 84-94.

Williams, M. (2004) Sustainable New Zealand-the way forward. *New Zealand Geographic* 70, 7-8.

Willer, H. and Yussefi, M. (eds) (2006) *The World of Organic Agriculture 2006: Statistics and Emerging Trends*. International Federation of Organic Agriculture Movements (IFOAM), Bonn.

Chapter 3 Field Evaluation of Ecosystem Services in Organic and Conventional Arable Land[1]

Abstract

Ecosystem services 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 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. This study also estimated the economic value of these services using experimental data, in contrast with 'value transfer' approaches used in previous studies. The results showed that background (un-manipulated) biological control of pests in conventional arable farming was 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. However, earthworm populations and the soil formation services they provide did increase with time since conversion to organic practices. This work quantified the role that land management practices play in the maintenance and enhancement of 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.

3.1 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

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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 & 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 & 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 & Swinton, 2005). The need to address the threats to ES is more acute in agriculture than in other ecosystems (Robertson & 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 yr^{-1}, with an annual mean of US \$33 trillion. This assessment was based on published studies and used 'value transfer' techniques (Wilson *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 yr^{-1}, while in New Zealand, Patterson & 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 & Swinton, 2005). These have been extensively modified by humans explicitly to provide a set of ecosystem goods and services (Heal & 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, 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 ES (biological control of pests, soil formation, and the mineralisation of plant nutrients) 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 to these key ES.

3.1.1 Biological control of pests

Biological control services provided by pests' natural enemies can prevent outbreaks of pests and stabilise agricultural systems worldwide (Naylor & 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 & 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 & Finch, 1971; Jones, 1975; Ryan, 1975) and predators play an important role in the population dynamics of the carrot rust fly (Burn, 1982).

3.1.2 Soil formation

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

3.1.3 Mineralisation of plant nutrients

Organic matter breakdown by soil micro-organisms and invertebrates (Parkinson & Coleman, 1991; Brady & 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 & Arancon, 2004).

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

3.2 Materials and methods

3.2.1 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 (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 (www.ifoam.org).

A list of arable farmers in Canterbury was obtained from the Foundation for Arable Research, Lincoln (www.far.org.nz) and OPENZ (Organic Products Exporters of New Zealand; 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. 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, filed beans, white clover for seed and onions. The number of conventional and organic fields in each of those crops was the same. The 29[th] field (conventional) was in peas. Codes O1-O14 were assigned to the organic fields and C1-C15 to the conventional ones. 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. 3.1.

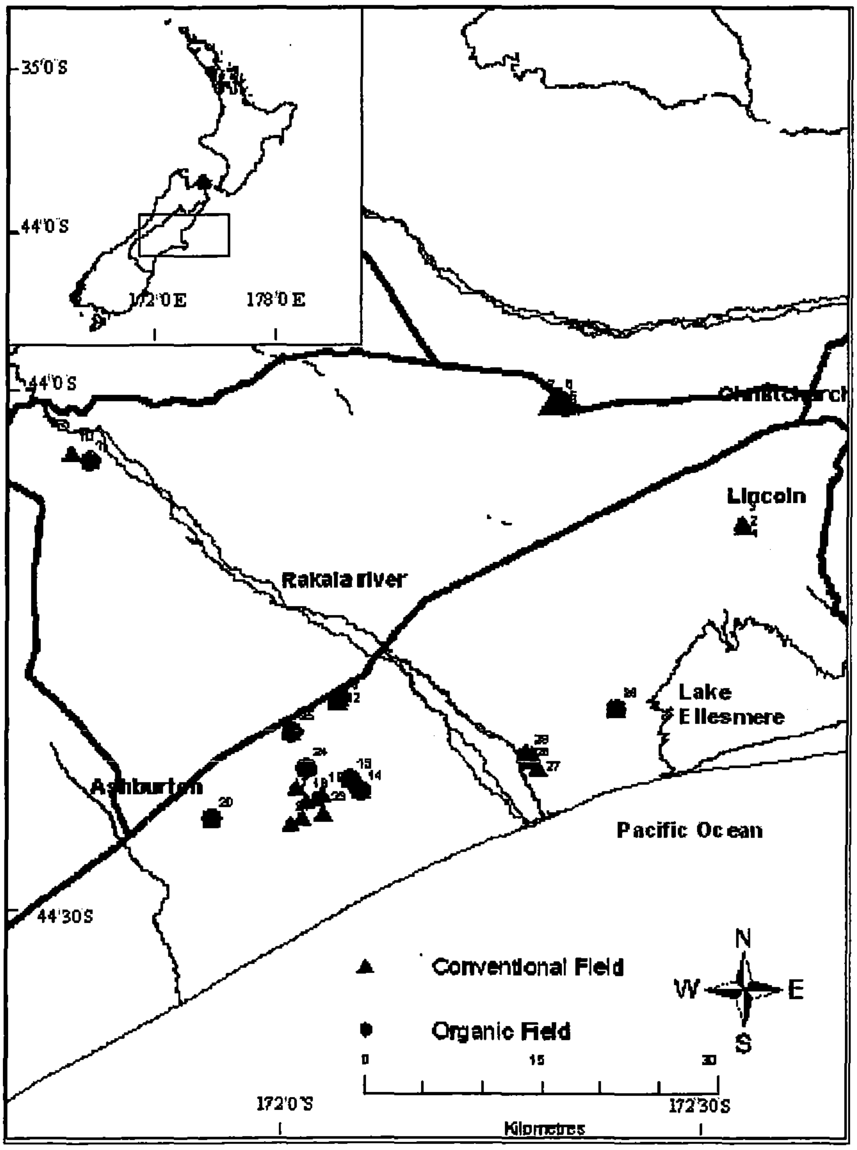

Fig. 3.1 Map of New Zealand showing the study area (selected fields).

3.2.2 Predation rate of aphids and fly eggs and its economic value

Aphids in many arable crops and the carrot rust fly (*Psila 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 each of two periods: November 2004 and January 2005. During November, 27 fields were assessed for predation rate as the crop was not sown in two fields. And during January, 23 fields were assessed as 6 fields were harvested by that time. In each period, two prey densities for each prey type were assessed. The aphid densities were selected in November 2004 ($1/25cm^2$ and $4/25cm^2$) and January 2005 ($4/25cm^2$ and $10/25cm^2$) 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 $3–8/25cm^2$ (Burn, 1982) in the field.

Predation rate was assessed using 'prey surrogates' comprising $25cm^2$ water-proof sandpaper squares pinned to the soil surface by wooden toothpicks. Live aphids (dorsal side uppermost) were glued onto the sandpaper (P150, Norton) using 3M repositionable glue in a grid pattern with 1cm 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 (5m apart) in each field and had a 225 cm^2 metal plate supported 10cm above to protect them from rain.

Predation rate was calculated from the removal of 'prey' types per 24 h period during the two study periods. 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 for each period, overall mean prey disappearance was calculated separately from the means of the two prey densities.

The economic value (2005 US $\$ha^{-1}yr^{-1}$) 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 $ha^{-1}yr^{-1}$ 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 $ha^{-1}application^{-1}$ 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 AC and TAC are provided on a $ha^{-1}yr^{-1}$ 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. Without the availability of a predator-prey model to estimate the decrease in pest populations following a 24 h predation event, the estimates of the economic value (AC and TAC) of biological control are based on the assumption that conventional farmers apply two such applications per year. This is reasonable, based on current spray recommendations (Chapman, 2004).

To calculate the economic value of aphid predation, three densities (with equal probability of occurrence) were used. These were: density 1 (d1; 10 aphids/25cm^2, maximum density used in the predation work), density 2 (d2; 7.5 aphids/25cm^2) and density 3 (d3; 6.25 aphids/25cm^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/25cm^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) were estimated for the two periods during November 2004 and January 2005.

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/25cm^2, ET2; 5 eggs/25cm^2, ET3; 3.75 eggs/25cm^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 AC and TAC was assigned to the fields in which predation rate was able to bring the pest population below the economic threshold. Then the values obtained for the two periods (November 2004 and January 2005) were added to provide the total economic value in each field.

3.2.3 Earthworm populations and their economic value in soil formation

Earthworm populations were assessed to estimate the quantity of soil formed $ha^{-1}yr^{-1}$. Sampling was done during the spring as earthworm populations are generally highest at this time in New Zealand (Martin, 1978). Four $25cm^3$ 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 $2m^2$ polythene sheet and earthworms were extracted by hand and placed in a collection jar. The samples from 29 fields were stored in the dark at 10°C prior to sorting for age class and species.

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

3.2.4 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 16cm long, 0.6cm broad and 1mm thick strips of rigid plastic with sixteen 2mm 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 & 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).

In this study, the economic value (2005 US \$ $ha^{-1}yr^{-1}$) 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 10cm 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 this and valued at the equivalent price of N kg^{-1} (US \$0.84 kg^{-1}; Ravensdown, 2005) providing the economic value of nutrient mineralisation (see Appendix for details).

3.3 Results

3.3.1 Predation rate of aphids and blowfly eggs and its economic value

The aphids removed in 24 h ranged from 3.3 to 80.0% in organic fields and 0–13.3% in conventional fields during November 2004. In January 2005 the data were 4.7–48.8% (organic) and 0–5.9% (conventional) (Fig. 3.2). The blowfly eggs removed in 24 h ranged from 5.9 to 75.7% in organic fields and 0–13.6% in conventional fields during November 2004. In January 2005 the data were 18.2–50.0% (organic) and 0–6.0% (conventional) (Fig. 3.3).

Predation rate of aphids and blowfly eggs in organic fields was compared with that in conventional fields using t-test for unequal sample variances. Predation rate of aphids was

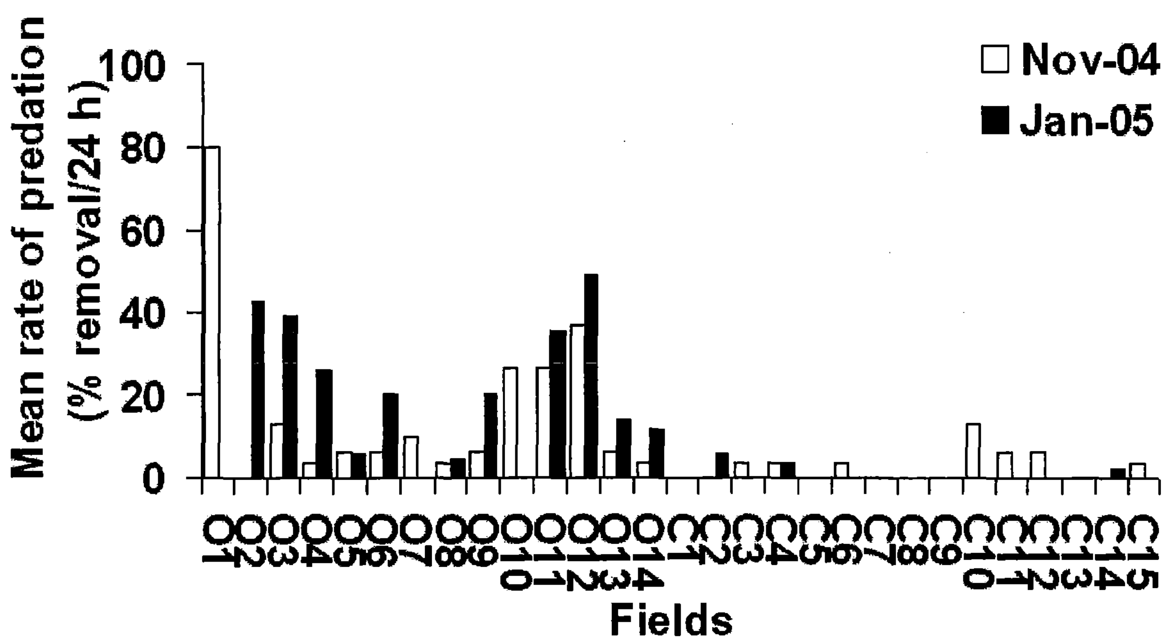

Fig. 3.2 Predation rate (% removal /24 h) of aphids in selected fields, November 2004 and January 2005. Organic fields: O1-O14, conventional fields: C1-C15.

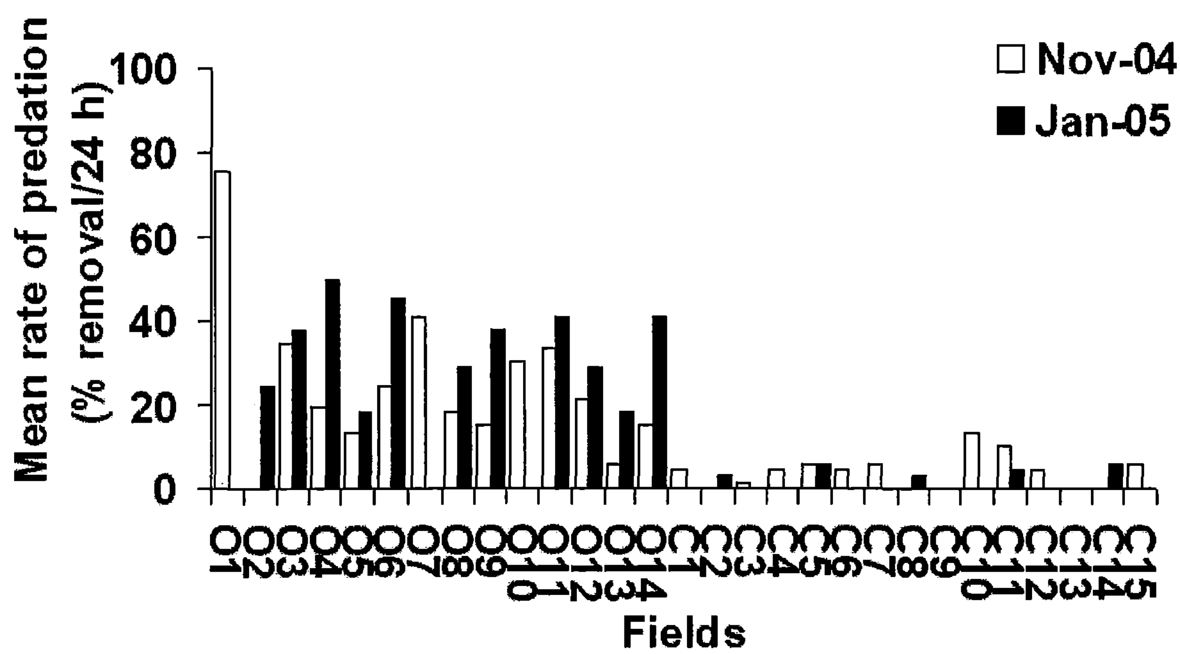

Fig. 3.3 Predation rate (% removal /24 h) of blowfly eggs in selected fields, November 2004 and January 2005. Organic fields: O1-O14, conventional fields: C1-C15.

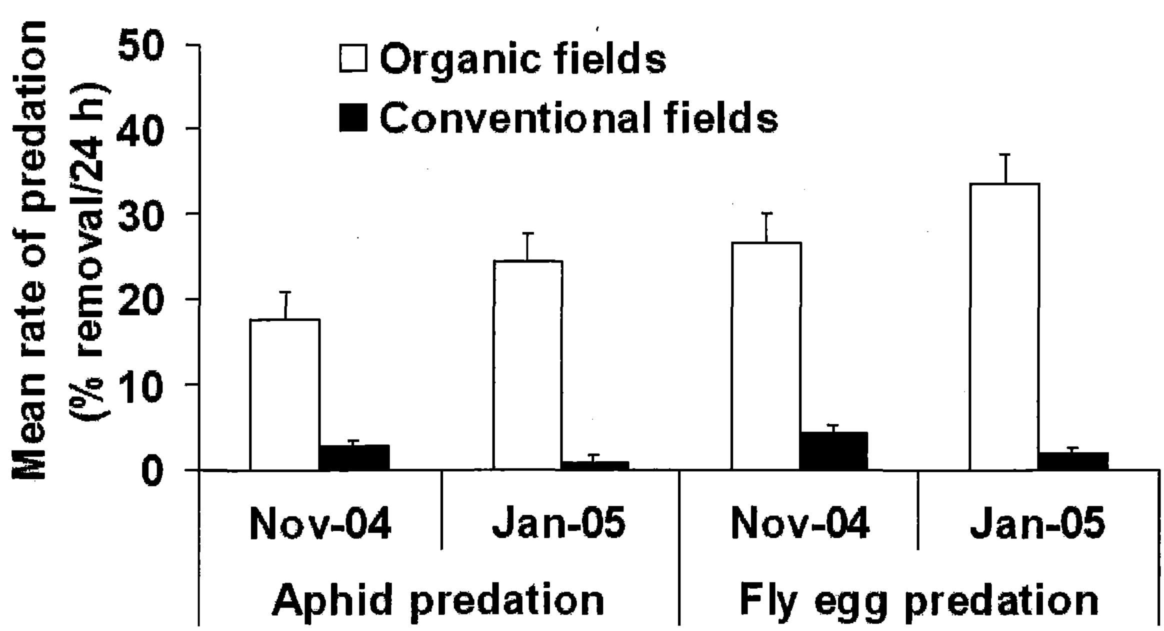

Fig. 3.4 Mean rate of predation (% removal/24 h) of aphids and blowfly eggs in organic and conventional fields. Error bars are 0.5 SE.

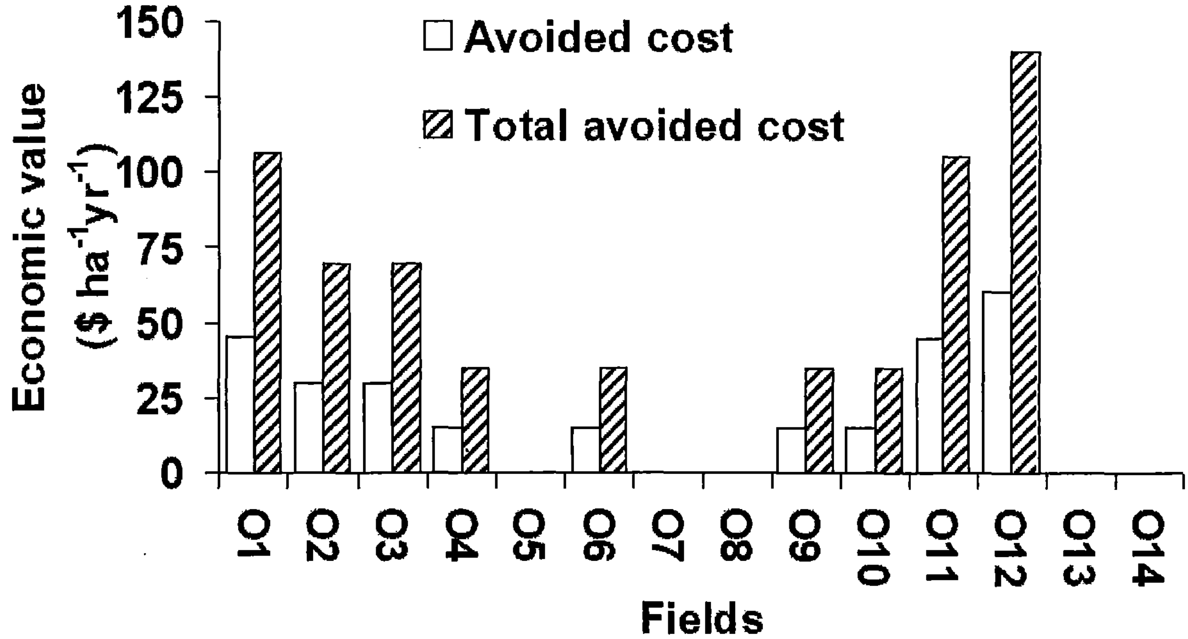

Fig. 3.5 Economic value of biological control of aphids in organic fields. Total avoided cost includes external cost (see Materials and Methods). In five fields, predation rate was so low that avoided costs could not be calculated (see text).

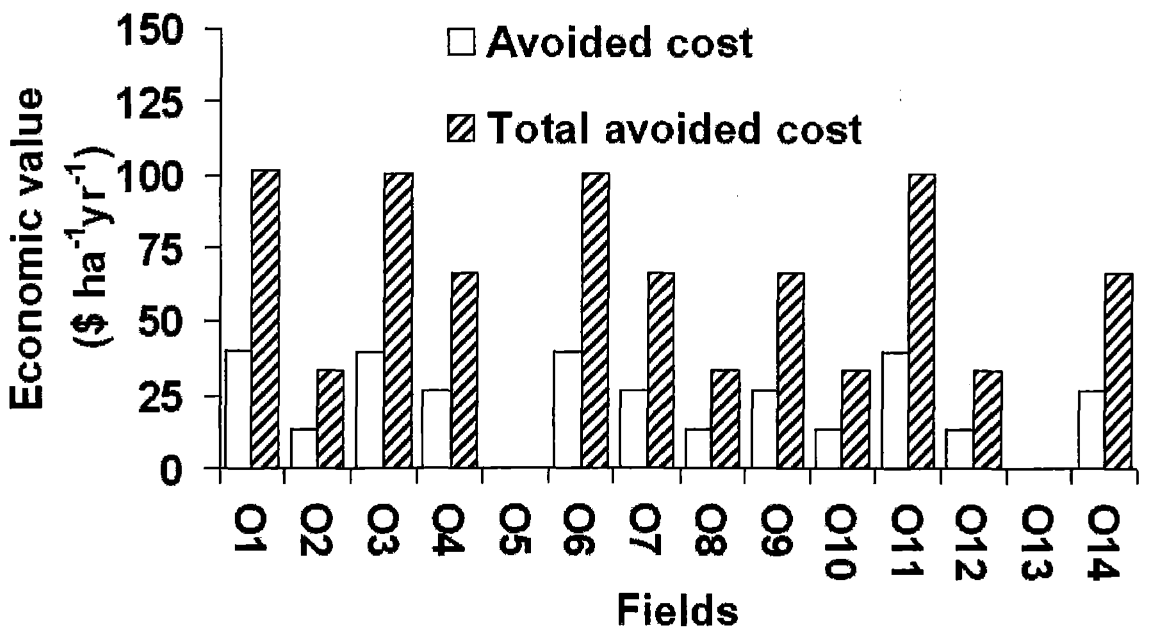

Fig. 3.6 Economic value of biological control of carrot rust fly in organic fields. Total avoided cost includes external cost. In two fields, predation rate was so low that avoided costs could not be calculated (see text).

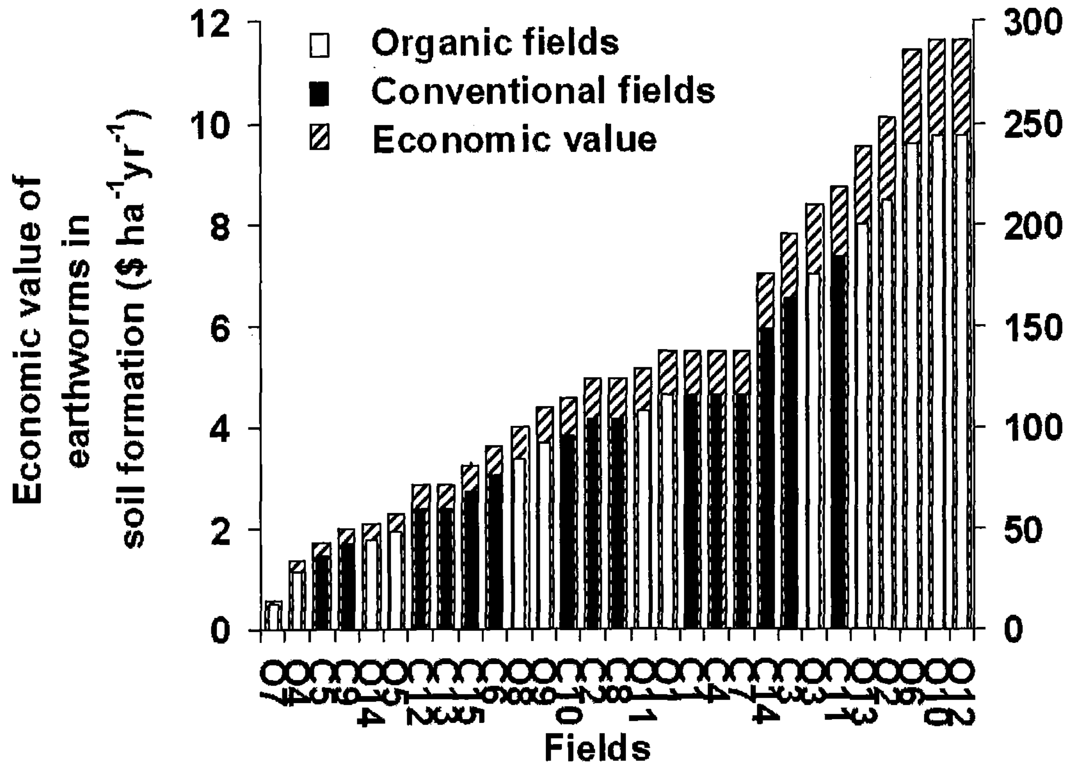

Fig. 3.7 Earthworm populations (no. m^{-2}) and their economic value in soil formation ($ ha^{-1}yr^{-1}) in ranked organic (O1-O14) and conventional fields (C1-C15). There were no significant differences between the two field types (see text).

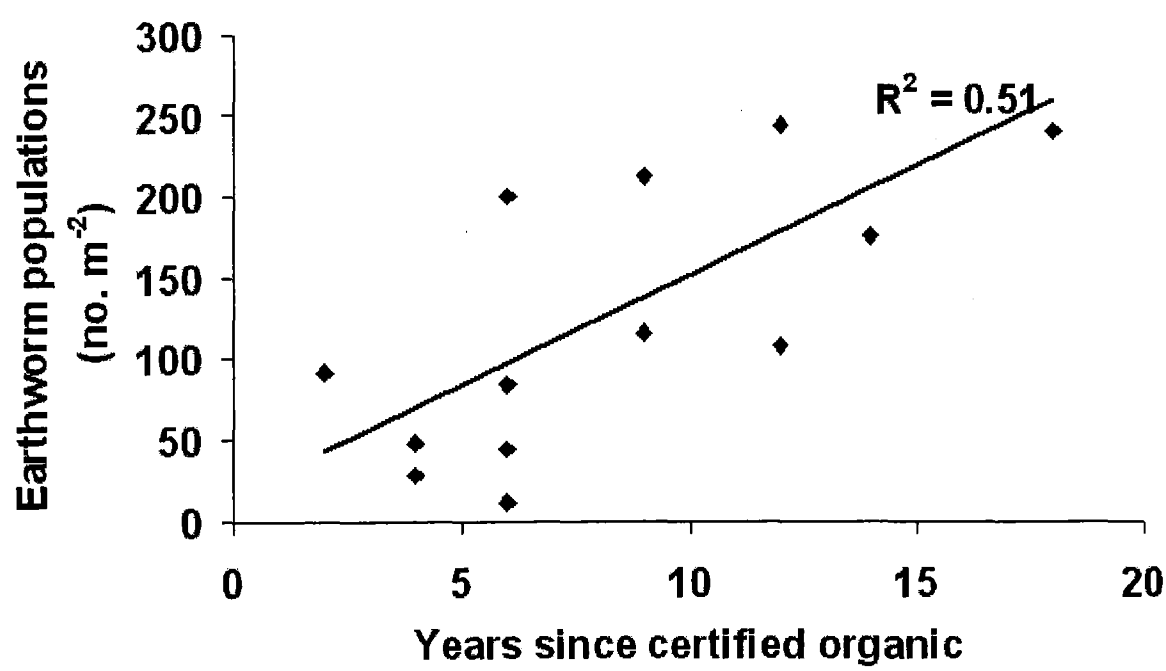

Fig. 3.8 Earthworm population (no. m^{-2}) in organic fields in relation to the number of years since conversion to organic.

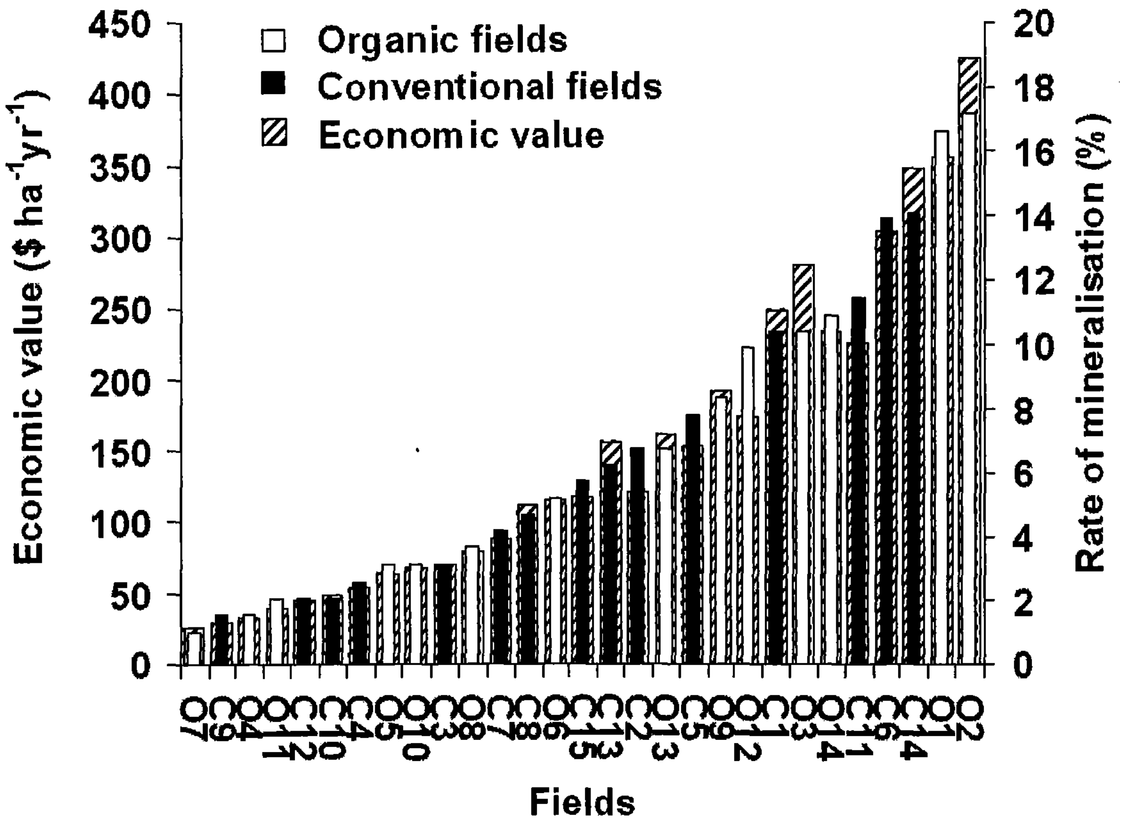

Fig. 3.9 Mineralisation of plant nutrients (mean % removal of bait) using bait-lamina probes and its economic value (\$ ha^{-1}yr^{-1}) in ranked organic (O1-O14) and conventional fields (C1-C15). There were no significant differences between the two field types (see text).

significantly higher in organic fields than in the conventional ones ($p < 0.05$, November 2004; $p < 0.001$, January 2005). That of blowfly eggs was also significantly higher ($p < 0.001$, November 2004; $p < 0.001$, January 2005) in organic fields than the conventional ones (Fig. 3.4). There was no significant increase in predation of aphids or blowfly eggs on any of the periods in relation to number of years since the fields had been certified organic.

The economic value of the biological control of aphids was in the range of US \$15.00–60.00 ha^{-1}yr^{-1} (AC) and US \$35.00–140.00 ha^{-1}yr^{-1} (TAC) in nine organic fields (O1, O2, O3, O4, O6, O9, O10, O11, O12) as presented in Fig. 3.5. 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 \$13.00–40.00 ha^{-1}yr^{-1} (AC) and US \$33.00–101.00 ha^{-1}yr^{-1} (TAC) for in all the organic fields except O5 and O13 (Fig. 3.6). 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.

3.3.2 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. 3.7). There were no significant differences between organic and conventional fields. However, earthworm populations increased significantly ($p < 0.01$) with the number of years the farm has been certified organic (Fig. 3.8). Non-linear regression was also conducted but the results did not change.

From the assumptions and economic information in section 2.3 above, the value of soil formation was calculated (Fig. 3.8). It was in the range of US \$0.60–11.60 $ha^{-1}yr^{-1}$ (mean US \$6.00 $ha^{-1}yr^{-1}$) in organic fields and US \$1.70–8.75 $ha^{-1}yr^{-1}$ (mean US \$4.75 $ha^{-1}yr^{-1}$) in conventional fields.

3.3.3 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. 3.9. The extent of removal in organic fields was 1.04–17.18% and 1.56–14.06% in conventional ones. There were no significant differences between organic and conventional fields. There was no significant increase in mineralisation rate in relation to the number of years since conversion to organic practices.

The range in mineralisation was from US \$25.60 to 425.50 $ha^{-1}yr^{-1}$ (mean US \$160.65 $ha^{-1}yr^{-1}$) in organic fields and US \$30.00–348.00 $ha^{-1}yr^{-1}$ (mean US \$142. $ha^{-1}yr^{-1}$) in conventional ones (Fig. 3.9).

3.4 Discussion

The economic values of selected ES were calculated based on experimental assessment in each field. Conventional arable farming can suppress the ability of farmland to provide 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 'bottom-up' approach used in the current work demonstrate 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. Organic agriculture, as one way of enhancing agricultural sustainability, can contribute in this regard, and results here (Fig. 3.8) support this.

Mineralisation of plant nutrients by soil biota is also an important ES (Tate & Rogers, 2002) and its economic value for organic and conventional fields is estimated in the current study. 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 (Barberi, 2002; Stonehouse *et al.*, 1996) and the mechanical methods which are often used can reduce soil carbon levels (Grace *et al.*, 1995; Heenan *et al.*, 1995; Russell & Williams, 1982; 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.*, in press). 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).

3.5 Conclusion

The current study was designed to assess the effects of arable farming on the provision of ES at the field level. This work demonstrates that the engineered system studied is both a consumer and a provider of three key 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 were sometimes 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.

References

Andrade De Souza, D., Colozzi-Filho, A., Balota, E.L. and Hungria, M. (2003) Long-term effects of agricultural practices on microbial community. In: Garcia-Torres, L., Benites, J., Martinez-Vilela, A. and Holgado-Cabera, A. (eds) *Conservation Agriculture* (pp. 301-306). Kluwer Academic Publishers, Dordrecht.

Anonymous (1994) Certified BIO-GRO Organic Production Standards, Northcote, Auckland, New Zealand, Biological Producers and Consumers Council (Inc.)

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rossendo, S., Roughgarden, J., Trumper, K. and Turner, R.K. (2002) Economic reasons for saving wild nature. *Science* 297, 950–953.

Barberi, P. (2002) Weed management in organic agriculture: are we addressing the right issue? *Weed Research* 42, 177–193.

Beare, M., van der Weerden, T., Tregurtha, C. and Williams, P. (2001) Soil quality management system user manual. New Zealand Institute for Crop and Food Research Limited, Christchurch.

Brady, N.C. (1990) *The Nature and Properties of Soils*. Macmillan Publishing Company, New York.

Brady, N.C., Weil, R.R. (2004) *Elements of the Nature and Properties of Soils*. Prentice Hall, New Jersey.

Breemen, N.V. and Buurman, P. (2002) *Soil Formation*. Kluwer Academic Publishers, Dordrecht.

Burn, A.J. (1982) The role of searching efficiency in carrot fly egg loss. *Annals of Applied Biology* 101, 154–159.

Burn, A.J. (1984) Life tables for the carrot fly, *Psila rosae*. *Journal of Applied Ecology* 21, 891–902.

Chambers, R.J., Sunderland, K.D., Wyatt, I.J. and Vickermann, G.P. (1983) The effects of predator exclusion and caging of cereal aphids in winter wheat. *Journal of Applied Ecology* 20, 209–224.

Chapman, B. (2004) Insect pest control. In: Fleming, P.H. (ed.) *Farm Technical Manual,* Farm Management Group, Lincoln University. The Caxton Press, Christchurch.

Chiverton, P.A. (1986) Predator density manipulation and its effect on populations of *Rhopalosiphum padi* (Hom: Aphididae) in spring barley. *Annals of Applied Biology* 109, 49–60.

City Care (2005) *Rock and Landscape Supplies*, Christchurch, New Zealand.

Coaker, T.H. and Finch, S. (1971) The cabbage root fly, *Erioischia brassicae* (Bouchè). Report of the National Vegetable Research Station for 1970.

Coleman, D.C., Cole, C.V. and Elliot, E.T. (1984) Decomposition, organic matter turnover and nutrient dynamics in agroecosystems. In: Lowrance, R., Stiner, B.R. and House, G.J. (eds) *Agricultural Ecosystems–Unifying Concepts* (pp. 83-104). Wiley-Interscience, New York.

Costanza, R. (2001) Visions, values, valuation, and the need for an ecological economics. *BioScience*, 459–468.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. *Nature* 387, 253–260.

Cullen, R., Takatsuka, Y., Wilson, M. and Wratten, S. (2004) Ecosystem services on New Zealand arable farms. Lincoln University, Agribusiness and Economics Research Unit, Discussion Paper 151, 84–91.

Curry, J.P. (2004) Factors affecting the abundance of earthworms in soils. In: Edwards, C.A. (ed.), *Earthworm Ecology* (pp. 91-113), CRC press, Florida..

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

Daily, G.C., Alexander, S., Ehrlich, P.R., Goulder, L., Lubchenco, J., Matson, P.A., Mooney, H.A., Postel, S., Schneider, S.H., Tilman, D. and Woodwell, G.M. (1997) Ecosystem services: benefits supplied to human societies by natural ecosystems. *Issues in Ecology* 2, 1-18.

de Bach, P. (1974) *Biological Control by Natural Enemies*. Cambridge University Press, London.

de Groot, R.S., Wilson, M. and Boumans, R.M.J. (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41, 393–408.

Edwards, C.A. (2004) The importance of earthworms as key representatives of the soil fauna. In: Edwards, C.A. (ed.) *Earthworm Ecology* (pp. 3-11). CRC press, Florida.

Edwards, C.A. and Arancon, N.Q. (2004) Interactions among organic matter, earthworms, and microorganisms in promoting plant growth. In: Magdoff, F. and Weil, R.R. (eds.) *Soil Organic Matter in Sustainable Agriculture* (pp. 327-376). CRC press, Florida.

Ekbom, B.S., Wiktelius, S. and Chiverton, P.A. (1992) Can polyphagous predators control the bird cherry-oat aphid (*Rhopalosiphum padi*) in spring cereals? A simulation study. *Entomologia experimentalis et applicata* 65, 215–223.

Farber, S.C., Costanza, R. and Wilson, M.A. (2002) Economic and ecological concepts for valuing ecosystem services. *Ecological Economics* 41, 375–392.

Fraser, P.M., Williams, P.H. and Haynes, R.J. (1996) Earthworm species, population size and biomass under different cropping systems across the Canterbury Plains, New Zealand. *Applied Soil Ecology* 3, 49–57.

Grace, P.R., Oades, J.M., Keith, H. and Hancock, T.W. (1995) Trends in wheat yields and soil organic carbon in the Permanent Rotation Trial at the Waite Agricultural Research Institute, South Australia. *Australian Journal of Experimental Agriculture* 35, 857–864.

Gurr, G.M., Scarratt, S.L., Wratten, S.D., Berndt, L. and Irvin, N. (2004) Ecological engineering, habitat manipulation and pest management. In: Gurr, G.M., Wratten, S.D. and Altieri, M.A. (eds) *Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods* (pp. 1-12). CSIRO, Victoria.

Heal, G.M. and Small, A.A. (2002) Agriculture and ecosystem services. In: Gardner, B.L. and Rausser, G.C. (eds) *Handbook of Agricultural Economics* (pp. 1341-1369). Elsevier, Amsterdam.

Helling, B., Pfeiff, G. and Larink, O. (1998) A comparison of feeding activity of collembolan and enchytraeid in laboratory studies using the bait-lamina test. *Applied Soil Ecology* 7, 207–212.

Heenan, D.P., McGhie, W.J., Thomson, F.M. and Chan. K.Y. (1995) Decline in soil organic carbon and total nitrogen in relation to tillage, stubble management and rotation. *Australian Journal of Experimental Agriculture* 35, 877–884.

Jacometti, M.A., Wratten, S.D., Walter, M. and Jaspers, M.V. (2006) Enhancing ecosystem services in vineyards: understorey management to reduce *Botrytis cinerea* primary inoculum. *Biological Control* (in press).

Jones, M.G. (1975) The predators of wheat-bulb fly. *Annals of Applied Biology* 80, 128–130.

Kratz, W. (1998) The bait-lamina test: general aspects, applications and perspectives. *Environmental Science and Pollution Research* 5, 94–96.

Kremen, C. (2005) Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters* 8, 469–479.

Kumar, P. (2005) Market for ecosystem services. International Institute for Sustainable Development, Canada.

Lee, K.E. (1985) *Earthworms: their Ecology and Relationships with Soils andLandUse.* Academic Press, Sydney.

Lys, J. (1995) Observation of epigeic predators and predation on artificial prey in a cereal field. *Entomologia experimentalis et applicata* 75, 265–272.

Martin, N.A. (1978) Earthworms in New Zealand agriculture. In: Proceedings of the 31st New Zealand Weed and Pest Control Conference.

Matson, P.A., Parton, W.J., Power, A.G. and Swift, M.J. (1997) Agricultural intensification and ecosystem properties. *Science* 277, 504–509.

McCloy, B.L. (2004) Wheat management guidelines. In: Fleming, P.H. (ed.), *Farm Technical Manual* (pp. D37-40). Farm Management Group, Lincoln University. The Caxton Press, Christchurch. .

Millennium Ecosystem Assessment (2003) *Ecosystems and Human Well-being: a Framework for Assessment.* Island Press, Washington, DC.

Myers, N. (1996) Environmental services of biodiversity. *Proceedings of the National Academy of Sciences USA* 93, 2764–2769.

Naeem S., Chair, F.S., Chapin III, Costanza, R., Ehrlich, P.R., Golley, F.B., Hooper, D.U., Lawton, J.H., O'Neill, R.V., Mooney, H.A., Sala, O.E., Symstad, A.J. and Tilman, D. (1997) Biodiversity and ecosystem functioning: maintaining natural life support processes. *Issues in Ecology* 4, pp. 14.

Naylor, R.L. and Ehrlich, P.R. (1997) Natural pest control services and agriculture. In: Daily, G.C. (ed.) *Nature's Services: Societal Dependence on Natural Ecosystems* (pp. 151-174). Island Press, Washington, D.C.

Östman, Ö., Ekbom, B. and Bengston, J. (2003) Yield increase attributable to aphid predation by ground-living polyphagous natural enemies in spring barley in Sweden. *Ecological Economics* 45, 149–158.

Palmer, M., Bernhardt, E., Chornesky, E., Collins, S., Dobson, A., Duke, C., Gold, B., Jacobson, B., Kingsland, S., Kranz, R. Mappin, M., Martinez, M., Micheli, F., Morse, J., Pace, M., Pascual, M., Palumbi, S., Reichman, O., Simons, A., Townsend, A. and Turner, A. (2004) Ecology for a crowded planet. *Science* 304, 1251–1252.

Papini, R., Gamba, C., Piovanelli, C. and Brandi, G. (2002) Impact of tillage practices on seasonal nitrate dynamics, leaching and microbial activity in a crop rotation. In: Violante, A., Huang, P.M., Bollag, J.M. and Gianfreda, L. (eds) *Soil Mineral-Organic Matter-Microorganism Interactions and Ecosystem Health* (pp. 275-287). Elsevier, Amsterdam.

Parkinson, D. and Coleman, D.C. (1991) Microbial communities, activity and biomass. *Agriculture Ecosystems and Environment* 34, 3–33.

Patterson, M. and Cole, A. (1999) Assessing the value of New Zealand's biodiversity. Massey University, School of Resource and Environmental Planning, Occasional Paper no. 1.

Pimentel, D., Acquay, H., Biltonen, M., Rice, P., Silva, M., Nelson, J., Lipner, V., Giordano, S., Horowitz, A. and D'Amore, M. (1992) Environmental and economic costs of pesticide use. *BioScience* 42, 750–760.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. and Blair, R. (1995) Environmental and economic costs of soil erosion and conservation benefits. *Science* 267, 1117–1125.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T. and Cliff, B. (1997) Economic and environmental benefits of biodiversity. *BioScience* 47, 747–758.

Pimentel, D. and Wilson, A. (2004) World population, agriculture and malnutrition. *World Watch* 17, 22–25.

Pretty, J.N. (2005) *The Pesticide Detox: Towards a More Sustainable Agriculture.* Earthscan, London.

Pretty, J.N., Brett, C., Gee, D., Hine, R.E., Mason, C.F., Morison, J.I.L., Raven, H., Raymant, M.D. and van der Bijl, G. (2000) An assessment of the total external costs of UK agriculture. *Agricultural Systems* 65, 113–136.

Ravensdown (2005) National Price List, Ravensdown Fertiliser Co-operative Limited, New Zealand.

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar, P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell, J. and Zurek, N.B. (2005) *Millennium Ecosystem Assessment Synthesis report.* Island Press, Washington, D.C.

Robertson, G.P. and Swinton, S.M. (2005) Reconciling agricultural productivity and environmental integrity: a grand challenge for agriculture. *Frontiers in Ecology and the Environment* 3, 38–46.

Root, R.B. (1967) The niche exploitation pattern of the blue-gray gnatcatcher. *Ecological Monographs* 37, 317–350.

Russell, J.S. and Williams, C.H. (1982) Biochemical interactions of carbon, nitrogen, sulphur and phosphorus in Australian agroecosystems. In: Galbally, I.E. and Freney, J.R. (eds) *Cycling of Carbon, Nitrogen,Sulphur and Phosphorus in Terrestrial and Aquatic Ecosystems* (pp. 61-75). Springer, Berlin.

Ryan, M.F. (1975) The natural mortality of wheat-bulb fly pupae, *Leptohylemia coarctata* (Fall.) (Dipt., Anthomyiidae). *Plant Pathology* 24, 27–30.

Schmidt, M. H., Lauer, A., Purtauf, T., Thies, C., Schaefer, M. and Tscharntke, T. (2003) Relative importance of predators and parasitoids for cereal aphid control. *Proceedings of the Royal Society B* 270, 1905–1909.

Sherrod, L.A., Peterson,G.A., Westfall, D.G. and Ahuja, L.R. (2005) Soil organic carbon pools after 12 years in no-till dryland agroecosystems. *Soil Science Society of America Journal* 69, 1600–1608.

Statistics New Zealand (2003) Agricultural production statistics. Wellington, Statistics New Zealand.

Stockdill, S.M.J. (1982) Effects of introduced earthworms on the productivity of New Zealand pastures. *Pedobiologia* 24, 29–35.

Peter Stonehouse, D., Weise, S.F., Sheardown, T., Gill, R.S. and Swanton, C.J. (1996) A case study approach to comparing weed management strategies under alternative farming systems in Ontario. *Canadian Journal of Agricultural Economics* 44, 81– 99.

Sunderland, K.D., Fraser, A.M. and Dixon, A.F.G. (1986) Field and laboratory studies on money spiders (Linyphiidae) as predators of cereal aphids. *Journal of Applied Ecology* 23, 433–447.

Takatsuka, Y., Cullen, R., Wilson, M. and Wratten, S. (2005) Values of ecosystem services on arable land and the role of organic farming. Proceedings of the New Zealand Agricultural and Resource Economics Society (NZARES) 11th annual conference, Nelson, New Zealand.

Tate III, R.L. and Rogers, B.F. (2002) Soil ecosystem properties, microbial diversity, and ecosystem assessments. In: Violante, A., Huang, P.M., Bollag, J.M. and Gianfreda, L.

(eds) *Soil Mineral-Organic Matter-Microorganism Interactions and Ecosystem Health* (pp. 79-93). Elsevier, Amsterdam.

Tegtmeier, E.M. and Duffy, M.D. (2004) External costs of agricultural production in the United States. *International Journal of Agricultural Sustainability* 2, 1-20.

Thies, C., Roschewitz, I. and Tscharntke, T. (2004) The landscape context of cereal aphid-parasitoid interactions. *Proceedings of the Royal Society B* 449, 1–449.8.

Tilman, D. (1999) Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. *Proceedings of the National Academy of Sciences USA* 96, 5995–6000.

Tilman, D., Cassman, G., Matson, P.A., Naylor, R. and Polasky, S. (2002) Agricultural sustainability and intensive production practices. *Nature* 418, 671–677.

Torne, E. (1990) Assessing feeding activities of soil-living animals: I. Bait-lamina tests. *Pedobiologia* 34, 89–101.

UN (2005) *The Millennium Development Goals report*, United Nations, New York.

Vickerman, G.P. and Wratten, S.D. (1979) The biology and pest status of cereal aphids in Europe: a review. *Bulletin of Entomological Research* 69, 1–32.

Vitousek, P.M., Mooney, H.A., Lubchenco, J. and Melillo, J.M. (1997) Human domination of earth's ecosystems. *Science* 277, 494–499.

Wackernagel, M. and Rees, W. (1996) *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers, Gabriola Island, B.C.

Weil, R. and Magdoff, F. (2004) Significance of soil organic matter to soil quality and health. In: Magdoff, F. and Weil, R. (eds) *Soil Organic Matter in Sustainable Agriculture* (1-43). CRC Press, Florida.

Wilson, M., Troy, M. and Costanza, R. (2004) The economic geography of ecosystem goods and services: revealing the monetary value of landscapes through transfer methods and geographic information systems. In: Dieterich, M. and van der Straaten, J. (eds) *Cultural Landscapes and Land Use: the Nature Conservation–Society Interface* (pp. 69-94). Kluwer Academic Publishers, Dordrecht,.

Winder, L. (1990) Predation of the cereal aphid *Sitobian avenae* by polyphagous predators on the ground. *Ecological Entomology* 15, 105–110.

Winder, L., Hirst, D.J., Carter, N., Wratten, S.D. and Sopp, P.I. (1994) Estimating predation of the grain aphid *Sitobion avenae* by polyphagous predators. *Journal of Applied Ecology* 31, 1–12.

Chapter 4 The future of farming: the value of ecosystem services in conventional and organic arable land. An experimental approach[1]

Abstract

In the current work, a novel, experimental 'bottom-up' approach is used to quantify the economic value of ecosystem services (ES) associated with highly modified arable landscapes in Canterbury, New Zealand. First, the role of land management practices in the maintenance and enhancement of ES in agricultural land was investigated by quantifying the economic value of ES at the field level. This quantification was based on an experimental approach. Total annual economic value of ES in organic fields ranged from US \$1610 to US \$19,420 ha^{-1} yr^{-1} and that of conventional fields from US \$1270 to US \$14,570 ha^{-1} yr^{-1}. The non-market value of ES in organic fields ranged from US \$460 to US \$5240 ha^{-1} yr^{-1}. The range of non-market values of ES in conventional fields was US \$50 – 1240 ha^{-1} yr^{-1}. There were significant differences between organic and conventional fields for the economic values of some ES. Next, this economic information was used to extrapolate and to calculate the total and non- market value of ES in Canterbury arable land. The total annual economic and non-market values (2005 US \$) of ES for the conventional arable area in Canterbury (125,000 ha) were US \$332 million and US \$71 million, respectively. If half the arable area under conventional farming shifted to organic practices, the total economic value of ES would be US \$192 million and US \$166 million annually for organic and conventional arable area, respectively. In this case, the non-market value of ES for the organic area was US \$65 million and that of conventional area was US \$35 million anually. The work showed that conventional New Zealand arable farming practices can severely reduce the financial contribution of some of these services in agriculture whereas organic agriculture practices enhance their economic value.

4.1 Introduction

Change is inevitable in nature (Disraeli, 1867). And so a long journey from a subsistence existence to abundance and providing food for billions has changed the nature of farming from 5000 BC to 2000 AD (Fussell, 1965; Pretty, 2002; Bruinsma, 2003). Modern agriculture

[1] Submitted to Ecological Economics

in the last century and currently, is the most advanced form of farming humans have ever practised (Federico, 2005). This has potentially offered to banish hunger. However, at present, the world population is nearly 6.5 billion with 800 million malnourished and is projected to grow to 9 billion by 2050 (Pimentel & Wilson, 2004). All the nations of the world have pledged to achieve the Millennium Development Goals by 2015 that include the eradication of hunger (UN, 2005).

Modern agriculture made it possible to grow more food per unit area as wished by Jonathan Swift (1726) in Gulliver's Travels "...and he gave it for his opinion, that whoever could make two ears of corn or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country than the whole race of politicians put together". It is presumed that Swift was not aware of the consequences of the science of growing more from the same piece of land using modified seeds and chemical inputs (Norse & Tschirley, 2003). Although, agricultural science has made enormous progress to increase productivity as well as to measure and alleviate some of its negative consequences (Altieri, 1995; Pretty, 1995; Thrupp, 1996; Pretty & Hine, 2001; Tilman *et al.*, 2002; Gurr *et al.*, 2004), the current challenge 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 & Swinton, 2005).

One approach to achieving farm sustainability is to utilise nature's services on farmland to increase productivity by replacing most external inputs (Gurr *et al.*, 2004). These nature's services or ecosystem services (ES) support life on earth through a wide range of processes and functions (Myers, 1996; Daily, 1997; Daily *et al.*, 1997). Overuse of natural resources has led to their decline worldwide and this has resulted in the loss of valuable ES (Reid *et al.*, 2005). Research literature provides information on the economic value of global and regional ES (Costanza *et al.*, 1997; de Groot *et al.*, 2002; Millennium Ecosystem Assessment, 2003) based on 'top-down' approaches, including value transfer (Costanza *et al.*, 1997; Pimentel *et al.*, 1997a; Patterson & Cole, 1999). However, there is a lack of detailed understanding of the ES associated with highly-modified or 'engineered'/designed landscapes (Balmford *et al.*, 2002; Robertson & Swinton, 2005) such as arable land and also of changes in ES when agricultural production shifts from conventional to organic methods.

The role of ES in farming is investigated in the current study by calculating its economic value under organic and conventional arable systems in Canterbury, New Zealand by using a 'bottom-up' approach comprising field experiments to quantify ES. It focuses on one sector (arable farming) of an 'engineered' ecosystem (agriculture). The work attributes economic values to a suite of ES which were quantified experimentally, in contrast with earlier evaluations of ES, which have used 'value transfer' approaches. The total economic value of ES in arable land in the province of Canterbury, New Zealand is also calculated here by using 'bottom-up' approach (Sandhu *et al.*, 2005) and extrapolation using GIS techniques. It also provides information on the change in the economic value of ES in a scenario in which conventional farming shifts to organic farming.

4.2 Materials and methods

4.2.1 Study site

The province of Canterbury is the major arable area of New Zealand of which the total arable area is 125,000ha (Statistics New Zealand, 2003) (Fig. 4.1). The rest of the agricultural land consists of land in horticulture, grasslands, forest plantations, etc. In this work, 29 arable fields were selected in September 2004, distributed over the Canterbury Plains and comprising 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 (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 (www.ifoam.org).

A list of arable farmers in Canterbury was obtained from the Foundation for Arable Research, Lincoln (www.far.org.nz) and OPENZ (Organic Products Exporters of New Zealand; 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. 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. Codes O1-O14 were assigned to the organic fields and C1-C15 to the conventional ones. The crops were wheat, barley, carrots for seed, process peas, field beans, white clover for seed and onions.

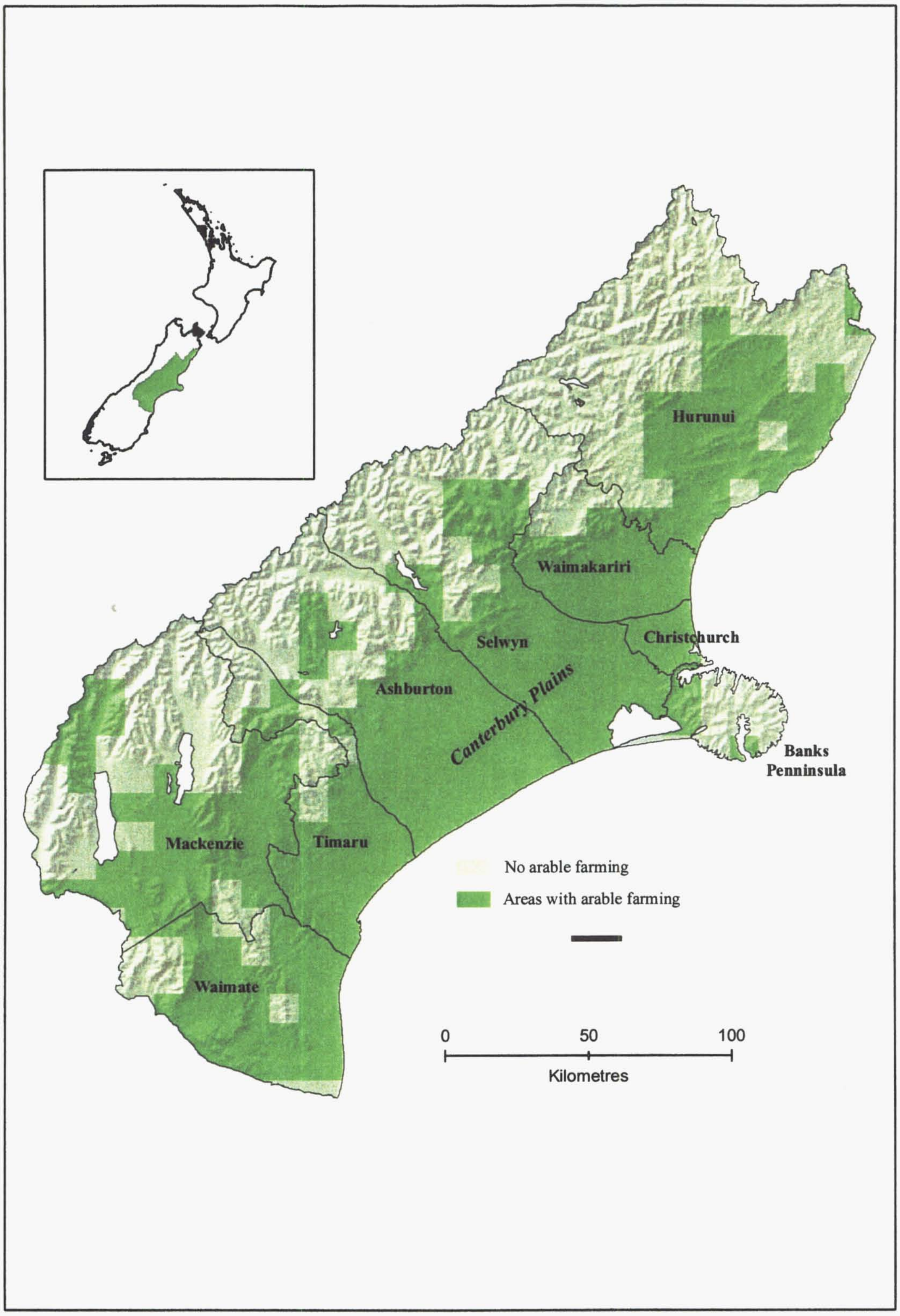

Fig. 4.1 Map of New Zealand showing study area (Province of Canterbury).

4.2.2 Field assessment of ES on arable fields

The assessment of ES associated with arable land in this work follows the typology provided by Reid *et al.* (2005). The work is based on the premise that developing a deeper scientific understanding of the complex relationships between 'engineered' ecosystems and the types of ES they affect will provide a better informed basis for ecosystem service management in agricultural landscapes (Farber *et al.*, 2006).

ES associated with arable farming in Canterbury, New Zealand were assessed by conducting field experiments using 'bottom-up' assessment methods (Sandhu *et al.*, 2005; 2006), also see appendix. Economic value (2005 US $\$ha^{-1}yr^{-1}$) of each ES was then calculated for each of the 29 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; pollination, ES_4; services provided by shelterbelts and hedges, ES_5; hydrological flow, ES_6; aesthetics, ES_7; food, ES_8; raw material, ES_9; carbon accumulation, ES_{10}; nitrogen fixation, ES_{11}; soil fertility, ES_{12} (Eq.1)

$$ES_{total} = \sum ES_n = \sum ES_{market} + \sum ES_{non\text{-}market} \qquad \text{(Eq.1)}$$

The market value of ES included the economic value of product and raw material produced (Eq. 2). These are the only two which are products traded by farmers in the market. Rest of the ES comprised non-market values (Eq. 3) (McTaggart et al., 2003). These market and non-market values are the two components of total economic value of ES (Eq. 1).

$$ES_{market} = ES_8 + ES_9 \qquad \text{(Eq. 2)}$$

$$ES_{non\text{-}market} = ES_1 + ES_2 + ES_3 + ES_4 + ES_5 + ES_6 + ES_7 + ES_{10} + ES_{11} + ES_{12} \qquad \text{(Eq.3)}$$

Assuming a shift of half of the conventional area to organic, the change in the value of ES for Canterbury arable land is calculated by using the value of organic and conventional areas (Eq. 4).

$$\Delta ES = \sum ES_{organic} - \sum ES_{conventional} \qquad \text{(Eq.4)}$$

ES here include goods and services (Daily, 1997) that are consumed and/or produced on arable land (Cullen *et al.*, 2004). The methods used to estimate their economic value in each of the 29 fields are described below.

4.2.2.1 Biological control of pests

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' (detailed methods in Sandhu *et al.*, 2006); 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 of eggs of the carrot rust fly (*Psila rosae* Fab.), using egg 'surrogates' in the latter case.

Predation rate was calculated from the removal of 'prey' types per 24 h period during spring and summer study periods. The economic value of this 'background' (i.e., unmanipulated) biological control of aphids and the 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, described by Sandhu et al. (2006).

4.2.2.2 Soil formation

Soil formation is an important ecosystem service provided by soil biota (Breemen & Buurman, 2002). Earthworms are the most important component of this soil in this respect and in the maintenance of soil structure and fertility (Stockdill, 1982; Lee, 1985; Edwards, 2004). Earthworm populations were assessed to estimate the quantity of soil formed $ha^{-1}yr^{-1}$ (Sandhu *et al.*, 2005).

The economic value of earthworms in soil formation was calculated based on the assumptions that the mean biomass of an earthworm is 0.2g (Fraser, 1996) and that one tonne of earthworms forms 1000 kg of soil $ha^{-1}yr^{-1}$ (Pimentel *et al.*, 1995). The value of purchased top-soil in New Zealand is US \$23.60 $tonne^{-1}$ (City Care, 2005; www.citycare.co.nz).

4.2.2.3 Mineralisation of plant nutrients

Organic matter breakdown by soil micro-organisms and invertebrates (Brady & 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 (Edwards & Arancon, 2004). The rate and economic value of mineralisation of plant nutrients was assessed in all the fields using bait-lamina probes (Kratz, 1998; Torne, 1990) as described by Sandhu *et al.* (2005).

4.2.2.4 Pollination

The transfer of pollen grains from anthers to stigmas is pollination (Free, 1970). The dependence of important food crops on pollination makes this service crucial in agriculture. Earlier work provides information on the value of pollination services (Matheson, 1987; Pimentel *et al.*, 1997a; Kremen *et al.*, 2002; Ricketts *et al.*, 2004). Extensive use of insecticides in agriculture, and habitat loss are leading to a decline of this ES (Nabhan & Buchmann, 1997, 1998) which is worth US $200 billion annually in cropland worldwide (Pimentel *et al.*, 1997a). The value to New Zealand is estimated to be in the range of US $1.4-2 billion annually (Matheson, 1987; Matheson & Schrader, 1987). New Zealand arable land produces high-value seed crops including clovers and requires bees for pollination. The grain and seed industry in New Zealand is worth US $300 million annually (www.maf.govt.nz/mafnet/rural-nz/overview/nzoverview012.htm). To provide increased pollination services for this industry, farmers rent honey-bee hives every year, adding to the costs of production. Any major reduction in populations of pollinators will lead to severe losses to the seed industry. This ES therefore plays a vital role in the economy of New Zealand, especially of Canterbury province.

The economic value of this service was estimated by using the direct cost incurred by farmers to buy pollination service by hiring honey bee-hives for the period of pollination. The economic value of this ES is considered as zero for the fields where the crops do not require pollinators.

4.2.2.5 Services provided by shelterbelts and hedges

Shelterbelts on farmland benefit crops and farm animals by improving crop yields and quality (Sturrock, 1969; Kort, 1988). This is because of reduced wind speed, minimising soil erosion, improving microclimate and giving higher levels of soil moisture (Kort *et al.*, 1988). They also provide shelter and pollen/nectar resources to pollinators (Norton, 1988) and to natural enemies that perform biological control of pests and diseases (Thomas et al., 1991; Landis *et al.*, 2000; de Groot *et al.*, 2002; Heal & Small, 2002;). In Canterbury, New Zealand, good shelter can increase crop yield by up to 35 per cent (Sturrock, 1981).

The potential permeability of the shelterbelts was quantified by digital images of three sections of each side; each section measured 2m long and 1.5 m high. These digital images were analysed automatically to give the percentage of the image that was occupied by opaque objects such as leaves, branches, fence posts, etc. using the hardware and software described by Varley *et al.* (1994). The mean percentages of the three sections that were dark in the images were calculated and used to determine the permeability percentage of each shelterbelt. In Canterbury, New Zealand, shelterbelts are usually on the north-west side of the fields to protect crops, animals and soils as most of the potentially destructive winds come from that direction (Sturrock, 1969). Based on the study by Sturrock (1981), the increased yield derived from shelterbelt was estimated for each crop type for each field depending upon the permeability of shelterbelt. The value of that increased yield is the economic value of services provided by shelterbelts and hedges in each of the 29 fields.

4.2.2.6 Hydrological flow

Hydrological flow in the plant-soil-atmosphere plays a critical role in arable farming. The hydrological cycle renews the earth's supply of water by distilling and distributing it (Gordon *et al.*, 2005).

The economic value of this service is calculated by estimating the input (based on rainfall data and irrigation data of each of the 29 fields) and output of water (water use by crops in each of the 29 fields; Pimentel *et al.*, 1997b) and the amount of water that is recharged into the ground in each of the fields (FAO, 1998). The cost of applying water is calculated at the rate of US \$33.00 per 75 mm water ha^{-1} (Farm Management Group, 2006). The water recharged into the ground is estimated and valued from the cost of applying water and this gives the economic value of this ES for each field.

4.2.2.7 Aesthetics

Cultural services contribute to the maintenance of human health and well-being by providing recreation, aesthetics and education (Costanza *et al.*, 1997; de Groot *et al.*, 2002; Reid *et al.*, 2005). Agriculture provides these services as some farmers conserve field-boundary vegetation or enhance landscapes by planting hedgerows, shelterbelts or trees. Arable farms in Canterbury are characterised by highly managed shelterbelts. Some farms also provide accommodation and recreational activities for family members as well as for national and international visitors.

There was no direct method available to estimate the economic value of this ES. However, Takatsuka *et al.*, 2005 have estimated the aesthetic value of improved landscape on New Zealand arable farms to be US \$ 21 ha^{-1} using contingent valuation method. This value is used here as a standard value of aesthetic services provided by New Zealand arable farms.

4.2.2.8 Food

Agriculture has played a major role in shaping the environment as well as the economy of the world. Although natural ecosystems are sources of a considerable amount of wild foods, including fish, the needs of the growing population will be largely fulfilled by agriculture. The economic value is calculated here by the farm gate prices of the products (grains, beans, seed, peas and onions) for each field.

4.2.2.9 Raw materials

Arable farming in Canterbury, New Zealand produces straw, fuel wood, medicinal plants etc., as well as food and seeds. The economic value has been calculated here by the farm gate prices of various products such as straw bales.

4.2.2.10 Carbon accumulation

The amount of crop and root residue was estimated in each of the 29 fields (crop residue is 1.5 times the crop grain yield and 40% of this is carbon; Johnson *et al.*, 2006) and then amount of carbon accumulated by that tissue in the soil was calculated based on soil carbon analysis by using the Walkley-Black chromic acid wet oxidation method (McLeod, 1973). This was used to calculate the economic value of carbon accumulation in each field. The economic value of carbon accumulated by crop and root residue is estimated based on US \$ 21 $tonne^{-1}$ of carbon accumulated (www.niwascience.co.nz/ncces/archive/27-03-2002-1/index.html).

4.2.2.11 Nitrogen fixation

Nitrogen fixation by growing legumes is a widely used practice in arable farming world wide. Clovers are common features in Canterbury arable rotations because of this nitrogen fixation. These are used as a restorative phase between phases of crop cultivations.
The economic value of nitrogen fixed by different crops was estimated by the amount of nitrogen fixed per hectare which was then valued at the unit price of urea (US \$0.84 kg^{-1}) in New Zealand.

4.2.2.12 Soil fertility

The ability of a soil to provide nutrients to plants is known as soil fertility (Brady, 1990). In this study, an economic value is attributed to the ability of soil to provide nitrogen.

Nitrogen is one of the main requirements of all crops. Of the total nitrogen present in soil, the amount in available forms in the soil is small. Under natural conditions 2% yr^{-1} (Brady, 1990) of this nitrogen becomes available to plants. The amount of nitrogen available to the crops next year was estimated for each field based on soil nutrient analysis. This information was used to calculate the economic value of nitrogen availability in each field valued at the unit price of urea (see above).

4.2.3 Economic valuation and spatial mapping of ES for Canterbury arable land

The total economic value of ES for Canterbury arable land was calculated by extrapolating ES values compiled for the 29 study fields to the total arable area (125,000 ha) in the Canterbury province, stratified by the nine administrative districts within Canterbury (Fig. 4.1). Each of the districts had a different suite of crops. The market and non-market values of ES were calculated from the means of the organic fields and for the conventional ones. These values were used to calculate the total ES value in each of the nine districts based on the total area of each crop, by district, derived from New Zealand agricultural census data (Statistics New Zealand, 2003). ES values were then recalculated under the scenario that half the arable area of Canterbury was converted to an organic (Anon., 1994) regime. Based on this scenario, the predicted change in the economic value of ES for the whole province was estimated using market and non market values for each organic field, by crop type.

Next, total and non-market ES values for both the full conventional and half conventional/half-organic scenarios were spatially extrapolated and mapped across Canterbury using a spatial analysis within the ArcGIS 9.0 (ESRI, 2004) Geographic Information System (GIS) software and displayed at a 10x10 km grid resolution. This exercise was carried out in several steps:

1. A GIS layer containing up-to-date agricultural data for farm properties in Canterbury (AgriBase™ Farms Data, 2005) was used to calculate the overall proportion of arable farming currently occurring on each farm.

2. A 10x10 km resolution polygon grid and a GIS layer demarcating district boundaries were spatially combined with the AgriBase dataset. This resulted in a spatial layer containing farm polygons with associated data, such as: farm and grid cell identification, district name, total area, and proportion of arable farming.
3. The effective area of each of the five crop types occurring within each farm, by district, was calculated by multiplying the overall proportion of each crop type censused within each district (Statistics New Zealand, 2003) by the total area per farm polygon derived in step 2.
4. Total and non-market ES values were calculated for each farm polygon by multiplying the per-hectare ES values per crop type, as quantified via the field study, by the total effective area of each crop type occurring on each farm.
5. ES values were summarised and mapped by grid cell.
6. A similar process was carried out to map ES under the scenario of converting half of Canterbury's conventional arable farm areas to organic-based farming. To do this, half of the total area per crop type occurring on each farm (step 3) was instead multiplied by field-derived organic ES values at step 4. The percent change in total and non-market ES relative to the full conventional scenario was calculated and mapped in the GIS.

4.3 Results

Total economic value of ES in organic fields ranged from US \$1610 to US \$19,420 $ha^{-1}yr^{-1}$ and that of conventional fields from US \$1270 to US \$14,570 ha^{-1} yr^{-1} (Fig. 4.2). The total non-market value of ES ranged from US \$460 to US \$5240 ha^{-1} yr^{-1} in organic fields and from US \$50-1240 ha^{-1} yr^{-1} in conventional ones (Fig. 4.3). There were significant differences between organic and conventional fields for the economic values of 3 ES (biological control of aphids; $p<0.001$ and fly eggs; $p<0.001$ and services provided by shelterbelts and hedges; $p<0.05$ (Table 4.1). The non-market economic value of ES was significantly greater ($p<0.05$) in organic fields than in conventional ones.

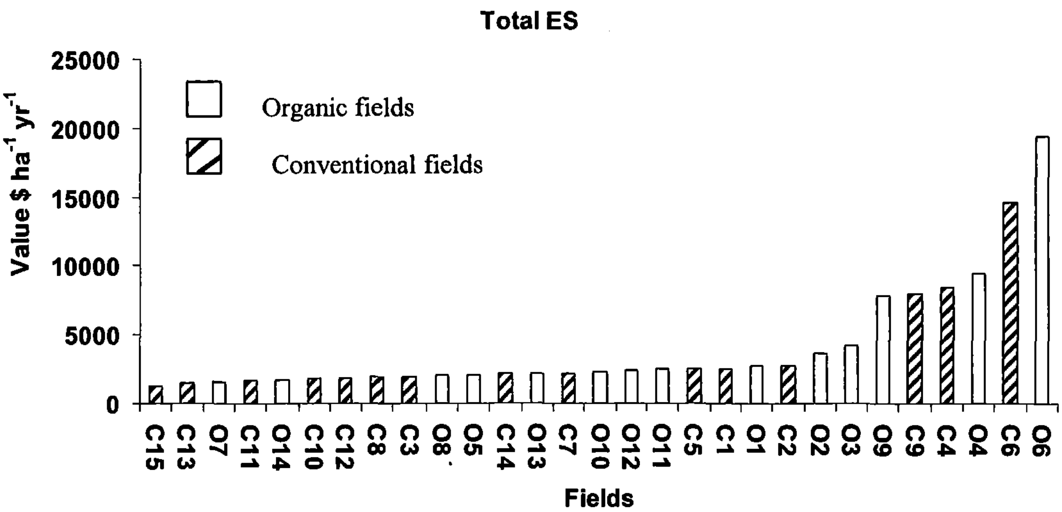

Fig. 4.2 Total economic value of ecosystem services in organic and conventional fields.

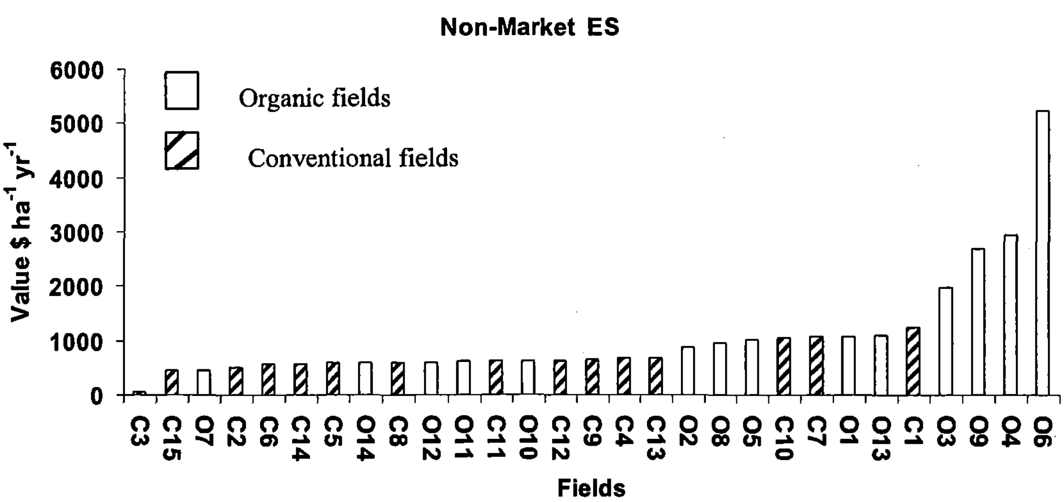

Fig. 4.3 Non-market value of ecosystem services in organic and conventional fields.

Table 4.1 - Summary of mean and range of economic value of ecosystem services in organic and conventional fields.

	Ecosystem services	Economic value (range) in US \$ $ha^{-1}yr^{-1}$ Organic fields	Conventional fields
1	Biological control of pests	50 (0-100)	0 (0-0)
2	Mineralization of plant nutrients	260 (26-425)	142 (30-349)
3	Soil formation	6 (0.7-11)	5 (2-9)
4	Food	3990 (1150-18900)	3220 (840-14000)
5	Raw materials	22 (0-224)	38 (0-298)
6	Carbon accumulation	22 (0-210)	20 (0-210)
7	Nitrogen fixation	40 (0-92)	43 (0-92)
8	Soil fertility	68 (53-82)	66 (54-73)
9	Hydrological flow	107 (-111 – 190)	54 (-118 – 194)
10	Aesthetic	21 (21-21)	21 (21-21)
11	Pollination	62 (0-438)	64 (0-455)
12	Shelterbelts	880 (0-472)	200 (0-617)
	Total economic value of ES	4600 (1607-19412)	3680 (1263-14570)
	Non-market value of ES	1480 (452-5237)	670 (48-1235)

Table 4.2 - Total economic and non-market value of ecosystem services in Canterbury conventional arable land.

Economic value	Total US \$ yr^{-1}	Non-market US \$ yr^{-1}
Hurunui District	10,034,070	2,202,900
Waimakariri District	15,854,740	3,357,120
Christchurch City	2,322,430	709,450
Banks Peninsula District	1,255,630	380,630
Selwyn District	57,691,200	12,381,950
Ashburton District	170,855,390	35,924,440
Timaru District	37,788,720	7,998,680
Mackenzie District	3,511,470	1,034,380
Waimate District	32,726,800	7,225,050
Total	332,040,450	71,214,600

Table 4.3 - Total economic and non-market value of ecosystem services in Canterbury, New Zealand when half of the arable area is converted to organic farming.

Economic value	Organic area Total (US \$ yr^{-1})	Conventional area Total (US \$ yr^{-1})	Organic area Non-market (US \$ yr^{-1})	Conventional area Non-market (US \$ yr^{-1})
Hurunui District	5,497,800	5,017,030	1,771,380	1,101,450
Waimakariri District	8,621,550	7,927,370	2,796,100	1,678,560
Christchurch City	1,415,490	1,161,220	443,910	354,730
Banks Peninsula District	634,380	627,820	184,630	190,320
Selwyn District	32,957,050	28,845,600	11,073,550	6,190,980
Ashburton District	99,452,810	85,427,700	33,942,190	17,962,220
Timaru District	22,053,980	18,894,360	7,570,930	3,999,340
Mackenzie District	2,074,540	1,755,730	642,350	517,190
Waimate District	19,519,770	163,633,400	6,764,300	3,612,530
	192,227,370	166,020,230	65,189,340	35,607,320

4.3.1 Economic value of ES in Canterbury arable land by district

The total and non-market economic value of ES for conventional arable crops in Canterbury was US \$332 million and US \$71 million annually, respectively (Table 4.2). If half the area is converted to organic farming in Canterbury, the total economic value of ES for organics is US \$192 million and US \$166 million annually for the conventional area (Table 4.3). The corresponding non-market economic value of ES are US \$65 million and US \$35 million for organic and conventional arable area, respectively (Table 4.3).

Assuming the minimum and maximum values of total and non-market values of organic and conventional fields, the economic value of Canterbury arable land was calculated. The range of total economic value for the 125,000 ha area (conventional) is from US \$0.15 to 1.8 billion and for the non-market values it is US \$6 to 154 million annually. If half the area is converted to organics, the total economic value for the organic part ranged from US \$0.1 to 1.2 billion (conventional US \$0.08 to 0.9 billion). For the non-market component it was US \$28 to 227 million (organics) and from US \$3 to 77 million (conventional).

4.3.2 GIS mapping of the value of ES across Canterbury

Under the fully-conventional scenario, the GIS-based analysis produced an estimated total ES for Canterbury of *c.*US \$468 million annually, with non-market ES accounting for *c.* US

$100 million of the annual total. With a conversion to a half-organic scenario, the estimated total Canterbury ES was *c.* US $505 million annually, with non-market ES comprising US $142 million of total annual ES This was an increase in total and non-market ES of US $37 million and US$ 42 million, respectively.

Calculated and mapped at the 10 x 10 km grid cell resolution, the total conventional arable ES values for Canterbury ranged from less than US $10,000 to over US $15 million annually (Fig. 4.4). Depending on the grid cell, the spatial pattern of total conventional ES across Canterbury was highly heterogeneous, reflecting the interspersion of arable with pastoral farms across this region; the highest levels of total ES were found in the Canterbury plains region of the Selwyn and Ashburton districts, while the Banks Peninsula, Hurunui, and Mackenzie districts contributed the least to total Canterbury ES (Fig. 4.4). Non-market conventional arable ES for each grid cell in the region ranged from less than US $1,000 to over US $4 million annually; the spatial distribution of this non-market ES generally mirrored that for total ES, with the exception of several grid cells in the Timaru, Ashburton, Selwyn, and Waimakariri districts (Fig. 4.5).

Under the 'half-organic' scenario, there was a 1% to 12% increase in total Canterbury ES based on the GIS analysis (Fig. 4.6). Spatially, the extent of increase in total ES varied by district, with a trend of increasing ES from northeast to southwest Canterbury (Fig. 4.6). By comparison, results suggest that a 1% to 45% increase in non-market ES would occur in Canterbury as a result of a conversion of half of the conventional arable farms to organic practices, with the exception of the Banks Peninsula district which would experience a predicted decrease in non-market ES (Fig. 4.7). Spatially, relatively large gains of > 25% in non-market ES would occur across most of Canterbury, with exception of the Mackenzie, Christchurch, and Banks Peninsula districts (Fig. 4.7).

4.4 Discussion

'Engineered' ecosystems such as arable farmland use ES as 'subsidies' provided by nature and facilitated by governments to generate food and raw materials. Most of these services remain outside routine decision making, are in a state of decline and above all are not paid for or traded (Daily, 1997; Costanza, 1998; Reid *et al.*, 2005; Heal *et al.*, 2005). This approach to ES will have to change to make farms more sustainable and to be able to feed a 9 billion human population by 2050 (Tilman *et al.*, 2002; Robertson & Swinton, 2005). Farmers need to modify their role from being primarily producers of food and fibre to being managers and

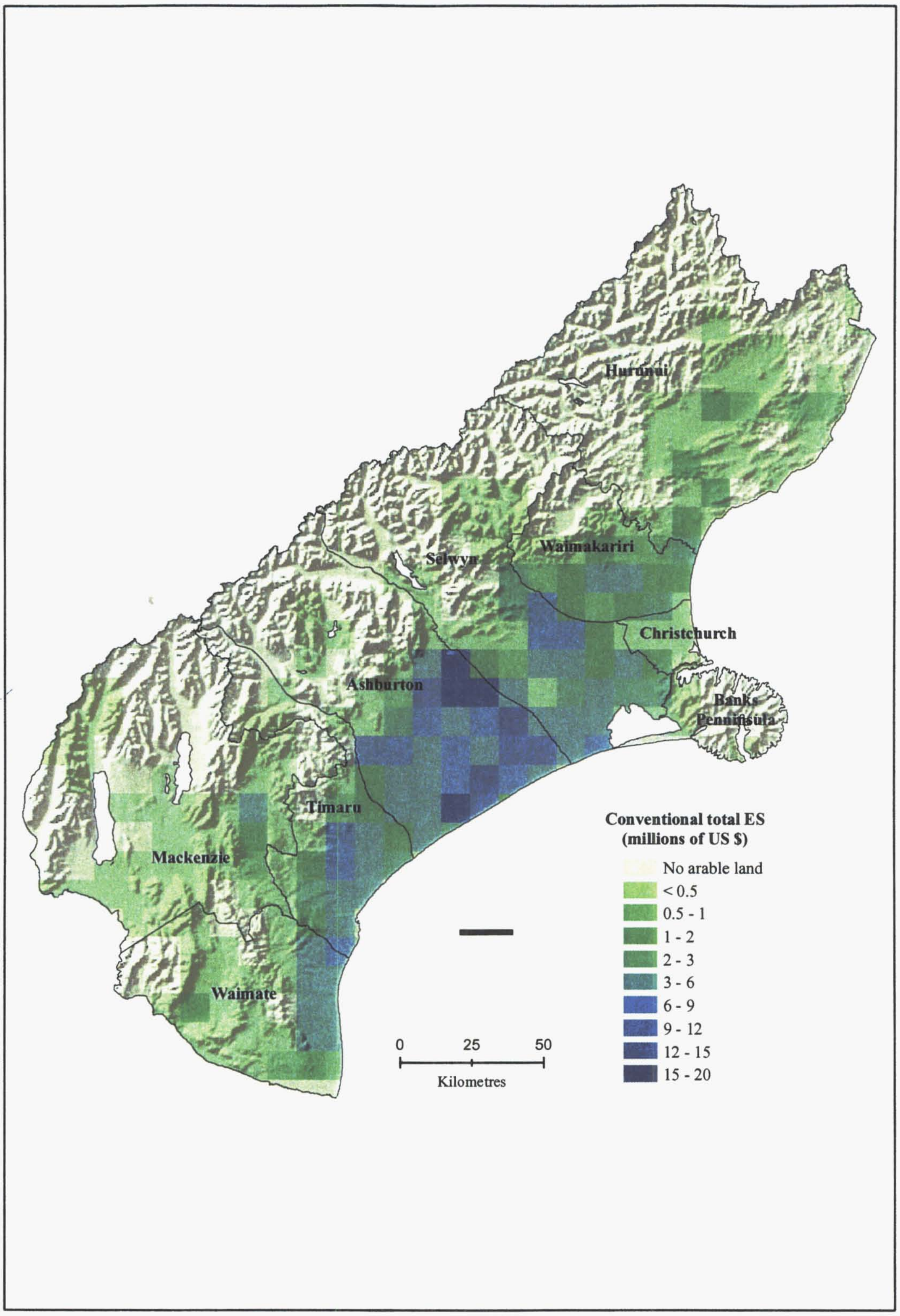

Fig. 4.4 The total economic value of ecosystem services provided by conventional farming practices for arable land in Canterbury, New Zealand.

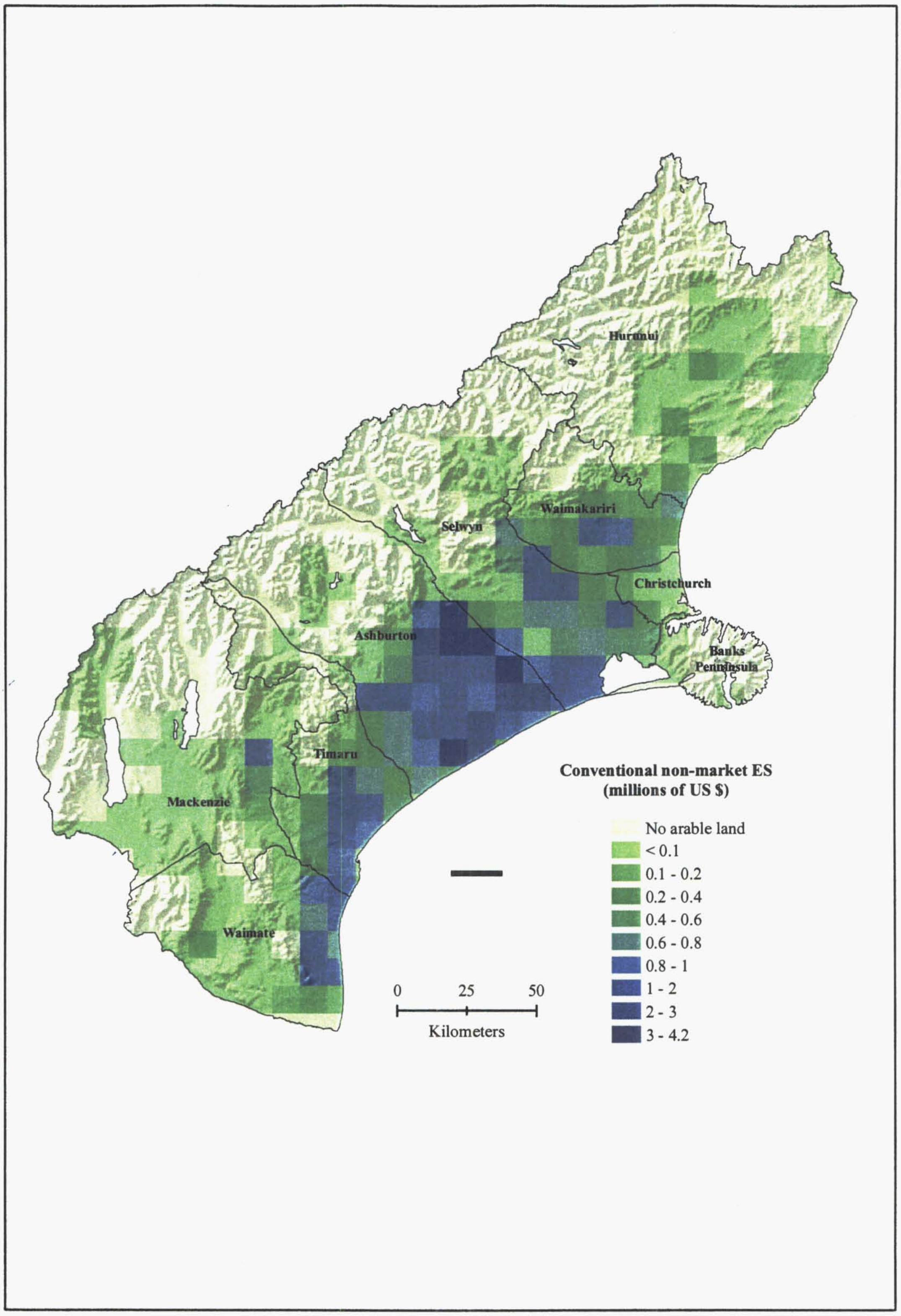

Fig. 4.5 The non-market economic value of ecosystem services provided by conventional farming practices, for arable land in the Canterbury region.

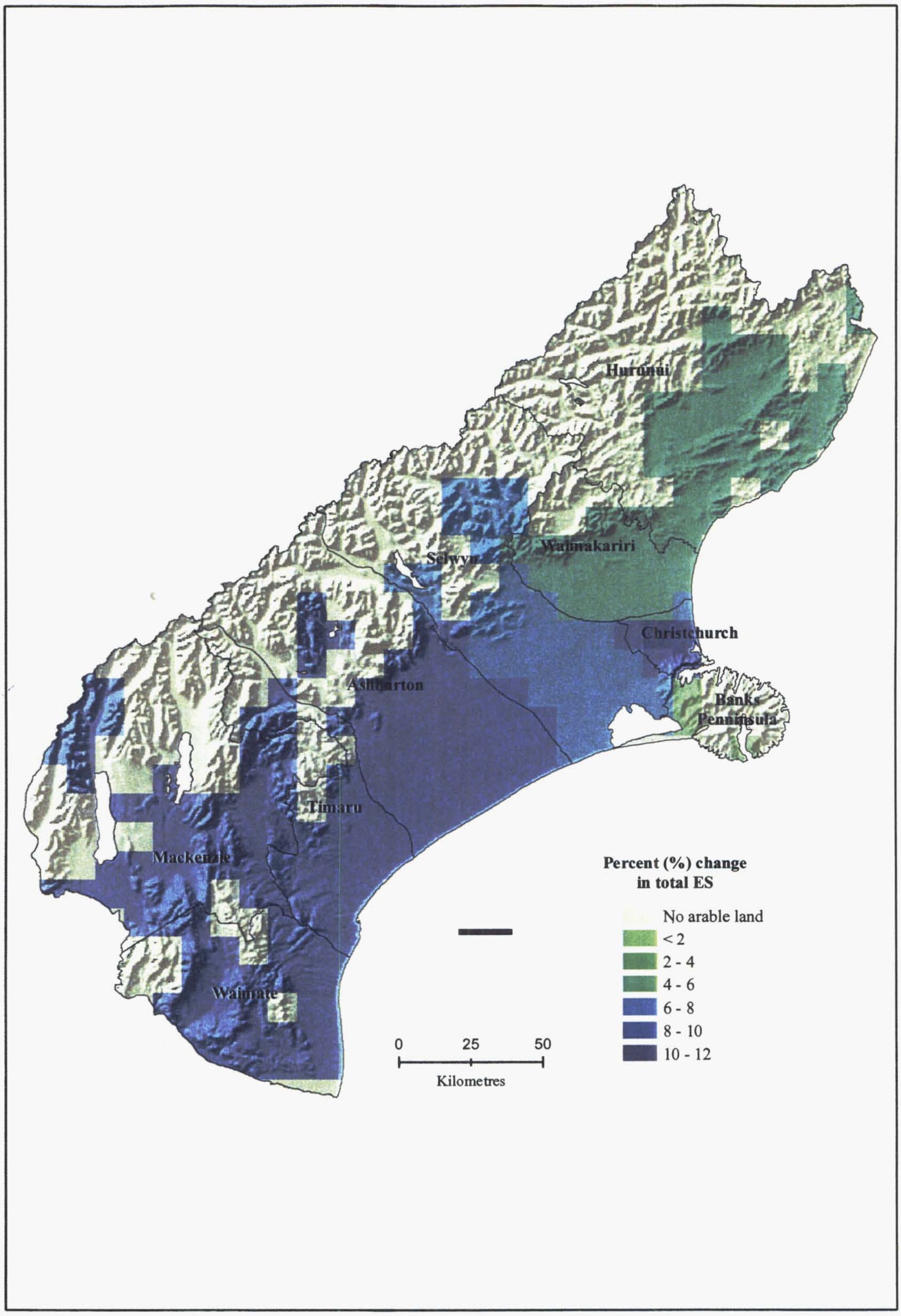

Fig. 4.6 The increased percentage in total economic value of ecosystem services when half of the conventional area is converted to organic farming.

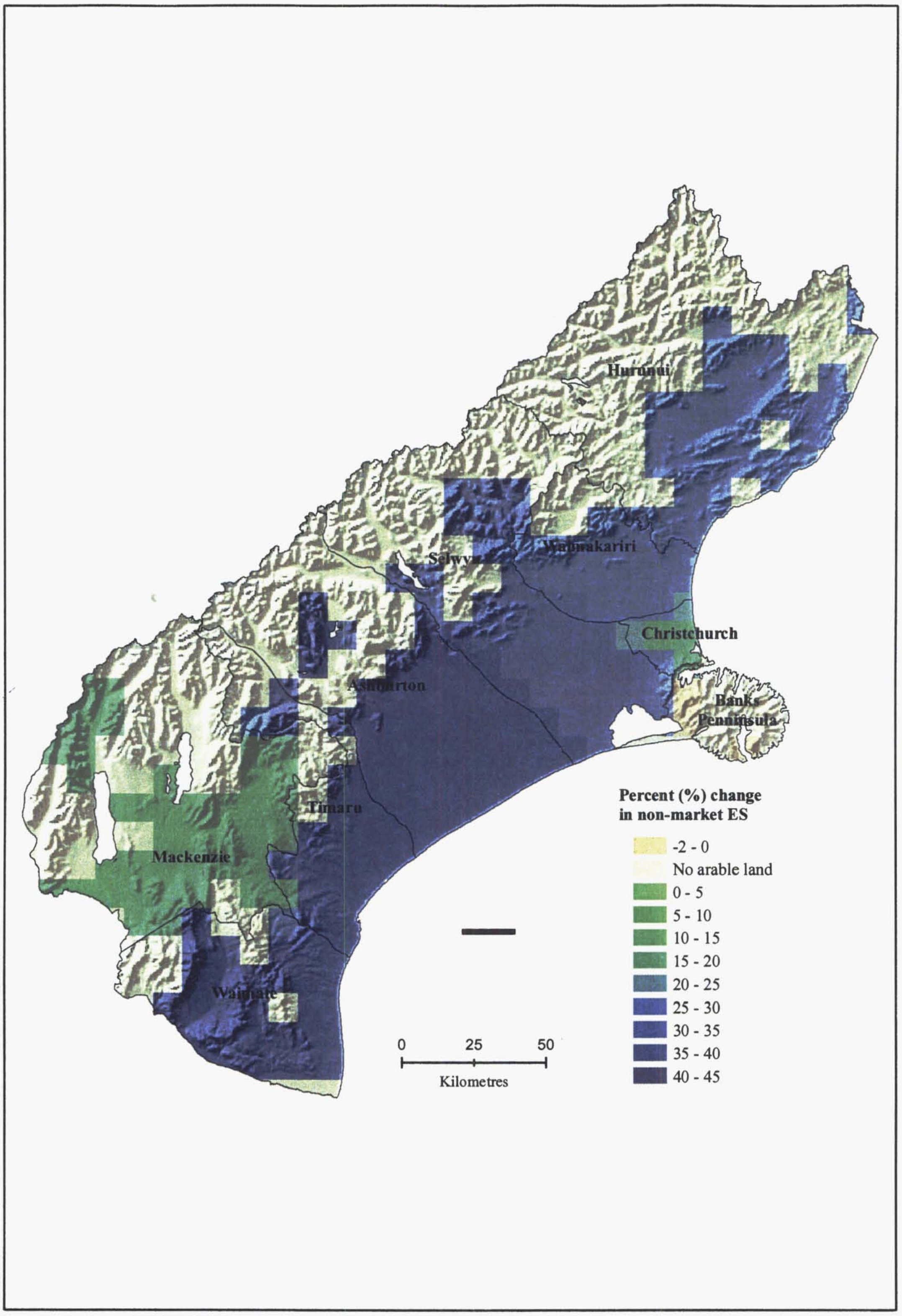

Fig. 4.7 The increased percentage in non-market economic value of ecosystem services when half of the conventional area is converted to organic farming.

providers of a range of ES (Porter & Jensen, 2003).This awareness has led to an increasing interest in the economic value of ES in agriculture. The current study was designed to quantify this in arable land experimentally under different land management practices using a 'bottom-up' measurement approach, which is in contrast to earlier studies that have used 'top down' techniques. Costanza *et al.* (1997) estimated aggregate values of ES for each biome using broad scale value transfer methodologies (Wilson *et al.*, 2004). In the Costanza study, cropping land did not receive much consideration, as only three ES were evaluated for it, and the remaining potential services were considered either negligible or not to occur. One plausible reason for this conclusion is that the valuation was heavily weighted towards natural ecosystems rather than 'engineered' ones, which are actively modified by humans (Balmford et al., 2002). These 'engineered' or designed ecosystems do, however, provide a range of important ES (Cullen *et al.*, 2004; Takatsuka *et al.*, 2005). Current intensive and high-input agricultural practices 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 (Heywood, 1995; Krebs *et al.*, 1999; Tilman *et al.*, 2001). A key 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 sustained food production for the growing human population (Tilman *et al.*, 2002; Robertson & Swinton, 2005).

The total economic value of ES in Canterbury arable land was estimated by using experimentation and extrapolation from field to province using both direct numeric and GIS-based extrapolation methods. The arable economy of Canterbury takes into consideration the market value of ES (food and raw materials) but the remaining of the ES are never considered as a part of general accounting and remain outside economic decision making (Heal *et al.*, 2005). This approach used here demonstrates the value of non-market ES at the field level in addition to the usual market value of ES in arable land.

This exercise was necessary because of the increasing importance of the economic value of ES in 'engineered' landscapes (Matson *et al.*, 1997; Gurr *et al.*, 2004; Kremen, 2005; Robertson & Swinton, 2005). Evidence of ecological disturbances sometimes does not generate much attention unless the evidence includes dollar values (Daly, 1998). The information generated in the present work can be used by researchers and policy makers to increase ecological and economic wealth in a sustainable way and a greater awareness of the ES provision of farmland can contribute to the 'future-proofing' of agriculture in an increasingly uncertain food-production environment (Kristiansen *et al.*, 2006).

Some researchers argue that the market value of the products in agriculture also represents the value of those ES which help in its production (Heal & Small, 2002). But unless it is known how much each of these services is contributing towards the production of food, it is difficult to plan for their maintenance and conservation (Daly, 1998). In the present study the value of individual ES on arable farmland was estimated (as well as the food and fibre values) and this forms the non-market value of ES. These are the 'shadow prices' (Little & Scott, 1976) of ES which are not normally exchanged in markets but are traded off against each other in agricultural landscapes. The present work demonstrates that conventional farming results in a decline in some of these services compared with organic farming, with an associated lower economic value for ES in conventional farms. The current work put forward a new approach to look at the future of farming by considering ES as an important factor in production and indicates that it should be included in decisions concerning the future of agricultural production (Reid *et al.*, 2005).

The economic value of ES in Canterbury arable land were calculated for current practices and also by assuming half of the arable area shifts to organic farming. It is reasonable to provide such estimates in view of the global trends of organic agriculture (increasing 20 % yr^{-1}; Willer & Yussefi, 2006). This increase in area will result in an increased supply of organic products and this may possibly bring down the market value of that produce. However, it is expected that the non-market value of ES will increase as ES become scarce in future (Costanza *et al.*, 1997; Batabyal *et al.*, 2003).

This work also demonstrates the utility of GIS-based methods in using a spatial approach to the distribution of ES across a region. The main benefit of this is that district-level census data on arable crop composition can be spatially extrapolated and visualised, directly reflecting the spatial distribution of farms, their sizes and management activities, and the resultant impact of these factors on ecosystem services. The differences in total and non-market ES values calculated via GIS, as compared with direct numerical extrapolation, reflects the impact of using spatially-explicit farm data to carry out ES calculations for a given region. Ultimately, the GIS approach facilitates the exploration and visualisation of how potential changes in management practices and crop types may result in gains or losses of future ES, thereby providing a useful tool for decision-making, discussion and policy.

4.5 Conclusion

The benefits of ES in 'engineered' ecosystems are substantial as demonstrated by their economic value in arable land in Canterbury, New Zealand. The ecological and economic value of some of the ES can be maintained and enhanced on arable farmland by adopting sustainable practices such as organic farming (Lampkin & Measures, 2001; Sandhu *et al.*, 2005; Kristiansen *et al.*, 2006). This study makes clear that arable farmland provides a range of ES which can be measured using field experiments based on ecological principles by incorporating a 'bottom-up' approach. It provides information for policy and decision makers to consider the financial contribution of different farming practices towards the sustainability of arable farming.

References

AgriBase™ Farms Data (2005) AgriQuality Ltd., Auckland, New Zealand.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998) Crop evapotranspiration: guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper* 56, Rome.

Altieri, M. (1995) *Agroecology: The Science of Sustainable Agriculture*. Westview Press, Colorado.

Anonymous (1994) *Certified BIO-GRO Organic Production Standards*, Northcote, Auckland, New Zealand, Biological Producers and Consumers Council (Inc.)

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rossendo, S., Roughgarden, J., Trumper, K. and Turner, R.K. (2002) Economic reasons for saving wild nature. *Science* 297, 950–953.

Batabyal, A.A., Kahn, J.R. and O'Neill, R.V. (2003) On the scarcity value of ecosystem services. *Journal of Environmental Economics and Management* 46, 334-352.

Brady, N.C. (1990) *The Nature and Properties of Soils*. Macmillan Publishing Company, New York.

Brady, N.C. and Weil, R.R. (2004) *Elements of the Nature and Properties of Soils*. Prentice Hall, New Jersey.

Breemen, N.V. and Buurman, P. (2002) *Soil Formation*. Kluwer Academic Publishers, Dordrecht.

Bruinsma, J. (2003) *World agriculture: Towards 2015/2030*. Earthscan Publications Ltd., London.

Chapman, B. (2004) Insect pest control. In: Fleming, P.H. (Ed.), *Farm Technical Manual, Farm Management Group*, Lincoln University. The Caxton Press, Christchurch.

City Care (2005) *Rock and Landscape Supplies*, Christchurch, New Zealand.

Costanza, R. (1998) The value of ecosystem services. *Ecological Economics* 25, 1-2.

Costanza, R. (2001) Visions, values, valuation, and the need for an ecological economics. *BioScience* 459–468.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt,

M. (1997) The value of the world's ecosystem services and natural capital. *Nature* 387, 253–260.

Cullen, R., Takatsuka, Y., Wilson, M. and Wratten, S. (2004) Ecosystem services on New Zealand arable farms. Lincoln University, *Agribusiness and Economics Research Unit, Discussion Paper* 151, 84–91.

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 DC, pp. 1-10.

Daily, G.C., Matson, P. and Vitousek, P. (1997a) Ecosystem Services Supplied by Soil. In: Daily, G.C. (Ed.), *Nature's Services: Societal Dependence on Natural Ecosystems.* Island Press, Washington DC, pp. 113-132.

Daily, G.C., Alexander, S., Ehrlich, P.R., Goulder, L., Lubchenco, J., Matson, P.A., Mooney, H.A., Postel, S., Schneider, S.H., Tilman, D. and Woodwell, G.M. (1997b) Ecosystem services: benefits supplied to human societies by natural ecosystems. *Issues in Ecology* 2, pp. 18.

Daly, H.E. (1998) The return of Lauderdale's paradox. *Ecological Economics* 25, 21-23.

de Groot, R.S., Wilson, M. and Boumans, R.M. J. (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41, 393-408.

Disraeli, B. (1867) Speech on Reform Bill of 1867, Edinburgh, Scotland.

Edwards, C.A. (2004) The importance of earthworms as key representatives of the soil fauna. In: Edwards, C.A. (Ed.), *Earthworm Ecology,* CRC Press, Florida, pp. 3-11.

Edwards, C.A., Arancon, N.Q., 2004. Interactions among organic matter, earthworms, and microorganisms in promoting plant growth. In: Magdoff, F., Weil, R.R. (Eds.), *Soil Organic Matter in Sustainable Agriculture.* CRC press, Florida, pp. 327-376.

ESRI (2004) *ArcGIS software, version 9.0.* Environmental Systems Research Institute Inc., Redlands, California, USA.

Farber, S.C., Costanza, R. and Wilson, M.A. (2002) Economic and ecological concepts for valuing ecosystem services. *Ecological Economics* 41, 375–392.

Farber, S., Costanza, R., Childers, D.L., Erickson, J., Gross, K., Grove, M., Hopkinson, C., Kahn, J., Pincetl, S., Troy, A., Warren, P. and Wilson, M.A. (2006) An ecosystem services framework that links science, values, and environmental decision making. *Bioscience* 56, 121-133.

Federico, G. (2005) *Feeding the World: An Economic History of Agriculture, 1800-2000.* Princeton University Press, Princeton.

Farm Management Group, (2006) *Financial Budget Manual, Lincoln University.* The Caxton Press, Christchurch.

Fraser, P.M., Williams, P.H. and Haynes, R.J. (1996) Earthworm species, population size and biomass under different cropping systems across the Canterbury Plains, New Zealand. *Applied Soil Ecology* 3, 49–57.

Free, J.B. (1970) *Insect Pollination of Crops.* Academic Press, London.

Fussell, G.E. (1965) *Farming Technique from Prehistoric to Modern Times.* Pergamon Press, Oxford.

Garcia-Torres, L., Benites, J., Martinez-Vilela, A. and Holgado-Cabera, A., (Eds.) (2003) *Conservation Agriculture.* Kluwer Academic Publishers, Dordrecht.

Gordon, L.J., Steffen, W., Jonsson, B.F., Folke, C., Falkenmark, M. and Johannessen, A. (2005) Human modification of global water vapour flows from the land surface. *Proceedings of the National Academy of Sciences USA* 102, 7612-7617.

Gurr, G.M., Wratten, S.D. and Altieri, M.A. (Eds.) (2004) *Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods.* CSIRO, Victoria.

Heal, G.M. and Small, A.A. (2002) Agriculture and ecosystem services. In: Gardner, B.L., Rausser, G.C. (Eds.), *Handbook of Agricultural Economics Vol. 2a,* Elsevier, Amsterdam, pp. 1341-1369.

Heal, G.M., Barbier, E.B., Boyle, K.J., Covich, A.P., Gloss, S.P., Hershner, C.H., Hoehn, J.P., Pringle, C.M., Polasky, S., Segerson, K. and Schrader-Frechette, K. (2005) *Valuing Ecosystem Services: Towards Better Environmental Decision-Making.* The National Academic Press, Washington DC.

Johnson, J.M.F., Allmaras, R.R. and Reicosky, D.C. (2006) Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. *Agronomy Journal* 98, 622-636.

Kort, J. (1988) Benefits of windbreaks to field and forage crops. *Agriculture, Ecosystems and Environment* 22/23, 165-190.

Kort, J. Collins, M. and Ditsch, D. (1988) A review of soil erosion potential associated with biomass crops. *Biomass and Bioenergy* 14, 351-359.

Kratz, W. (1998) The bait-lamina test: general aspects, applications and perspectives. *Environmental Science and Pollution Research* 5, 94–96.

Kremen, C. (2005) Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters* 8, 469–479.

Kremen, C., Williams, N.M. and Thorp, R.W. (20020 Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences USA* 99, 16812-16816.

Kristiansen, P., Taji, A. and Reganold, J. (2006) Organic agriculture: opportunities and challenges. In: Kristiansen, P., Taji, A., Reganold, J. (Eds.) *Organic Agriculture: A Global Perspective*. CSIRO Publishing, Australia, pp. 421-441.

Kumar, P. (2005) Market for ecosystem services. International Institute for Sustainable Development, Canada.

Lampkin, N. and Measures, M. (2001) *Organic Farm Management Handbook: Organic Farming Research Unit.* Aberystwyth: Institute of Rural Studies, University of Wales.

Landis, D.A., Wratten, S.D. and Gurr, G.M. (2000) Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology* 45, 175-201.

Lee, K.E. (1985) *Earthworms: their Ecology and Relationships with Soils and Land Use.* Academic Press, Sydney.

Little, I.M.D. and Scott, M.F.G. (1976) *Using Shadow Prices*. Heinemann Educational, London.

Magdoff, F. and Weil, R.R., (Eds.) (2004) *Soil Organic Matter in Sustainable Agriculture.* CRC press, Florida

Matheson, A. (1987) The value of honey bees to New Zealand. *The New ZealandBeekeeper* 194, 29.

Matheson, A. and Schrader, M. (1987) The value of honey bees to New Zealand's primary production. Ministry of Agriculture and Fisheries, New Zealand.

Matson, P.A., Parton, W.J., Power, A.G. and Swift, M.J. (1997) Agricultural intensification and ecosystem properties. *Science* 277, 504–509.

McLeod, S. (1973) Studies on wet oxidation procedures for the determination of organic carbon in soils. CSIRO Division of Soils, *Notes on Soil Techniques* 73-79.

McTaggart, D., Findlay, C. and Parkin, M. (2003) Economics. Pearson Education, Australia.

Millennium Ecosystem Assessment, 2003. *Ecosystems and Human Well-being: a Framework for Assessment.* Island Press, Washington, DC.

Myers, N. (1996) Environmental services of biodiversity. *Proceedings of the National Academy of Sciences USA* 93, 2764–2769.

Nabhan, G.P. and Buchmann, S.L. (1997) Services provided by pollinators. In: Daily, G.C. (Ed.) *Nature's Services: Societal Dependence on Natural Ecosystems.* Island Press, Washington, pp. 133-150.

Nabhan, G.P. and Buchmann, S.L. (1998) *Forgotten Pollinators.* Island Press, Washington.

Norse, D. and Tschirley, J. (2003) Agriculture and the environment: changing pressures, solutions and trade-offs. In: Bruinsma, J. (Ed.) *World Agriculture: Towards 2015/2030. An FAO Perspective.* Earthscan Publications and Food and Agriculture Organization of the United Nations, London, pp. 331-356.

Norton, R.L. (1988) Windbreaks: benefits to orchard and vineyard crops. *Agriculture, Ecosystems and Environment* 22/23, 205-213.

Patterson, M. and Cole, A. (1999) Assessing the value of New Zealand's biodiversity. Massey University, School of Resource and Environmental Planning, Occasional Paper no. 1.

Pimentel, D. and Wilson, A. (2004) World population, agriculture and malnutrition. *World Watch* 17, 22–25.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. and Blair, R. (1995) Environmental and economic costs of soil erosion and conservation benefits. *Science* 267, 1117–1125.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T. and Cliff, B. (1997a) Economic and environmental benefits of biodiversity. *BioScience* 47, 747–758.

Pimentel, D., Houser, J., Preiss, E., White, O., Fang, H., Mesnick, L., Barsky, T., Tariche, S., Schreck, J. and Alpert, S. (1997b) Water resources: agriculture, the environment, and society. *Bioscience* 47, 97-106.

Porter, J. and Jensen, E.S. (2003) European farmer of tomorrow-a provider of service. In: Proceedings of the International conference on ecosystem services in European agriculture – theory and practice, Falkenberg, Sweden.

Pretty. J.N. (2002) *Agri-Culture: Reconnecting People, Land and Nature.* Earthscan Publishing Ltd., London.

Pretty, J. N. (2005) *The Pesticide Detox: Towards a More Sustainable Agriculture.* Earthscan, London.

Pretty, J., Hine, R., 2001. Reducing Food Poverty with Sustainable Agriculture: a Summary of New Evidence. Final Report from the "SAFE- World" (The Potential of Sustainable Agriculture to Feed the World) Research Project, University of Essex

Commissioned by UK Department for International Development. On WWW at http://www2.essex.ac.uk/ces/ ResearchProgrammes/CESOccasional Papers/SAFErepSUBHEADS.htm

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar, P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell, J. and Zurek, N.B. (2005) Millennium Ecosystem Assessment Synthesis report. Island Press, Washington DC.

Ricketts, T.H., Daily, G.C., Ehrlich, P.R. and Michener, C.D. (2004) Economic value of tropical forest to coffee production. *Proceedings of the National Academy of Sciences USA* 101, 12579-12582.

Robertson, G.P. and Swinton, S.M. (2005) Reconciling agricultural productivity and environmental integrity: a grand challenge for agriculture. *Frontiers in Ecology and the Environment* 3, 38–46.

Root, R.B. (1967) The niche exploitation pattern of the blue-gray gnatcatcher. *Ecological Monographs* 37, 317–350.

Sandhu, H.S., Wratten, S.D. and Cullen, R. (2005) Evaluating ecosystem services on farmland: a novel, experimental, 'bottom-up' approach. In: Proceedings of the 15th International Federation of Organic Agriculture Movements (IFOAM) Organic World Congress, Adelaide, Australia.

Sandhu, H.S., Wratten, S.D. and Cullen, R. (2006) Field evaluation of ecosystem services in organic and conventional arable land. *International Journal of Agricultural Sustainability*, in press.

Statistics New Zealand, (2003) Agricultural production statistics. Statistics New Zealand, Wellington.

Stockdill, S.M.J. (1982) Effects of introduced earthworms on the productivity of New Zealand pastures. *Pedobiologia* 24, 29–35.

Sturrock, J.W. (1969) Aerodynamic studies of shelterbelts in New Zealand-1. Low to medium height shelterbelts in mid-Canterbury. *New Zealand Journal of Science* 12, 754-756.

Sturrock, J.W. (1981) Shelter boosts crop yield by 35 per cent: also prevents lodging. *New Zealand Journal of Agriculture* 143, 18-19.

Swift, J. (1726) *Gulliver's Travels*. E.P. Dutton and Co., New York.

Thomas M.B., Wratten, S.D. and Sotherton, N.W. (1991) Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: predator densities and emigration. *Journal of Applied Ecology* 28, 906-917.

Takatsuka, Y., Cullen, R., Wilson, M. and Wratten, S. (2005) Using choice modelling to value ecosystem services on arable land. In: Proceedings of the 49th Australian Agricultural and Resource Economics Society (AARES) Annual Conference, Coffs Harbour, Australia.

Thrupp, L A. (1996) *Partnerships for Sustainable Agriculture.* World Resources Institute, Washington DC.

Tilman, D., Cassman, G., Matson, P.A., Naylor, R. and Polasky, S. (2002) Agricultural sustainability and intensive production practices. *Nature* 418, 671-677

Torne, E. (1990) Assessing feeding activities of soil-living animals: I. Bait- lamina tests. *Pedobiologia* 34, 89–101

UN (2005) *The Millennium Development Goals report,* United Nations, New York.

Varley, M.J., Copeland, M.J.W., Wratten, S.D. and Bowie, M.H. (1994) Parasites and predators. In: Wratten, S.D. (Ed.), *Video Techniques in Animal Ecology and Behaviour.* Chapman and Hall, London, pp. 33-63.

Willer, H. and Yussefi, M., (Eds.) (2006) *The World of Organic Agriculture 2006: Statistics and Emerging Trends.* International Federation of Organic Agriculture Movements (IFOAM), Bonn.

Wilson, M., Troy, M. and Costanza, R. (2004) The economic geography of ecosystem goods and services: revealing the monetary value of landscapes through transfer methods and geographic information systems. In: Dieterich, M., van der Straaten, J. (Eds.), *Cultural Landscapes and Land Use: the Nature Conservation–Society Interface,* Kluwer Academic Publishers, Dordrecht, pp. 69-94.

Chapter 5 The influence of habitat strata on predator diversity, activity and predation of leafrollers in a vineyard[1]

Abstract

Preserving arthropod predator abundance and diversity in agricultural ecosystems may enhance a key ecosystem service (ES), i.e., biological control of pests. However, since natural enemy species vary in their impact on pest populations, it is crucial to identify which predators are effective at reducing pest abundance. Leafrollers, a ubiquitous pest, spend part of their life on the ground and part in the canopy of vineyards. In this experiment, predation of tethered leafrollers on the ground and in the vine canopy was compared in a New Zealand vineyard. Leafrollers in each stratum were recorded with video to identify predators that were consuming leafrollers. A separate experiment investigated the behaviour of *E. postvittana* larvae when encountered by earwigs on vines or concealed within leaf shelters. Predation rates of leafrollers did not differ between the ground and canopy strata. However, predator activity, attack rate, and species richness were higher on the ground. Six predator taxa consumed leafrollers on the ground whereas only earwigs consumed leafrollers in the canopy. Earwigs were more active, and killed significantly more leafrollers in the canopy than on the ground, compensating for the relatively low activity and diversity of other predators in that stratum. This research demonstrates the value of video recording in biological control ES research, as it permits identification of the predators contributing to pest reduction. In addition, it highlights the need to understand the contributions of individual predator taxa to biological control to better conserve the 'right diversity' in agricultural systems and benefit from this ecosystem service.

5.1 Introduction

Preserving and enhancing arthropod predator abundance and diversity in agricultural ecosystems can enhance a key ecosystem service (ES) - biological control of pests by reducing pest populations, subsequent loss in yield, and the need for insecticide applications (Landis *et al.*, 2000; Gurr *et al.*, 2004). However, simply increasing predator abundance (Prasad & Snyder, 2004) or diversity (Snyder & Ives, 2001; Snyder & Wise, 2001; Wilby *et*

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[1] Submitted to Biological Control

al., 2005) does not always result in greater control of target pests. In addition, since natural enemy species vary in their impact on pest populations, the identity of predators in an assemblage may have more influence on prey populations than species richness or abundance (Chalcraft & Resetarits, 2003; Finke & Denno, 2005; Straub & Snyder, 2006). Therefore, in agro-ecosystems it is crucial to identify which predators consume focal pests so efforts to enhance and preserve natural enemies can focus on the most important taxa. This targeted approach may lead to more efficient development of conservation biological control tactics and more effective pest control.

Leafroller (Lepidoptera: Tortricidae) larvae are important pests in commercial vineyards throughout the world. The light brown apple moth, *Epiphyas postvittana* (Walker), is a common leafroller species in New Zealand and Australian vineyards. This pest consumes grape leaves, flowers, and fruit. Leafroller feeding damage can predispose berries to bunch rot, *Botrytis cinerea* (Nair *et al.*, 1988), while contaminated larvae can transmit this disease from one bunch to another (Bailey *et al.*, 1997). Direct consumption of plant tissue and the subsequent infection by bunch rot can result in a lower grape yield and economic loss for growers (Lo & Murrell, 2000).

Leafroller pests of vineyards are generally managed with broad-spectrum insecticides such as organophosphates and carbamates which have inimical effects on resident natural enemies and other non-target organisms (Epstein *et al.*, 2000; Lo *et al.*, 2000; Nagarkatti *et al.*, 2002). In addition, some leafroller species, including *E. postvittana*, have begun to develop insecticide resistance (Suckling *et al.*, 1984; Lo *et al.*, 2000; Nagarkatti *et al.*, 2002). For these reasons, there is increasing interest in attracting and conserving arthropod natural enemies in vineyards to help reduce leafroller abundance and damage.

Leafrollers spend much of their life inside shelters made by webbing leaves together with silk which may give protection from natural enemies. Leafrollers will leave their shelters to forage on nearby foliage, to search for a new shelter or pupation site, or to move from the foliage to fruit (MacLellan, 1973). Movement within the canopy may render them more vulnerable to predation than when they are in shelters. *E. postvittana* overwinters as larvae on the vineyard floor feeding on the vegetation there (Danthanarayana, 1975). Leafrollers on the vineyard floor may encounter a different assemblage of predators, relative to that of the canopy, which may affect their survival. Research on the natural enemies and biological control of leafrollers in vineyards has been dominated by work on parasitoids (Danthanarayana, 1980a, b; Glenn *et al., 1997;* Berndt *et al.*, 2002). However, little is known about the frequency or consequence of leafroller exposure to the predator fauna of vineyards or the behavior of leafrollers when they are encountered by a predator.

The objective of this study was to determine the identity, activity, and species richness of predators in the canopy and on the ground of a vineyard and their ability to successfully kill leafrollers. We use time-lapse video monitoring to test the hypothesis that predator activity and diversity will be greater on the vineyard floor than in the canopy. Based on this expectation our second hypothesis is that predation of sentinel leafrollers will be greater on the vineyard floor than canopy. Using information from the video recordings we also compare the rate of attack and successful predation of *E. postvittana* by the different predator taxa to identify the predators most important in reducing leafroller abundance. To further understand the vulnerability of *E. postvittana*, we compare their escape and defensive behaviors while exposed on grape vines or concealed in leaf shelters. This research will increase our understanding of which predators contribute to leafroller predation and in which strata leafrollers are most susceptible. Understanding the role of predator taxa in pest suppression increases our ability to benefit from this ecosystem service (Gurr *et al.*, 2004).

The aim was to study one ES, i.e., biological control of pests in detail using a novel assessment technique that uses infra-red digital video analysis. In this work, an engineered landscape (vineyard) was studied. However, the results provide information that is relevant to arable farmland as the predator guilds are similar in two landscapes.

5.2 Materials and methods

The study site was a 2 ha Riesling vineyard in the Horticultural Research Area of Lincoln University, Canterbury, New Zealand. Herbicide was applied periodically to reduce weeds beneath the vines and fungicide was applied to manage botrytis disease. However, no insecticide had been used in the 2004/2005 season. At the time of this experiment the vegetation beneath the vines were approximately 10 cm high and consisted primarily of white clover, *Trifolium repens* (L.). The area between vine rows was planted with orchard grass *Dactylis glomerata* (L.) mowed to 5 cm high. The entire vineyard was surrounded by a windbreak of *Populus* spp.

5.2.1 Predation of sentinel leafrollers

Sentinel leafroller larvae were used to evaluate ambient rates of predation in the canopy and floor of the vineyard. The experiment was conducted in a different area of the vineyard on each of five nights, between 11 and 20 January 2005. Each night was a replicate. On each night 20 fifth instar leafroller larvae (2 cm long) were positioned on the ground below the grape vines and 20 in the grape vine canopy (= 2 treatments). Larvae were obtained from HortResearch, Auckland, New Zealand. All leafrollers were secured in their respective positions using size '0' insect pins (Frank & Shrewsbury 2004). Preliminary trials ensured *E. postvittana* larvae survived at least 12 hours after pinning and that they did not escape from the pins.

On each night half of the length (i.e. from one end of the rows to the center) of two adjacent rows of vines was used in the experiment. Leafrollers in the ground treatment were pinned to the ground directly below the vines in both vine rows. Larvae in the vine treatment were pinned to the base of a leaf petiole 10 to 20 cm above a vine trunk in both vine rows. All larvae were at least 2 m apart. Leafrollers were placed in the vineyard at 18:00 h on each night. The following morning at 06:00 h, the leafrollers were counted and classified as either eaten or not eaten.

Statistical analysis. The number of leafrollers (of 20) eaten in each treatment per night (5 replicates) was compared using a *t*-test.

5.2.2 Predator assemblages and activity

Leafroller larvae were monitored with video cameras to determine which predators were attacking and consuming the larvae in the canopy compared to the ground of the vineyard. The experiment was conducted on six nights between 15 and 26 January 2005. On each night, four larvae (two in the canopy and two on the ground) were monitored from 18:00 h to 06:00 h. The cameras were Bischke CCD50 12P hi-resolution, monochrome, lowlight surveillance cameras (Videotronic Uwe Bischke GMBH International, Neumünster, Germany) illuminated by infrared LED bulbs. Recordings were made on a Hitachi time-lapse video recorder (Model: VT-L1500E, Hitachi, Tokyo, Japan).

The cameras were positioned approximately 10 cm above larvae that were on the ground. Those in the canopy were recorded from a horizontal perspective with the lens 10 cm away. The cameras monitored an area approximately 10 cm in diameter (the 'arena') at the center of which was the leafroller. From the recordings, each time a predator entered the arena the species (or morphospecies), the time it entered and left the arena, and attacks on *E. postvittana* were recorded. This provided two measurements of predator activity: 1) the number of times a predator entered the arena (=visits); and 2) the duration of the visit

(=seconds). Predator attacks were classified as either unsuccessful (i.e. the leafroller was attacked but not killed) or successful (i.e. attack resulted in the death of the leafroller). Species richness, used to compare predator assemblages in each stratum, was calculated as the mean number of species (morphospecies) that entered the arena each night.

Statistical analysis. Twelve leafrollers on the ground and ten in the canopy were monitored by video. Many of the predators were occasional or appeared in only one of the two habitat strata and earwigs were most common. Therefore, separate *t*-tests were used to compare total (all predators combined) predator visits between the ground and canopy as well as European earwig, *Forficula auricularia* (L.) (Dermaptera: Forficulidae), visits between the strata. The other measure of activity, seconds, was analyzed the same way. Each monitored larva was a replicate.

Analysis of attack data was conducted by Chi-squared tests. The first test compared the number of visits and the number of attacks by each predator taxon using a 2 (visits and attacks) by 5 (5 predator taxa) contingency table. This analysis included visits prior to leafroller consumption, after which predators did not have an option to attack. The second Chi-squared test compared the number of attacks and the number of successful attacks by each predator taxon in a 2 (attacks and successful attacks) by 5 (5 predator taxa) contingency table. If the 2 x 5 table was significant ($P< 0.05$), pairwise comparisons were made between predator taxa using 2 x 2 contingency tables. A *t*-test was used to compare species richness (average number of predator taxa that visited the arena per night) between the ground and canopy strata.

5.2.3 Leafroller response to earwigs

The European earwig was the most common predator species recorded in the canopy. Therefore, an experiment was designed to determine how leafrollers respond when encountered by an earwig while exposed on a leaf or vine or concealed in a shelter. This experiment was conducted over four days using a potted grapevine that was 80 cm tall. The first day of the experiment 12 leafrollers were released onto the plant and allowed 30 minutes to settle on the leaves and vines. After 30 minutes, leafrollers had dispersed throughout the plant but had not constructed shelters (= exposed treatment). An adult earwig was released at the base of the plant and allowed to search until it encountered a leafroller exposed on a leaf or vine. The response of the leafroller was recorded and the earwig was removed from the plant. This process was repeated 12 times with different earwigs (alternating male and female) on the first day of the experiment. By the following day, most of the leafrollers had constructed shelters (= shelter treatment). An earwig was released as before and allowed to search until it encountered a leafroller in a shelter; the behavior of the leafroller was recorded. This was repeated nine times then all leafrollers were removed from the plant. The following day the same two-day protocol was repeated. Thirteen more observations were made of leafrollers on vines and leaves (total n = 25) while seven more were made of leafrollers in shelters (total n = 15). Leafroller response was recorded in one of two broad categories, escape or defense. Within these broad categories two escape and two defense behaviors were identified that were specific to larvae exposed on leaves and vines or those concealed in shelters. Leafrollers on vines dropped with a silk thread that kept them attached to the plant (escape), dropped without a thread and landed on the soil (escape), remained still as the earwig investigated (defense), or thrashed violently to deter the earwig (defense). Leafrollers in shelters dropped without a thread (escape), exited the shelter (escape), remained still (defense), or thrashed violently within the shelter (defense).

Statistical analysis. The number of times larvae exhibited escape and defense behavior while exposed and in shelters was compared by Chi-squared test using 2 (exposed and shelter) x 2 (escape and defense) contingency tables. The number of times the different responses were exhibited by leafrollers within the exposed or shelter group were compared separately by Chi-squared tests using 4 (four responses) x 2 (present or absent) contingency tables. If the 4 x 2 table was significant ($P < 0.05$), pairwise comparisons were conducted using 2 x 2 contingency tables.

5.3 Results

5.3.1 Predation of sentinel leafrollers

The mean number of leafrollers (± SE) consumed each night on the ground (10.6 ± 1.0) and in the canopy (12.6 ± 1.5) were not significantly different ($t = 1.10$; df = 8; $P > 0.05$).

5.3.2 Predator assemblages and activity

A total of 12 leafrollers were video recorded on the ground of which 7 (58%) were consumed. Ten leafrollers were recorded in the canopy of which 6 (60%) were consumed.

Predator activity. A total of twelve predator taxa were identified through video monitoring of the prey arenas. A summary of these taxa and their activity is presented in Table 5.1. Ants were responsible for killing one larva. During this single predation event, ants made 50 visits per hour to the arena which resulted in 766,620 seconds of activity. This value accounted for 85% of the total 899,509 seconds of predator activity recorded during all monitoring of ground predators. This one event dictated the results of all other analyses of predator activity data, obscuring the contributions of other taxa. Therefore, the ant activity data from this predation event were removed from analysis of predator activity which is presented in Table 5.1. All other ant activity was included in the analysis.

Table 5.1 Summary of the duration and number of visits by predator taxa observed in video-monitored leafroller arenas on the vineyard floor and canopy.

Predator taxa	Predator Activity on the Ground				Predator Activity in the Canopy			
	Seconds[a]	(%)	Visits[b]	(%)	Seconds	(%)	Visits	(%)
Formicidae	58,178	(42.6)	168	(42.5)	0	(0.0)	0	(0.0)
Forficulidae	10,066	(7.4)	48	(12.2)	72,002	(88.9)	108	(85.7)
Opilionidae	11,340	(8.3)	43	(10.9)	0	(0.0)	0	(0.0)
Araneae	17,814	(13.0)	28	(7.1)	8,667	(10.7)	12	(9.5)
Tricladida	16,717	(12.2)	16	(4.1)	0	(0.0)	0	(0.0)
Pulmonata	15,775	(11.5)	40	(10.1)	0	(0.0)	0	(0.0)
Hemerobiidae	1,893	(1.4)	30	(7.6)	363	(0.4)	6	(4.8)
Chilopoda	315	(0.2)	9	(2.3)	0	(0.0)	0	(0.0)
Coccinellidae	229	(0.2)	3	(0.8)	0	(0.0)	0	(0.0)
Staphylinidae	500	(0.4)	4	(1.0)	0	(0.0)	0	(0.0)
Carabidae	422	(0.3)	3	(0.8)	0	(0.0)	0	(0.0)
Acari	3,456	(2.5)	3	(0.8)	0	(0.0)	0	(0.0)
Total	136,705	(100.0)	395	(100.0)	81,032	(100.0)	126	(100.0)

[a] Total number of seconds (sum of all nights of video) spent in leafroller arenas by each predator taxon in the ground and canopy habitat strata.
[b] Total number of visits (sum of all nights of video) to leafroller arenas by each predator taxon in the ground and canopy habitat strata.

The mean number of visits by predators to prey arenas on the ground per night was significantly higher than in the canopy ($t = 4.18$; d.f. = 20; $P = 0.0005$) (Figure 5.1). Likewise, the mean total predator seconds spent in prey arenas per night in the ground arenas was significantly higher than those spent in the canopy ($t = 4.50$; d.f. = 20; $P = 0.0002$) (Fig. 5.1). Analysis of earwig data revealed opposite trends. The mean number of earwig visits per night in the canopy was significantly higher than on the ground ($t= 2.21$; d.f. = 20; $P = 0.038$) (Fig. 5.1). The mean number of seconds spent per night by earwigs was also significantly higher in the canopy than on the ground ($t = 3.05$; d.f. = 20; $P = 0.0064$) (Figure 5.1).

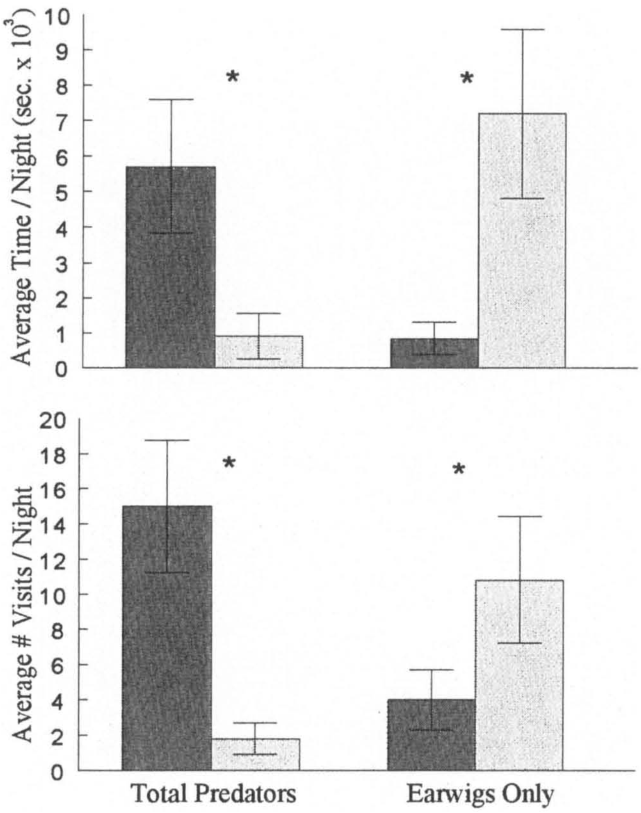


Fig. 5.1 The average number of seconds spent in, and number of visits to arenas by all predators combined (not including earwigs) and by earwigs each night. * indicates significant difference ($P < 0.05$) between habitat strata.

Table 5.2 The number of visits, total attacks and successful attacks by common vineyard predators of leafrollers on the ground.

Predator taxa	Visits	Total attacks		Successful attacks	
		#	%[a]	#	%[b]
Forficulidae	32	8	25.0	2	25.0
Opilionidae	29	14	48.3	1	7.1
Araneae	23	4	17.4	1	25.0
Tricladida	11	9	81.8	2	22.2
Pulmonata	22	6	27.3	0	0.0
Formicidae	363	--[c]	--	1	--
X^2, P		3.10, 0.013		17.95, <0.001	

[a] Percentage of visits in which an attack occurred (# attacks/ #visits x 100%)

[b] Percentage of attacks which resulted in a successful attack (# successful attacks/ # attacks x 100%)

[c] Attack data was not calculated for Formicidae because they attacked in large groups (see text).

Predator attacks. Predators that attacked very few times or never had a successful attack were not included in these analyses. As indicated above ants were also not included. A Chi-squared test of the visits and attacks on the ground by each predator taxon was significant (Table 5.2). Pairwise comparisons found that flatworms, *Arthurdendyus triangulates* (Dendy) (Platyhelminthes: Tricladida), and harvestmen, *Phalagium opilio* (L.) (Arachnida: Opilionidae), attacked more times relative to number of visits than did the other taxa (Table 2). The Chi-squared test comparing the number of attacks to the number of successful attacks was also significant between predator species (Table 5.2). Pairwise comparisons did not result in significant differences in the attack frequency relative to the number of successes (Table 5.2).

As earwigs were the only predator that attacked and killed leafrollers in the canopy the above analyses were not conducted. However, earwig attacks on the ground and in the canopy were compared to determine if there was a difference in the attack number or successful attacks by this predator between the two strata. Earwigs attacked more per visit in the canopy than on the ground ($X^2 = 14.41$, $P < 0.001$) although the number of successful attacks did not differ ($X^2 = 0.124$, $P = 0.335$) (Fig. 5.2). In addition, earwigs were responsible for all 6 of the leafrollers killed in the canopy which is significantly greater than the frequency of kills by earwigs on the ground ($X^2 = 6.96$, $P = 0.016$) (Fig. 5.2).

Predator species richness. Species richness was significantly higher on the ground (5.8 ± 0.9) than in the canopy (1.8 ± 0.3) ($t = 6.61$; df = 20; $P < 0.001$).

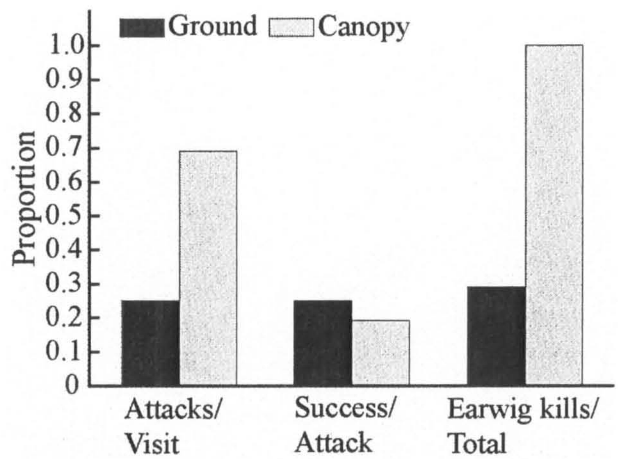


Fig. 5.2 Proportion of earwig visits that resulted in attacks (Attacks/Visit), percent of earwig attacks that were successful (Success/Attack), and percent of total leafrollers killed that were killed by earwigs (Earwig kills/Total) on the vineyard floor and canopy.

5.3.3 Leafroller response to earwigs

Escape and defense behavior was used by 22 (88%) and 3 (12%) leafrollers respectively when exposed on vines. This was significantly different from leafrollers in shelters of which 7 (47%) used escape and 8 (53%) used defensive behaviors ($X^2 = 8.03$, $P = 0.006$). When larvae were exposed on vines larvae dropped from the vine with or without a silk. The leafrollers that exhibited defensive behavior thrashed violently to ward off attack or remained still as the earwig investigated (Fig. 5.3). There were significant differences in the frequency of these four behaviors within the exposed treatment overall ($X^2 = 14.52$, $P = 0.002$) and as determined by pairwise Chi-square tests (Fig. 3). When larvae were in shelters, escape behavior consisted of exiting the shelter or dropping (Fig. 5.3). Defensive behaviors were either thrashing violently or remaining still within the shelter (Fig. 5.3). There was no significant difference in the number of leafrollers using each of these behaviors ($X^2 = 3.93$, $P = 0.27$) (Fig. 5.3).

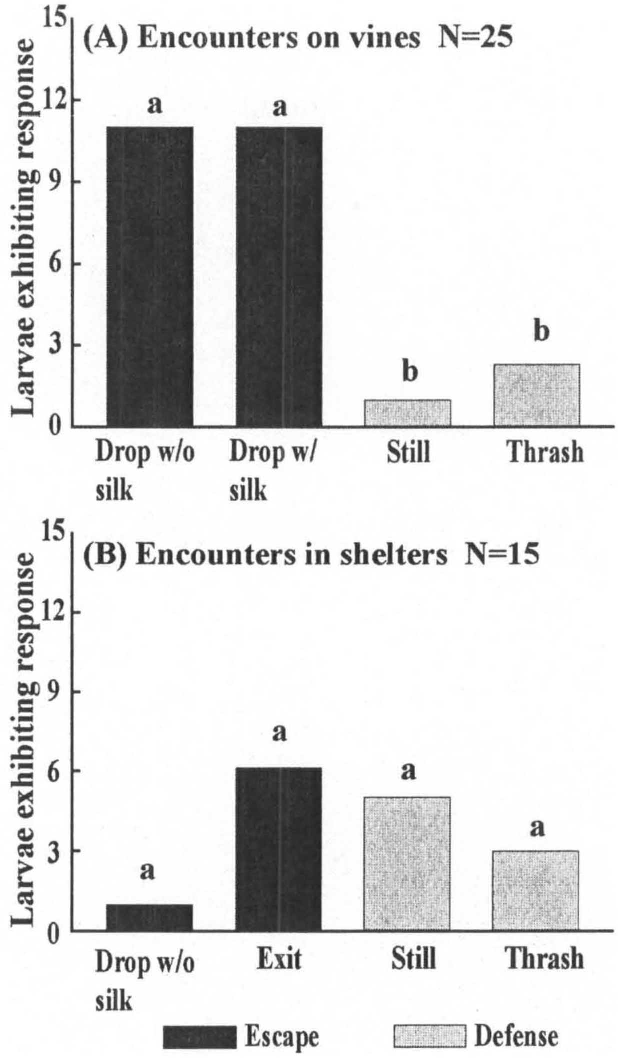


Fig. 5.3 The number of leafrollers that exhibited escape and defensive responses during encounters with earwigs while exposed on vines (A) or concealed in leaf shelters (B). Bars with different letters are significantly different at ($P < 0.05$).

5.4 Discussion

The study vineyard had an active and relatively diverse predator community that could likely exert significant pressure on natural populations of leafrollers. The overall predation rate of leafrollers on the ground and in the canopy was 50-60% per night. This does not support our hypothesis that predation would differ between the canopy and the ground. The similarity in predation rate is interesting in light of the differences in predator diversity and activity between the ground and canopy. Predator species richness was 4 times greater on the ground than in the canopy. Predator activity, as indicated by time spent and the number of visits to prey arenas, was also higher on the ground than in the canopy.

Of particular interest however, the most effective predator, in terms of total leafroller predation, was earwigs, which spent ten fold more time in the canopy arenas than in arenas on the ground. It appears the greater activity and efficiency of earwigs compensated for the lower activity and diversity of other predator taxa in the canopy relative to the ground, which resulted in similar rates of predation between the strata. Furthermore, although predator diversity was greater on the ground, three predator taxa - earwigs, spiders, and flatworms – accounted for 72% of leafroller predation there. High predation rates by a few taxa may partially explain why greater predator diversity did not result in higher levels of predation overall. These results suggest that predator identity may be more important than overall predator diversity in regulating herbivore populations in this system. This is similar to research in other agricultural systems where increasing species richness did not increase predation of pest species. For example, Straub & Snyder (2006) similarly demonstrated that aphid suppression was greatest in the presence of predators with the highest consumption rates rather than in the presence of a diverse predator assemblage.

This study demonstrated earwigs are the most active and effective predator of leafrollers in the vineyard canopy. Although *E. postvittana* spend more time in shelters than exposed on vines and leaves field observations have found earwigs within leafroller shelters actively feeding on larvae (Danthanarayana, 1983). Additionally, leafrollers leave shelters to feed on nearby foliage, to find a new shelter or pupation site, or in response to predators invading their current shelter (MacLellan, 1973). Our studies found that earwigs frequently encountered and attacked exposed leafrollers in the canopy and in 25% of attacks the leafroller was killed. Moreover, our laboratory studies indicated that unsuccessful attacks usually result in the leafroller dropping from the leaf or vine. However, our studies used pinned larvae which were restricted their ability to drop from the canopy. If larvae were free to use their dropping behavior this may have resulted in greater predation on the ground than in the canopy. As leafrollers escape by dropping, they are exposed to the diverse and active predator assemblage on the ground, from which they may be less able to escape. This evidence suggests that earwigs in the canopy may indirectly increase predation of leafrollers by ground dwelling predators. Similar interactive effects between canopy and ground foraging predators have been demonstrated in alfalfa as coccinellid predators elicit a dropping response in aphids which were then consumed by ground dwelling carabid beetles (Losey & Denno, 1998). Similarly, late instar leafrollers and codling moth larvae in orchards suffered high levels of predation if they dropped from the canopy or ventured down in search of pupation sites (Glen & Milsom, 1978; Epstein *et al.*, 2001). Predator avoidance behavior such as dropping from vines can also reduce herbivore feeding efficiency and damage (Beckerman *et al.*, 1997; Schmitz, 1998).

The use of video to monitor leafroller prey resulted in observations and conclusions that would not be attainable from unmonitored or sporadically monitored sentinel prey experiments. Video monitoring provided positive identification of predators that encountered the leafrollers and which ones were responsible for leafroller death on the ground and in the canopy. This kind of information allows for the development of conservation biological control techniques directed at specific predatory taxa that consume focal pest species. *A priori* identification of important predators could reduce the research time and resources required to develop effective conservation biological control techniques to be implemented by producers in vineyards and arable farmland.

This study fulfilled the first step in the development of biological control protocols in which we evaluated the ambient level of control by predators and identified which taxa are potentially important. Future research should determine how these and other predators affect the growth of natural leafroller populations. In addition, research should address whether vineyard habitat may be altered to attract and conserve greater populations of earwigs, spiders and flatworms shown to successfully kill *E. postvittana*.

References

Bailey, P. T., Ferguson, K. L., McMahon, R., and Wicks, T. J. (1997) Transmission of *Botrytis cinerea* by light brown apple moth larvae on grapes. *Australian Journal of Grape and Wine Research* 3, 90-94.

Beckerman, A. P., Uriarte, M., and Schmitz, O. J. (1997) Experimental evidence for a behavior mediated trophic cascade in a terrestrial food chain. *Proceedings of National Academy of Sciences* 94, 10735-10738.

Berndt, L. A., Wratten, S. D., and Hassan, P. G., 2002. Effects of buckwheat flowers on leafroller (Lepidoptera: Tortricidae) parasitoids in a New Zealand vineyard. *Agricultural and Forest Entomology* 4, 39-45.

Chalcraft, D. R., and W. J. Resetarits Jr. (2003. Predator identity and ecological impacts: functional redundancy or functional diversity. *Ecology* 84, 2407-2418.

Danthanarayana, W. (1975) The bionomics, distribution and host range of the light brown apple moth, *Epiphyas postvittana* (Walk.)(Tortricidae). *Australian Journal of Zoology* 23, 419-437.

Danthanarayana, W. (1980a) Occurence of Trichogramma funiculatum, an egg parasitoid of the light brown apple moth, *Epiphyas postvittana*. *Entomologia Experimentalis et Applicata* 28, 287-294.

Danthanarayana, W.(1980b) Parasitism of the light brown apple moth, *Epiphyas postvittana* (Walker), by its larval ectoparasite, *Goniozus jacintae* Farrugia (Hymenoptera: Bethylidae), in natural populations in Victoria. *Australian Journal of Zoology* 28, 685-692.

Danthanarayana, W. (1983) Population ecology of the light brown apple moth, *Epiphyas postvittana* (Lepidoptera: Tortricidae). *Journal of Animal Ecology* 52, 1-33.

Epstein, D. L., Zack, R. S., Brunner, J. F., Gut, L., and Brown, J. J. (2000) Effects of broad-spectrum insecticides on epigeal arthropod biodiversity in pacific northwest apple orchards. *Environmental Entomology* 29, 340-348.

Epstein, D. L., Zack, R. S., Brunner, J. F., Gut, L., and Brown, J. J., 2001. Ground beetle activity in apple orchards under reduced pesticide management regimes. *Biological Control* 21, 97-104.

Finke, D. L. and Denno, R. F., 2005. Predator diversity and the functioning of ecosystems: the role of intraguild predation in dampening trophic cascades. *Ecology Letters* 8, 1299-1306.

Frank, S. D., and Shrewsbury, P. M., 2004. Effect of conservation strips on the abundance and distribution of natural enemies and predation of *Agrotis ipsilon* (Lepidoptera: Noctuidae) on golf course fairways. *Environmenatl Entomology* 33, 1662-1672.

Glen, D. M., 1978. Survival of mature larvae of codling moth (*Cydia pomonella*) on apple trees and ground. *Annals of Applied Biology* 90, 133-146.

Glenn, D. C., Hercus, M. J., and Hoffmann, A. A., 1997. Characterizing Trichogramma (Hymenoptera: Trichogrammatidae) species for biocontrol of light brown apple moth (Lepidoptera: Tortricidae) in grapevines in Australia. *Annals of Entomological Society of America* 90, 128-137.

Gurr, G. M., S. D. Wratten, and M. A. Altieri., 2004. Ecological engineering for enhanced pest management: towards a rigorous science. Pages 219-226 in G. M. Gurr, S. D. Wratten, and M. A. Altieri, editors. *Ecological engineering for pest management: Advances in habitat manipulation for arthropods.* CSIRO Publishing, Collingwood.

Landis, D. A., S. D. Wratten, and G. M. Gurr., 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology* 45, 175-201.

Lo, P. L., and Murrell, V. C., 2000. Time of leafroller infestation and effect on yield in grapes. *New Zealand Plant Protection* 53, 173-178.

Lo, P. L., Walker, J. T. S., and Suckling, D. M., 2000. Insecticide resistance management of leafrollers (Lepidoptera: Tortricidae) in New Zealand. *New Zealand Plant Protection* 53, 163-167.

Losey, J. E., and Denno, R. F., 1998. Positive predator-predator interactions: Enhanced predation rates and synergisitc suppression of aphid populations. *Ecology* 79, 2143-2152.

MacLellan, C. R., 1973. Natural enemies of the light brown apple moth, *Epiphyas postvittana*, in the Australian Capital Territory. *Canadian Entomology* 105, 681-700.

Merfield, C. N., Wratten, S. D., and Navntoft, S., 2004. Video analysis of predation by polyphagous invertebrate predators in the laboratory and field. *Biological Control* 29, 5-13.

Nagarkatti, S., Tobin, P. C., Muza, A. J., and Saunders, M. C., 2002. Carbaryl resistance in populations of grape berry moth (Lepidoptera: Tortricidae) in New York and Pennsylvania. *Journal of Economic Entomology* 95, 1027-1032.

Nair, N. G., Emmett, R. W., and Parker, F. E., 1988. Some factors predisposing grape berries to infection by *Botrytis cinerea*. *New Zealand Journal of Experimental Agriculture* 16, 257-263.

Prasad, R. P., and Snyder, W. E., 2004. Predator interference limits fly egg biological control by a guild of ground-active beetles. *Biological Control* 31, 428-437.

Schmitz, O. J., 1998. Direct and indirect effects of predation and predation risk in old-field interaction webs. *American Naturalist* 151, 327-342.

Snyder, W. E., and Ives, A. R., 2001. Generalist predators disrupt biological control by a specialist parasitoid. *Ecology* 82, 705-716.

Snyder, W. E., and Wise, D. H., 2001. Constrasting Trophic cascades generated by a community of generalist predators. *Ecology* 82,1571-1583.

Straub, C. S., and Snyder, W. E., 2006. Species identity dominates the relationship between predator biodiversity and herbivore suppression. *Ecology* 87, 277-282.

Suckling, D. M., Chapman, R. B., and Penman, D. R., 1984. Insecticide resistance in the light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae): larval response to Azinphosmethyl. *Journal of Economic Entomology* 77, 579-582.

Wilby, A., Villareal, S. C., Lan, L. P., Heong, K. L., and Thomas, M. B., 2005. Functional benefits of predator species diversity depend on prey identity. *Ecological Entomology* 30, 497-501.

Chapter 6 General Discussion

The importance of ES in supporting human life and as a life-support system of the planet (Myers, 1996; Daily, 1997; Daily *et al.,* 1997) is now very well established and ES have been demonstrated to be of very high economic value (US $33 trillion/yr; Costanza *et al.*, 1997). Yet because most of these services are not traded in economic markets, they carry no 'price tags' (no exchange value in spite of their high use value) that could alert society to changes in their supply or deterioration of underlying ecological systems that generate them. However, recent reports, such as the United Nations Millennium Assessment, point towards increasing damage being done to these services worldwide.

Intensification of agriculture in the last century has resulted in the substitution of many ES with chemical inputs. An example is the use of urea in place of nitrogen fixation and insecticides in place of biological control agents. This has resulted in some serious detrimental effects which have led to worldwide concerns about the environmental consequences of modern agriculture. Moreover, as the world approaches 'peak oil' (Pimentel & Giampietro, 1994), so called conventional agriculture may no longer be able to depend as heavily or as easily on oil-derived 'substitution' inputs. Population growth and increasing food demands in the next 50 years also pose great challenges to the sustainability of modern farming practices. Because the threats to ES are increasing, there is a critical need for identification, monitoring and enhancement of ES both locally and globally, and for the incorporation of their value into decision-making processes (Daily *et al.*, 1997).

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). But the following gaps have been identified in the research literature:

- The economic value of ES are usually estimated by using only a 'top-down' approach based on broad-scale value transfer methodologies (Costanza *et al.*, 1997; Wilson et al., 2004).
- The valuation is heavily weighted towards natural ecosystems rather than 'engineered' ones, which are actively modified by humans (Balmford *et al.*, 2002).
- The economic value of ES in agriculture has rarely been evaluated in agricultural crops at field level.

- There is a lack of information on the change in economic value of ES when land management practices change from conventional to organic agriculture.

Therefore the current study was designed to calculate the total economic value of ES in arable land in the province of Canterbury, New Zealand by using a 'bottom-up' approach (Sandhu *et al.*, 2005) and extrapolation using GIS techniques. It also provided information on the change in the economic value of ES in a scenario in which conventional farming shifts to organic farming.

6.1 Ecosystem services in agriculture

'Engineered' or modified ecosystems such as arable farmland are providers and consumers of different types of ES as explained in Chapter 2 (Figure 6.1). This study was focused on one sector of an 'engineered ecosystem' (arable farming) and addressed both conventional and organic systems in Canterbury, New Zealand. First, a Delphi panel of experts (Brooks, 1979; Angus *et al.*, 2003; Curtis, 2004) was used to place all the ES identified in this work into one of five categories in terms of whether the perceived benefits were attributable mainly to private or public entities. Next, data were collected to study the perceptions of farmers towards ES. Individual farmers derive more immediate advantages from these ES compared with the benefits to the general public (Daily *et al.*, 1997; Heal & Small, 2002). However, the public also derives aesthetic and other advantages from these ES which are maintained and enhanced on farmland (Anon., 2001; Takatsuka *et al.*, 2005). Further research is required to study the net private and public benefits of ES on farmland. Better understanding of the importance of ES by farmers and the public is required to enable the inclusion of this natural, social and cultural capital into assessments of gross national product (GNP) (Williams, 2004).

6.2 Bottom-up approach to quantify ES

There are limited natural resources on farmland and to make rational choices among alternative uses of a given natural resource, it is important to know both what ES are provided by farmland and what those services are worth (Goulder & Kennedy, 1997). Therefore, the role of ES in farming is investigated in Chapters 3 and 4 by calculating its economic value under organic and conventional arable systems in Canterbury, New Zealand by using a

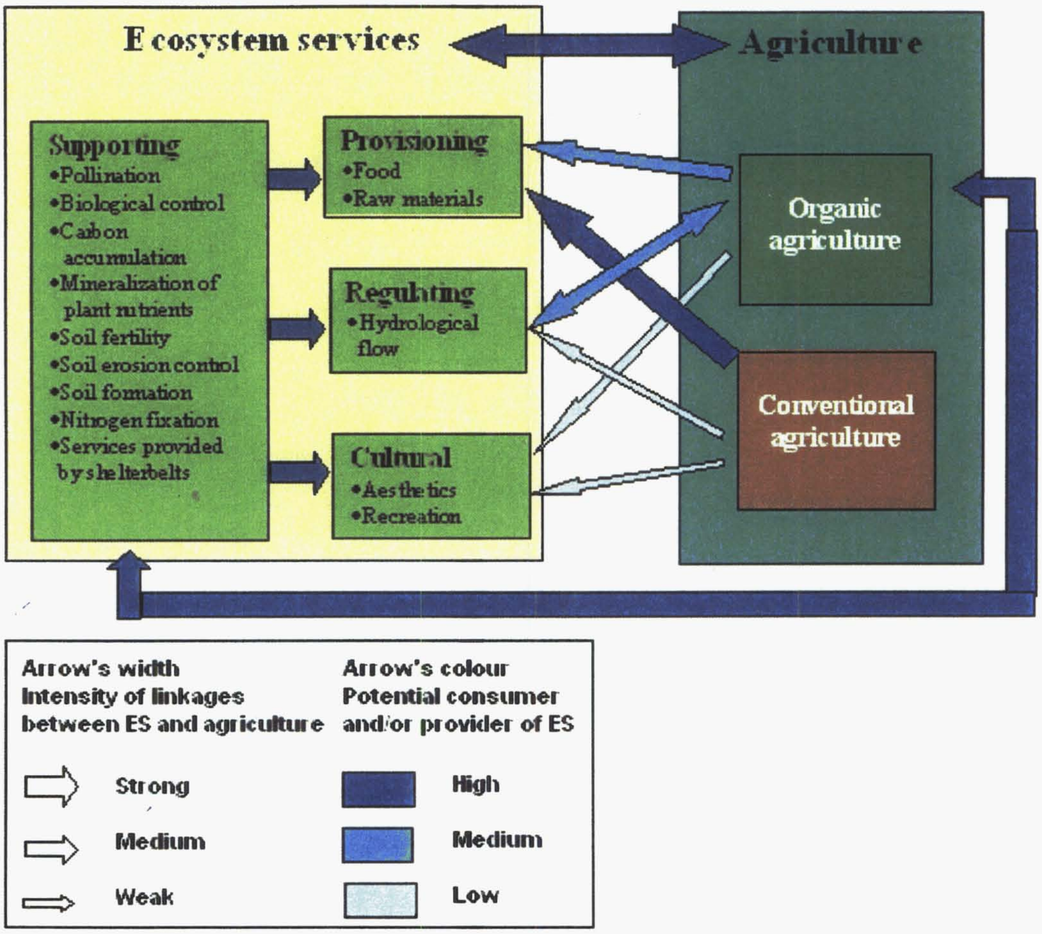


Fig. 6.1 Linkages between ES and agriculture (adapted form Reid *et al.*, 2005; Sandhu *et al.*, 2006)

'bottom-up' approach comprising field experiments to quantify ES. The work attributed economic values to a suite of ES which were quantified experimentally, in contrast with earlier evaluations of ES, which have used 'value transfer' approaches. The total economic value of ES in arable land in the province of Canterbury, New Zealand was also calculated here by using a 'bottom-up' approach (Sandhu *et al.*, 2005) and extrapolation using GIS techniques. It also provided information on the change in the economic value of ES in a scenario in which conventional farming shifts to organic farming. This exercise was necessary because of the increasing importance of the economic value of ES in 'engineered' landscapes (Matson *et al.*, 1997; Gurr *et al.*, 2004; Kremen, 2005; Robertson & Swinton, 2005). Evidence of ecological disturbances sometimes does not generate much attention unless the evidence includes dollar values (Daly, 1998).

The benefits of ES in 'engineered' ecosystems are substantial as demonstrated by their economic value in arable land in Canterbury, New Zealand. The ecological and economic value of some of the ES can be maintained and enhanced on arable farmland by adopting sustainable practices such as organic farming (Lampkin & Measures, 2001; Sandhu et al., 2005; Kristiansen et al., 2006). The current work showed that conventional New Zealand arable farming practices can severely reduce the financial contribution of some of these services to agriculture whereas organic agricultural practices enhance their economic value. However, this change is very slow as conventional farming practices have reduced these services to a large extent and organic practices are slow to respond to repair them. One example is that of the increase in earthworm populations in organic fields in relation to the number of years the later have been certified organic. Earthworms play a vital role in soil formation services, but their population recovery rate is slow.

6.3 Biological control of pests using infra-red digital video analysis

One of the key ES identified on farmland was biological control of pests. Chapter 5 explored this ES by using infra-red digital video analysis. The use of video to monitor leafroller prey resulted in observations and conclusions that would not be attainable from unmonitored or sporadically monitored sentinel prey experiments. Video monitoring provided positive identification of predators that encountered the leafrollers and which ones were responsible for leafroller mortality on the ground and in the canopy. This kind of information allows for the development of conservation biological control techniques directed at specific predatory taxa that consume focal pest species. *A priori* identification of important predators could reduce the research time and resources required to develop effective conservation biological control techniques to be implemented by producers in vineyards and arable farmland.

This study fulfilled the first step in the development of biological control protocols in which the ambient level of control by predators was evaluated which taxa are potentially important were identified. Future research should determine how these and other predators affect the growth of natural leafroller populations. In addition, research should address whether vineyard habitat may be altered to attract and conserve greater populations of earwigs, spiders and flatworms shown to kill *E. postvittana*.

6.4 Future research

This economic valuation will help in redesigning agricultural landscapes using new eco-technologies based on novel and sound ecological knowledge to enhance ES. This will improve farm incomes by replacing unsustainable inputs and by managing natural resources. This helps to ensure long-term sustainability and better stewardship of farms. These economic values reveal significant changes in ES in monetary terms and help ensure that arable farming is a contributor to improved social wellbeing as well as increased food production

Perspectives for further work,

- Research to improve understanding of basis of ecological processes and mechanisms to understand the trade-offs and synergies provided by different land management practices (conventional, organic or conservation agriculture).
- Evaluate and make recommendations for the 'best management practices' to enhance ecosystem services and reduce net externalities from arable agricultural system.
- Research to investigate the operation and behaviour of combined multifunctional cropping systems for food and fibre on local biodiversity and the system's economic and energy balance in terms of its fossil and renewable energy use and production.
- Future research should be aimed at designing food production systems that are both novel and made sustainable by the simultaneous production of biomass energy integrated with the food-producing crops within the system and are providers of ES (Kuemmel *et al.*, 1998).

6.5 Conclusions

Key findings
• The 'substitution' agriculture currently in practice has resulted in degradation of some ES to such an extent that they have no economic value on these 'engineered' or designed landscapes.
• The challenge of reversing the degradation of these ES can be partially met by practising 'ecological engineering' under some alternative form of land management practices such as organic agriculture.

This study made clear that arable farmland provides a range of ES which can be measured using field experiments based on ecological principles by incorporating a 'bottom-up' approach. It provides information for policy and decision makers to consider the financial contribution of different farming practices towards the sustainability of arable farming.
As the philosopher Karl Popper said: 'Bold ideas and unjustified assumptions are the only way of advancing science' (Popper, 1959). This project did not completely follow such an extreme view, but it does represent a novel approach to the assessment of ES, using real, *in situ*, ecological measurements to complement the general 'value-transfer' technique which is frequently used by environmental economists (de Groot, Costanza, Patterson and Cole, Cullen).

References

Anonymous (2001) *Private Lands, Public Benefits: Principles for Advancing Working Lands Conservation.* National Governors Association/ Center for Best Practices, Washington. On WWW at www.nga.org

Angus, A., Hodge, I., McNally, S. and Sutton, M. (2003) The setting of standards for agricultural nitrogen emissions: a case of the Delphi technique. *Journal of Environmental Management* 69, 323-337.

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rossendo, S., Roughgarden, J., Trumper, K. and Turner, R.K. (2002) Economic reasons for saving wild nature. *Science* 297, 950–953.

Brooks, K.W. (1979) Delphi technique: expanding applications. *North Central Association Quarterly* 54, 377-385.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. *Nature* 387, 253–260.

Curtis, I. (2004) Valuing ecosystem goods and services: a new approach using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes. *Ecological Economics* 50, 29-44.

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 DC, pp. 1-10.

Daily, G.C., Alexander, S., Ehrlich, P.R., Goulder, L., Lubchenco, J., Matson, P.A., Mooney, H.A., Postel, S., Schneider, S.H., Tilman, D. and Woodwell, G.M. (1997) Ecosystem services: benefits supplied to human societies by natural ecosystems. Issues in Ecology 2, pp. 18.

Daly, H.E. (1998) The return of Lauderdale's paradox. *Ecological Economics* 25, 21-23.

de Groot, R.S., Wilson, M. and Boumans, R.M. J. (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41, 393-408.

Goulder, L.H. and Kennedy, D. (1997) Valuing ecosystem services: philosophical bases and empirical methods. In: Daily, G.C. (Ed.), *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington DC, pp. 23-48.

Gurr, G.M., Wratten, S.D. and Altieri, M.A. (Eds.) (2004) *Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods*. CSIRO, Victoria.

Heal, G.M. and Small, A.A. (2002) Agriculture and ecosystem services. In: Gardner, B.L. and Rausser, G.C. (eds) *Handbook of Agricultural Economics Vol. 2a* (pp. 1341-1369). Elsevier, Amsterdam.

Kremen, C. (2005) Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters* 8, 469–479.

Kristiansen, P., Taji, A. and Reganold, J. (2006) Organic agriculture: opportunities and challenges. In: Kristiansen, P., Taji, A., Reganold, J. (Eds.) *Organic Agriculture: A Global Perspective.* CSIRO Publishing, Australia, pp. 421-441.

Kuemmel, B., Langer, V., Magid, J, Neergaard, A.De and Porter, J.R. (1998) Energetic, economic and ecological balances of a combined food and energy system. *Journal of Biomass and Bioenergy* 15, 407-416.

Lampkin, N. and Measures, M. (2001) *Organic Farm Management Handbook: Organic Farming Research Unit.* Aberystwyth: Institute of Rural Studies, University of Wales.

Matson, P.A., Parton, W.J., Power, A.G. and Swift, M.J. (1997) Agricultural intensification and ecosystem properties. *Science* 277, 504–509.

Millennium Ecosystem Assessment, (2003) *Ecosystems and Human Well-being: a Framework for Assessment.* Island Press, Washington, DC.

Myers, N., (1996) Environmental services of biodiversity. *Proceedings of the National Academy of Sciences USA* 93, 2764–2769.

Pimentel, D. and Giampietro, M. (1994). *Food, Land, Population and the U.S. Economy.* Carrying Capacity Network, Washington, DC.

Popper, K.R. (1959) *Logic of scientific discovery.* Basic Books, New York.

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar, P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell, J. and Zurek, N.B. (2005) *Millennium Ecosystem Assessment Synthesis report.* Island Press, Washington DC.

Robertson, G.P. and Swinton, S.M. (2005) Reconciling agricultural productivity and environmental integrity: a grand challenge for agriculture. *Frontiers in Ecology and the Environment* 3, 38–46.

Sandhu, H.S., Wratten, S.D. and Cullen, R. (2005) Evaluating ecosystem services on farmland: a novel, experimental, 'bottom-up' approach. In: *Proceedings of the 15th International Federation of Organic Agriculture Movements (IFOAM) Organic World Congress*, Adelaide, Australia.

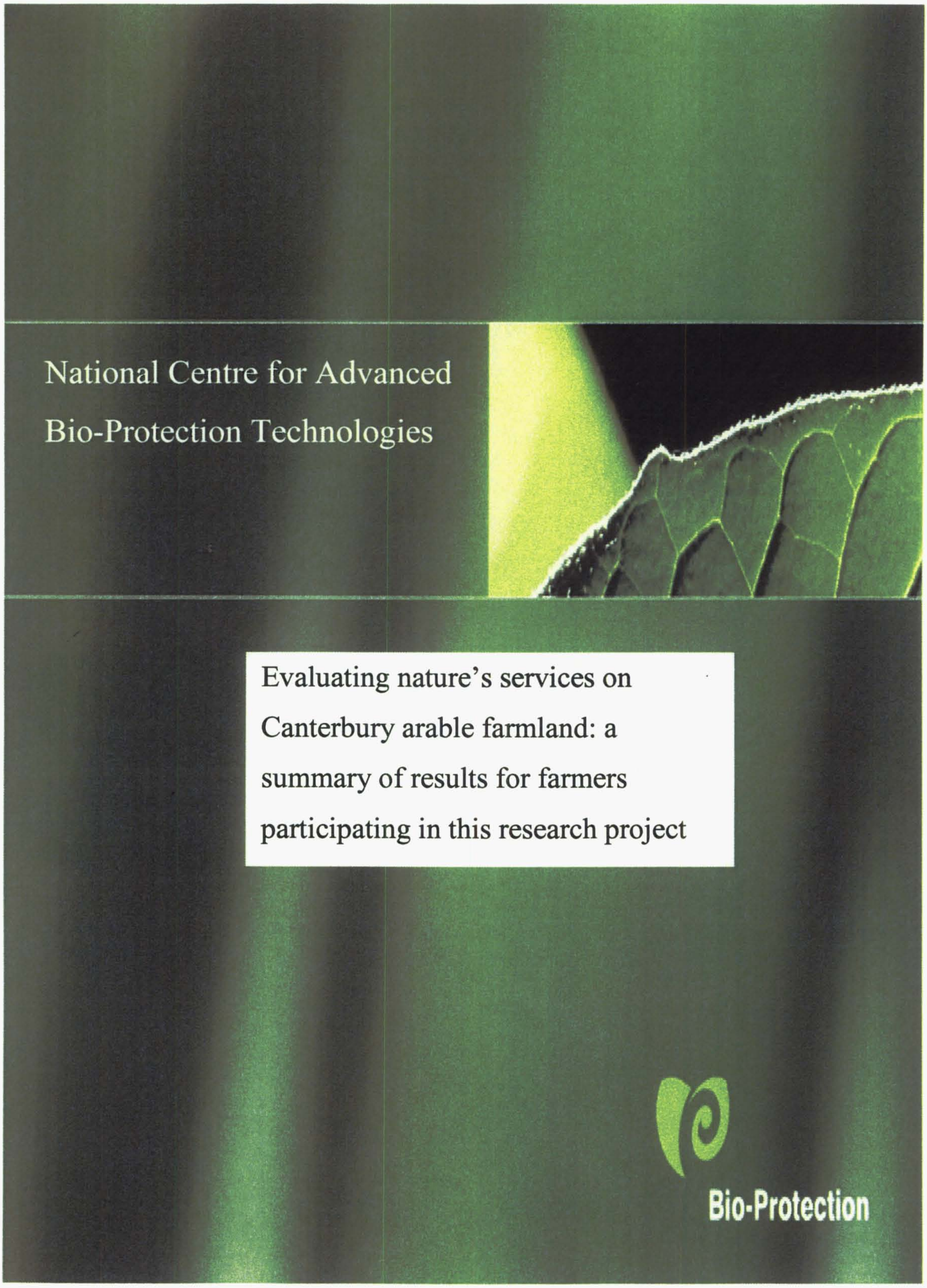
Sandhu, H.S., Wratten, S.D. and Cullen, R. (2006) Field evaluation of ecosystem services in organic and conventional arable land. *International Journal of Agricultural Sustainability*, in press.

Takatsuka, Y., Cullen, R., Wilson, M. and Wratten, S. (2005) Using choice modelling to value ecosystem services on arable land. In: *Proceedings of the 49th Australian Agricultural and Resource Economics Society (AARES) Annual Conference*, Coffs Harbour, Australia.

Williams, M. (2004) Sustainable New Zealand-the way forward. *New Zealand Geographic* 70, 7-8.

Wilson, M., Troy, M. and Costanza, R. (2004) The economic geography of ecosystem goods and services: revealing the monetary value of landscapes through transfer methods and geographic information systems. In: Dieterich, M., van der Straaten, J. (Eds.), *Cultural Landscapes and Land Use: the Nature Conservation–Society Interface*, Kluwer Academic Publishers, Dordrecht, pp. 69-94.

Appendix



National Centre for Advanced Bio-Protection Technologies

Evaluating nature's services on Canterbury arable farmland: a summary of results for farmers participating in this research project

Bio-Protection

Evaluating nature's services on Canterbury arable farmland: a summary of results for farmers participating in this research project

Part of a research programme, funded by the Foundation for Research, Science and Technology (FRST), entitled: Biodiversity, Ecosystem Services and Sustainable Agriculture (LINX 0303) with PhD scholarship support from the BHU Organics Trust, Lincoln University

Harpinder Singh Sandhu
Prof Steve Wratten
Prof Ross Cullen
Dr Roddy Hale

Lincoln University
October 2005

Researchers' contact details

Harpinder Singh Sandhu, Prof Steve Wratten, Dr Roddy Hale
National Centre for Advanced Bio-Protection Technologies
PO Box 84
Lincoln University
Canterbury

Phone: (3) 325 3838 extn 8221 (Prof Steve Wratten)
Fax: (3) 325 3864
Email: sandhuh@lincoln.ac.nz, wrattens@lincoln.ac.nz, haler@lincoln.ac.nz

Prof Ross Cullen
Commerce Division
PO Box 84
Lincoln University
Canterbury

Phone: (3) 325 3838 extn 7807
Fax: (3) 325 3847
Email: cullenr@lincoln.ac.nz

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YOUR FIELDS:

O10: Peas field
O11: Wheat field
O12: Barley field
C10: Peas field
C11: Wheat field
C12: Barley field

The above are your fields.
Organic fields (O10, O11, O12);
Conventional fields (C10, C11, C12).
They are highlighted in Tables and marked (⇧) in Figures.
If you do not have time to read all this report straight away, we suggest you read the summary on page 1 and see how your fields are performing environmentally in the Tables and Figures.

"Modern agricultural research has taught the farmer to profiteer at the expense of posterity. In businesses such attitudes result in bankruptcy"
(Sir Albert Howard, 1940)

SUMMARY

Natural and modified ecosystems support human life through nature's services or ecosystem services (ES). ES include services such as pollination of crops, biological control of pests, weeds and diseases, carbon sequestration, soil formation and protection, nutrient mineralisation, water regulation, air purification etc. ES are vital for human existence on earth; for example, a decline in the pollinators of crops would have serious economic implications; or a disruption of the carbon cycle could bring rapid climate change and thereby threaten the very existence of civilization.

The importance of ES or nature's services is now very well established and ES have been demonstrated to be of very high economic value. However, intensification of agriculture in the last century has resulted in the substitution of many ES with chemical inputs. An example is the use of urea in place of nitrogen fixation and insecticides in place of pest-eating predators. This has resulted in some serious detrimental effects which have led to worldwide concerns about the environmental consequences of modern agriculture. Moreover as the world approaches 'peak oil', so called conventional agriculture may no longer be able to depend as heavily or as easily on oil-derived 'substitution' inputs. Population growth and increasing food demands in the next 50 years also pose great challenges to the sustainability of modern farming practices.

The current study recognises these challenges and in accordance with the maxim "what is measured, counts", is designed to estimate the provisions of nature's services on farmlands in Canterbury. It identifies and quantifies the extent of ES under different arable farming systems.

In this study arable production systems in Canterbury are evaluated to provide estimates of their contribution towards the 'natural capital' of the nation. This research also calculates the economic value of key ES and thereby assesses their worth on farmland. Once the levels of ES are known, new eco-technologies based on novel and sound ecological knowledge can be targeted to enhance ES to improve farm incomes and replace unsustainable inputs. This ensures long- term sustainability of farms.

1. INTRODUCTION

Agricultural activities before the twentieth century were mainly dependent on crop rotation and natural control of pests and diseases. Farmers were able to meet the food requirements of the populations without being highly dependent on external chemical inputs. They had an instinctive, if not scientific, understanding of nature and its services.

However, since the onset of the industrial revolution, and now more than ever before, farmers are increasingly becoming very susceptible to pressures imposed by expanding international food markets. Modern agriculture is feeding more than six billion people and in the next 50 years, the human population is projected to grow to nine billion and the global grain demands will double. The markets and the populations thus demand higher production and year around availability of many products. This has led to massive expansion and intensification of agriculture. Intensive agriculture is heavily dependent on fossil fuels, chemical fertilizers and toxic pesticides. This overt dependence on chemical inputs has lead to some very serious detrimental effects on the environment. These "external costs" of chemical dependent and intensive agricultural practices include severe damages to soil fertility, water and biodiversity loss and loss of human health.

This has led to world wide concerns about the environmental consequences of modern agriculture. Coupled with this are the more pragmatic reasons. As the world approaches 'peak oil', agriculture may no longer be able to depend so heavily on oil-derived 'substitution' inputs.

The key challenge thus is to meet the food demands of a growing population and yet maintain and enhance the productivity of agricultural systems. There is thus now an enhanced interest in the services provided by nature.

Nature's services or ecosystem services (ES) and goods are the benefits that we derive from nature in the form of food, timber, biomass fuels, natural fibres etc. In agriculture, nature's services include pollination of crops, biological control, carbon sequestration, soil formation and protection, nutrient mineralisation, water regulation, air purification etc. They are so fundamental to life that they are easy to take for granted, and so large in scale that it is hard to imagine that human activities could irreplaceably disrupt them. And yet the recently concluded UN-funded Millennium Ecosystem Assessment states that approximately 60 percent of ecosystem services evaluated are in a state of decline. In agriculture it is primarily due to extensive intensification. The need, thus to assess the threats to ES, is acute in agriculture so that agricultural landscapes can increase the rate at which they provide multiple services without further degradation and meet the growing demands of increasing populations.

1.1. Aim of the study

Agriculture contributes a 16 percent share of the annual GDP in New Zealand. About half of the New Zealand land area is under pastoral and arable agricultural production. Arable landscapes are actively engineered systems, designed to maximize the delivery of socially valued goods and services. Some arable systems can reduce the ability of the ecosystem to provide goods and services while others may actually enhance the delivery of these services (thus ES may be more important in organic production systems as these systems are more dependent on ES for the production of food and fibre). To understand the provisions of ES under different arable farming systems is thus crucial for ensuring the long- term sustainability of these farms.

The focus of this study is on one sector of an engineered ecosystem (arable farming) and since Canterbury is the major arable growing area in New Zealand, this study identifies and experimentally assesses the key ES (biological control of pests, soil formation, and mineralization of plant nutrients) on Canterbury arable farms. It addresses both conventional and organic systems and also estimates the economic value of the key ES identified. It thereby assesses the worth of ES on arable farmland.

This study thus attempts to provide estimates of the contribution of ES towards the 'natural capital' of the nation. Once the levels of ES are known, new technologies based on novel and sound ecological knowledge can be targeted to enhance ES to improve farm incomes and replace unsustainable inputs.

1.2. Nature's (ecosystem) services associated with arable farming

Key recent publications estimated the value of global ecosystem goods and services, i.e., the economic value of global ES was calculated to be US $33 trillion per year, the economic value of biodiversity in New Zealand was estimated to be NZ $44 billion for the year 1994 using a value transfer method. There has been considerable progress in the development of a conceptual framework for the study of ES and mechanisms to evaluate the benefits derived from natural systems. However, there exists a significant gap in the recognition and understanding of ES in agricultural landscapes although the need for this knowledge is acute due to a growing population and increasing food demands, which will double by 2050.

In this study ES have been identified in agricultural landscapes based on literature and discussion with experts and are summarised in table 1.1.

Table 1.1 Nature's (ecosystem) services associated with arable farming

Provisioning services	***Regulating services***	***Cultural services***
Food Raw material Fuel wood Conservation of species Maintenance of genetic resources	Hydrological flow	Aesthetic Recreation Science and education
	Supporting services	
Pollination Biological control Carbon accumulation	Mineralization of plant nutrients Soil fertility Soil erosion control	Support to plants Soil formation Nitrogen fixation Shelterbelts

1.3. Magnitude of ecosystem services associated with arable farming systems

In the current work estimates are provided about the magnitudes of identified ES under different farming systems in New Zealand using Delphi technique. A Delphi panel of experts was chosen to assign the magnitudes of ES (on the scale of 1-5) for each of the ES under different arable farming systems in New Zealand. The panel comprised two research scientists (Lincoln University), one Agribusiness Consultant (Agribusiness Group, Christchurch) and the Director of Farms (Lincoln University). The experts completed the information in the first-round by assigning values on the scale of 1-5. The results were then sent to each member independently to invite them to modify their responses in the light of the evidences provided by other panel members. The second-round results are presented in Table 1.2 after the panel came to a consensus over the estimation of ES magnitudes. Best current practice is valued at scale 5, so there is at least one 5 in each row but rows cannot be compared.

Table 1.2 reports that many ES in traditional agriculture were given a medium rating. This reflects the fact that traditional agriculture is a reference point for the other agriculture systems. Keeping this in mind, it is noteworthy that most ES under conventional agriculture scored relatively lower than ones under traditional agriculture, except for food production. This indicates that conventional agriculture has negative impacts on several ES and lower ability to deliver some ES. On the other hand, the organic agriculture system achieved near the highest ratings in most of the ES attributes. The organic practices are judged to provide high levels of most ES except for food production. Conservation and Biodynamic agriculture systems are rated as somewhere between the traditional and organic agriculture systems.

Table 1.2 Estimated magnitudes of ecosystem services associated with arable farming systems using the Delphi technique- see text.

		Biodynamic Agriculture	Organic Agriculture	Traditional Agriculture	Conservation Agriculture	Conventional Agriculture
	Provisioning services					
1	Food	2	2	3	5	5
2	Fuel wood	4	5	3	2	2
3	Conservation of species	5	5	3	4	1
4	Medicinal resources	5	5	3	3	2
	Regulating services					
5	Gas and climate regulation	5	5	3	4	2
6	Water regulation	3	5	2	3	1
7	Disturbance prevention	3	3	3	5	3
	Cultural services					
8	Aesthetic	5	4	3	3	2
9	Recreation	4	5	2	2	1
10	Cultural and historic	4	4	5	4	2
	Supporting services					
11	Pollination	5	5	3	3	1
12	Biological control	5	5	3	3	1
13	*Services provided by soil*					
a	Carbon accumulation	3	4	3	5	2
b	Mineralization of plant nutrients	4	5	3	4	3
c	Soil erosion control	4	5	3	4	2
d	Support to plants	5	5	3	4	2
e	Soil formation	4	4	3	5	2
f	Nitrogen fixation	5	5	4	3	2

2. STUDY SITES

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. The remainder consists of land in horticulture, grasslands, forest plantation, etc.

A total of 30 fields were selected in September 2004, distributed over the Canterbury Plains comprising of 14 organic and 15 conventional fields and 1 conservation agriculture field with mean area of 10 ha. Of the 14 organic fields, seven were certified by AgriQuality, New Zealand and seven by BioGro, New Zealand. Both certifiers are accredited with IFOAM, the International Federation of Organic Agriculture Movements.

Codes O1-O14 for the organic fields and C1-C15 for the conventional ones and CA1 for conservation agriculture field were assigned.

All the 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. 2.1 below.

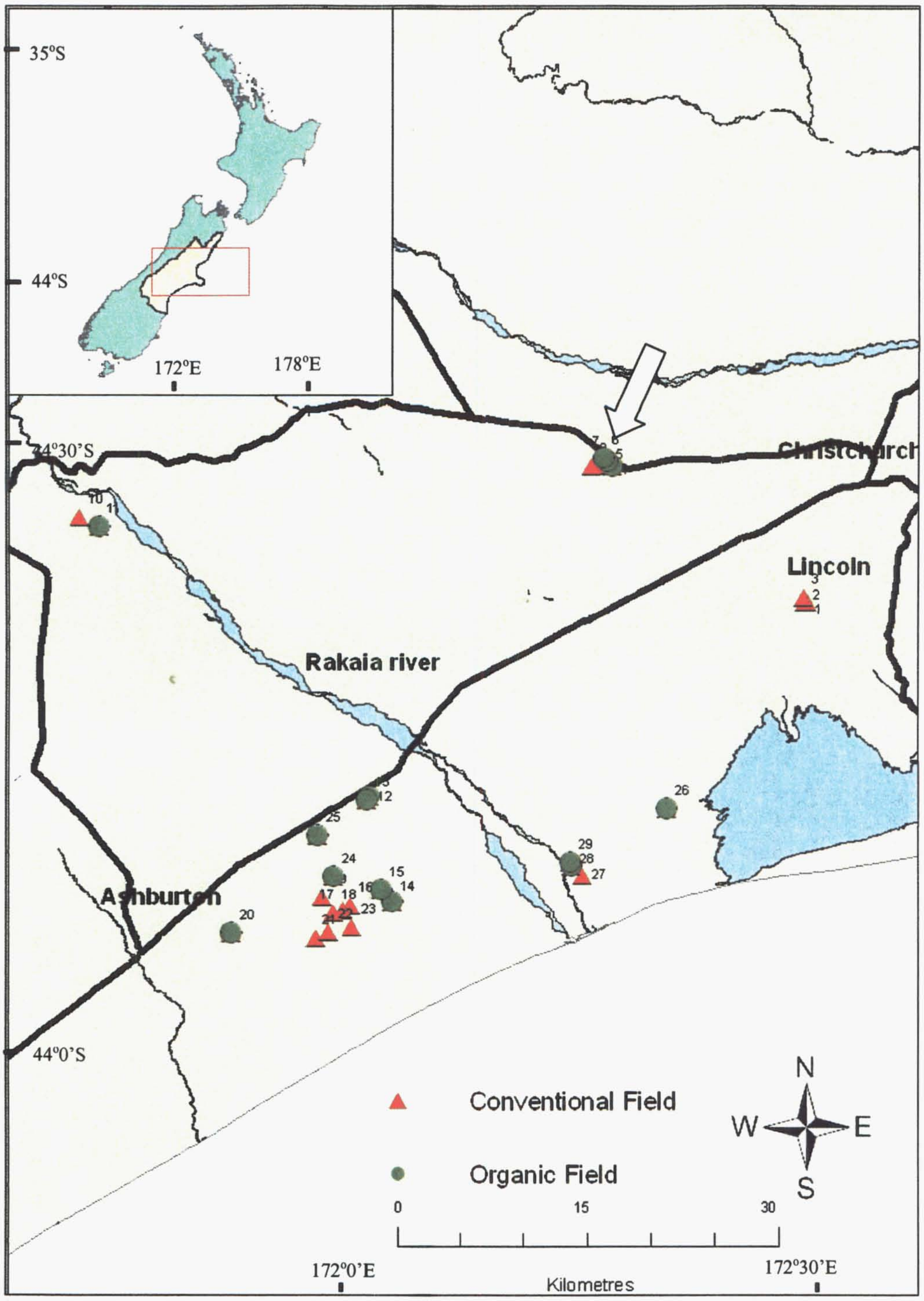

Fig. 2.1 Map of New Zealand showing the study area (selected fields). Arrow indicates your fields.

2.1. Customized profile of individual fields

The organic fields; peas field (O10), wheat field (O11) and barley field (O12) and conventional fields; peas field (C10), wheat field (C11) and barley field (C12) were selected from your farm for the evaluation of different ES. Soil samples from both fields were taken using standard sampling procedures after consultation with the Lincoln University soil science group and sent to Hill Laboratories, Hamilton for testing.

The results are presented in Table 2.1. Olsen P was lower than the average in all the six fields. Potassium was also found to be lower than the average in all the fields except O10 and C10.

Table 2.1 Soil analysis for the selected fields. Highlighted rows indicate your fields' data. me/100g (milli equivalent/100grams), mg/L (milligrams/litre).

	Fields	pH	Olsen P (mg/L)	Potassium (me/100g)	CEC (me/100g)	Base Saturation (%)	Bulk Density (g/cm^3)	Total Carbon (%)	Total Nitrogen (%)
1	O1	5.8	9	0.3	12	60	1.02	2.5	0.25
2	O2	5.8	12	0.83	14	56	0.93	3.2	0.32
3	O3	6.2	10	0.38	16	66	0.95	3.4	0.34
4	O4	5.7	18	0.5	13	50	1.02	2.5	0.25
5	O5	6.2	13	0.96	14	64	0.99	2.7	0.25
6	O6	5.9	12	1.06	16	68	0.99	2.7	0.27
7	O7	6	42	0.91	15	63	0.96	3.1	0.31
8	O8	6	11	0.18	13	59	1	2.6	0.26
9	O9	6.2	8	0.49	16	69	1.02	2.8	0.27
10	**O10**	**6**	**7**	**0.6**	**15**	**64**	**0.97**	**2.8**	**0.27**
11	**O11**	**6.3**	**8**	**0.37**	**14**	**71**	**1.01**	**2.4**	**0.23**
12	**O12**	**6.2**	**12**	**0.4**	**14**	**68**	**1**	**2.4**	**0.21**
13	O13	5.8	6	0.33	14	57	0.99	3	0.29
14	O14	6.2	8	0.65	14	65	1.03	2.6	0.25
15	C1	6.3	11	0.24	17	74	0.92	3	0.31
16	C2	5.5	16	0.36	12	53	1.08	2.1	0.2
17	C3	5.7	19	0.24	13	48	0.96	3	0.28
18	C4	5.9	24	0.42	15	60	1.01	2.7	0.25
19	C5	6.4	25	0.56	15	70	1.03	2.4	0.23
20	C6	5.3	36	0.66	17	61	1.01	2.9	0.26
21	C7	5.9	15	0.29	14	57	1.02	2.8	0.25
22	C8	6.2	15	0.32	16	67	0.96	3	0.3
23	C9	6.2	16	0.4	14	66	1.05	2.3	0.22
24	**C10**	**5.7**	**14**	**0.66**	**16**	**56**	**0.94**	**3.1**	**0.3**
25	**C11**	**6**	**11**	**0.34**	**14**	**64**	**0.98**	**2.5**	**0.24**
26	**C12**	**6**	**13**	**0.22**	**15**	**66**	**0.98**	**2.8**	**0.27**
27	C13	6	30	0.42	17	70	0.98	3.1	0.31
28	C14	6.4	21	0.5	17	76	1.02	3	0.29
29	C15	5.9	20	0.33	12	55	1.08	2.6	0.23
30	CA1	6.3	20	0.6	24	80	0.93	4.1	0.42

Comment: Bulk density was higher than the average in all the organic fields (O10, O11 and O12) but lower in conventional fields (C10, C11 and C12).

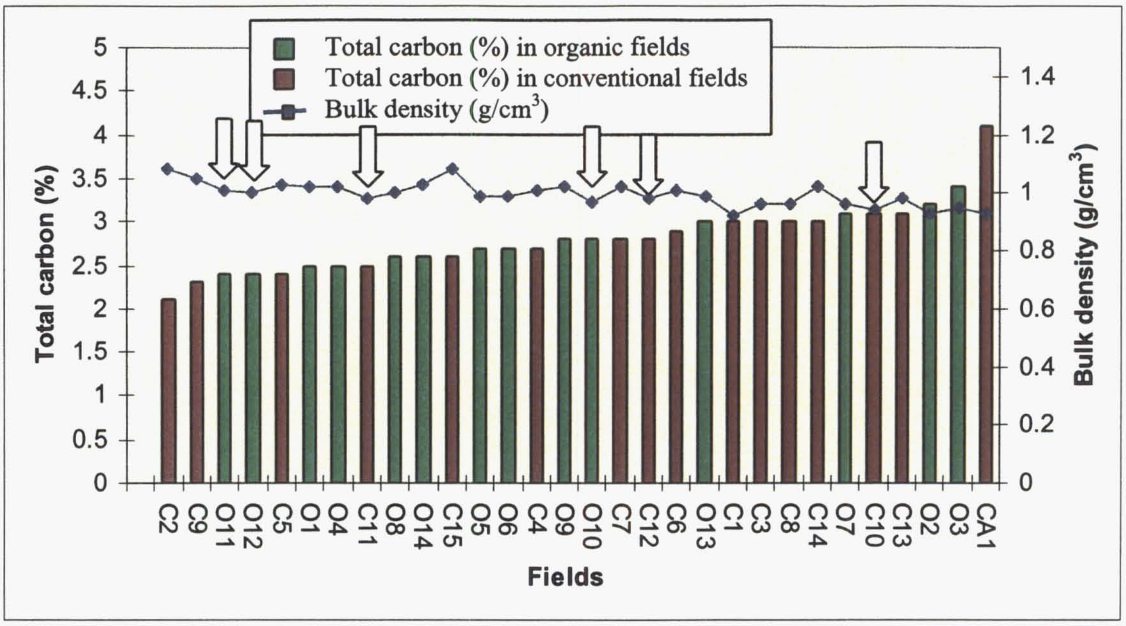

Fig. 2.2 Analysis of total carbon (%) and bulk density (g/cm^3) of soil in selected fields. Arrow indicates your fields.

Comment: There was no difference in bulk density of all the six fields than the average. Total carbon was lower than the average in all the fields except conventional field C10.

3. BIOLOGICAL CONTROL OF PESTS

Natural pest control services provided by their natural enemies prevent the outbreaks of pests and stabilize the agricultural systems world over. It is estimated that 99 per cent of agricultural pests and diseases are controlled by their natural enemies - predators, parasites, and pathogens. Such 'natural' suppression is of great significance in organic agriculture as that system is more dependent on such services to keep pest populations low. The process of pest removal by soil-surface predators was assessed in the current work.

3.1. Assessing the predation rate of aphids and fly eggs in arable fields in Canterbury

Aphids in many arable crops and the carrot rust fly in carrots are important pests in Canterbury. Live pea aphids were used and frozen eggs of the blow fly were simulated carrot rust fly eggs. Predation of these two prey items was assessed in all the fields on each of two dates: November 2004 and January 2005 and are presented in Figs 3.1 and 3.2. Mean rate of predation in organic and conventional fields is presented in Fig. 3.3.

Table 3.1 shows the predation rates of aphids and fly eggs in individual fields during Nov 2004 and Jan 2005.

Table 3.1 Rates of predation of aphids and fly eggs during Nov 2004 and Jan 2005 in selected fields. Highlighted rows indicate your fields' data.

	Field type	Aphid predation		Fly egg predation	
		Rate of predation (%removal/24h) during Nov 2004	Rate of predation (%removal/24h) during Jan 2005	Rate of predation (%removal/24h) during Nov 2004	Rate of predation (%removal/24h) during Jan 2005
1	O1	80	0	75.7	0
2	O2	0	42.8	0	24.2
3	O3	13.3	39.2	34.8	37.8
4	O4	3.3	26.2	19.6	50
5	O5	6.6	5.9	13.6	18.2
6	O6	6.6	20.2	24.2	45.4
7	O7	10	0	40.9	0
8	O8	3.3	4.7	18.2	28.7
9	O9	6.6	20.2	15.2	37.8
10	**O10**	**26.6**	**0**	**30.3**	**0**
11	**O11**	**26.6**	**35.7**	**33.3**	**40.9**
12	**O12**	**36.6**	**48.8**	**21.2**	**28.7**
13	O13	6.6	14.2	5.9	18.2
14	O14	3.3	11.9	15.2	40.9
15	C1	0	0	4.5	0
16	C2	0	5.9	0	3
17	C3	3.3	0	1.5	0
18	C4	3.3	3.5	4.5	0
19	C5	0	0	6	6
20	C6	3.3	0	4.5	0
21	C7	0	0	6	0
22	C8	0	0	0	3
23	C9	0	0	0	0
24	**C10**	**13.3**	**0**	**13.6**	**0**
25	**C11**	**6.6**	**0**	**10.6**	**4.5**
26	**C12**	**6.6**	**0**	**4.5**	**0**
27	C13	0	0	0	0
28	C14	0	2.3	0	6
29	C15	3.3	0	6	0
30	CA1	70	60	72	86.3

Comment: Predation of aphids and fly eggs was found to be very high in the organic fields as compared to conventional fields.

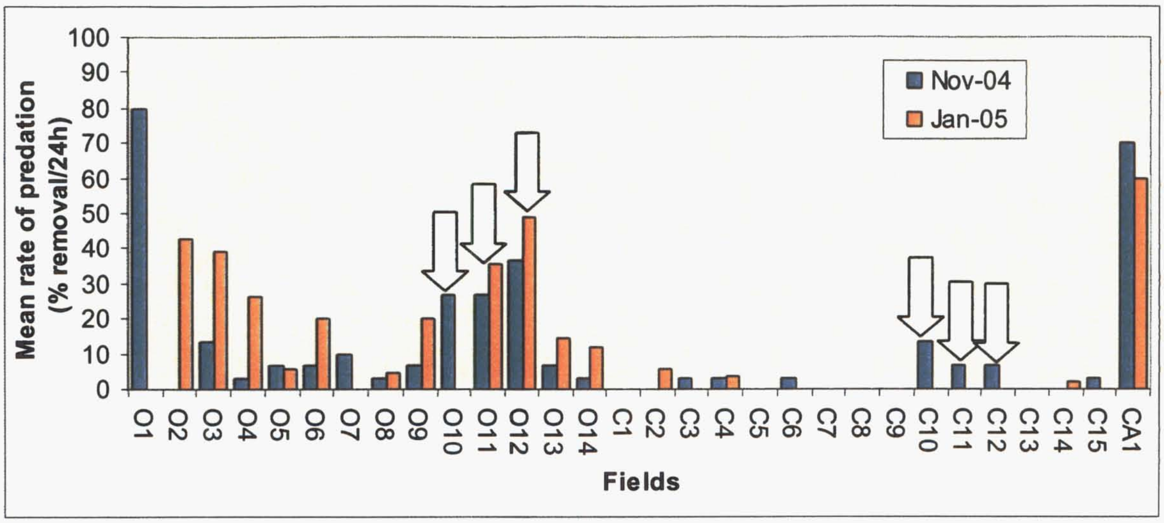

Fig. 3.1 Predation rate (% removal /24h) of aphids in selected fields, November 2004 and January 2005. Organic fields are O1-O14, conventional fields are C1-C15 and conservation agriculture field is CA1. Arrow indicates your fields.

Comment: Predation rate of aphids increased during Jan 2005 as compared to that during Nov 2004 in organic fields.

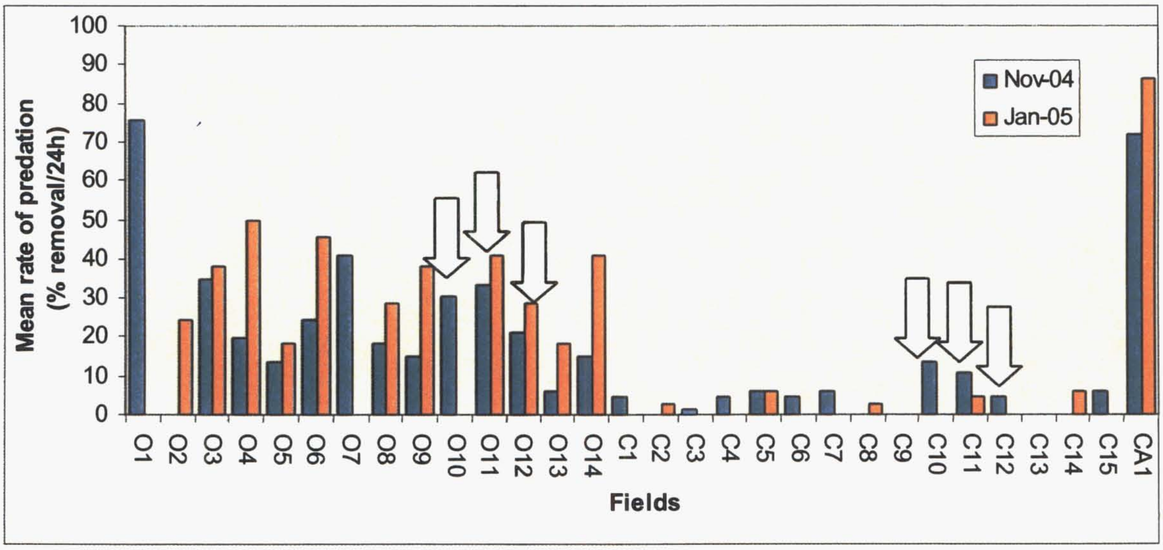

Fig. 3.2 Predation rate (per cent removal /24h) of fly eggs in selected fields, November 2004 and January 2005. Organic fields are O1-O14, conventional fields are C1-C15 and conservation agriculture field is CA1. Arrow indicates your field.

Comment: Predation rate of fly eggs also increased during Jan 2005 as compared to that during Nov 2004 in organic fields.

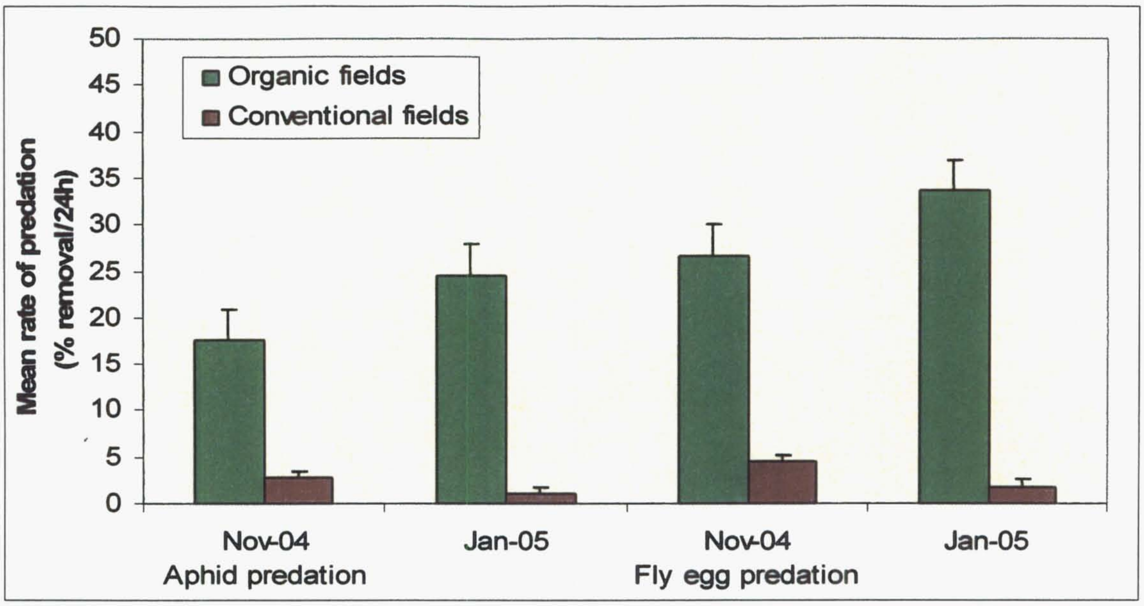

Fig. 3.3 Mean rate of predation (per cent removal/24h) of aphids and fly eggs in selected fields.

Comment: Predation rates of aphids and fly eggs were significantly higher in organic fields as compared to conventional ones during November 2004 and January 2005.

3.2. Economic value of biological control of aphids and carrot rust fly in arable fields

The economic value of background biological control of aphids and the carrot rust fly is estimated by using avoided cost (AC) of pesticides based on the cost of pesticides (conventional farmers' spending to control aphids and carrot rust fly), and total avoided cost (TAC) of pesticides that includes \$87/ha/yr as the external cost of pesticides.
The economic value of biological control of aphids and carrot fly are presented in Figs 3.4 and 3.5, respectively.

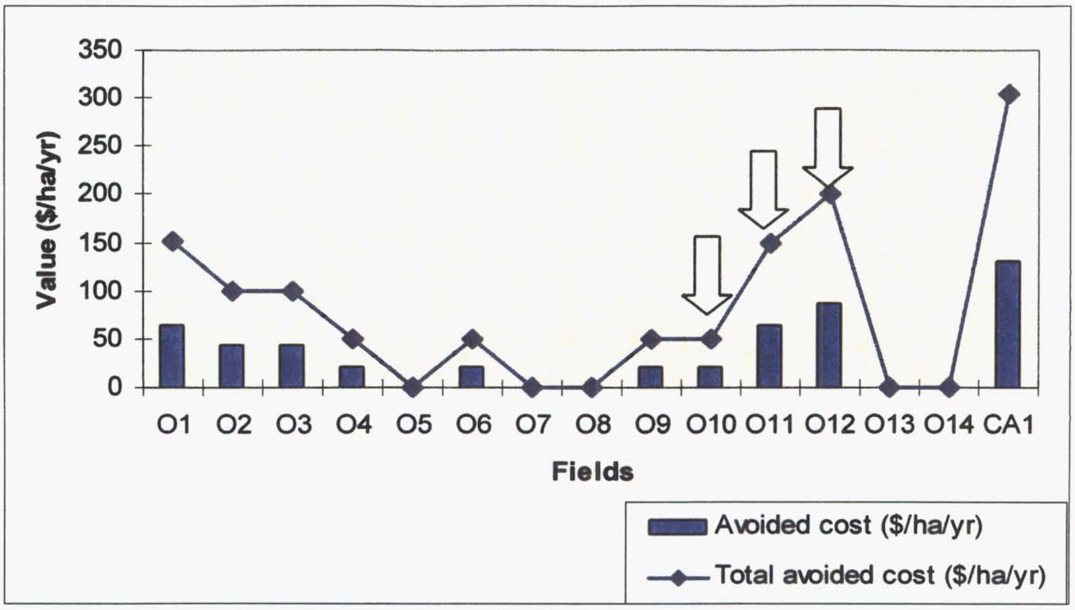

Fig. 3.4 Economic value of biological control of aphids in organic and conservation agriculture fields. Total avoided cost includes external cost also. Arrows indicate your fields.

Comment: Economic value of biological control of aphids was demonstrated only in organic fields. It was found to be \$21.5/ha/yr (avoided cost) and \$50/ha/yr (including external cost) in O10, \$64.5/ha/yr (avoided cost) and \$150/ha/yr (including external cost) in O11, \$86/ha/yr (avoided cost) and \$200/ha/yr (including external cost) in O12.

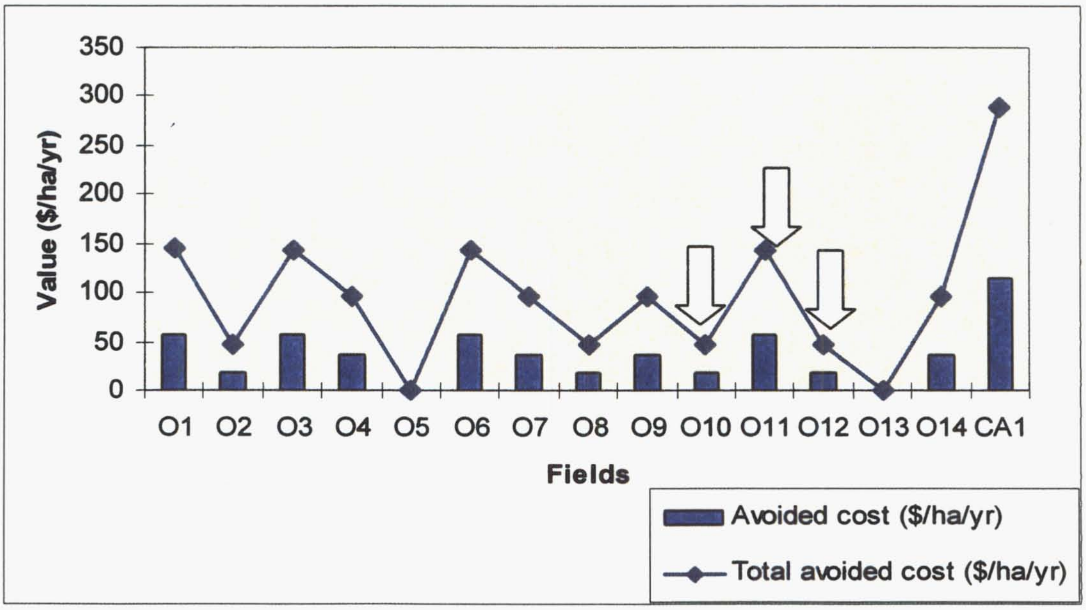

Fig. 3.5 Economic value of biological control of carrot rust fly in organic and conservation agriculture fields. Total avoided cost includes external cost also. Arrows indicate your fields.

Comment: Economic value of biological control of carrot fly was demonstrated only in organic fields. It was found to be \$18.9/ha/yr (avoided cost) and \$47.7/ha/yr (including external cost) in O10, \$56.3/ha/yr (avoided cost) and \$143/ha/yr (including external cost) in O11, \$18.9/ha/yr (avoided cost) and \$47.7/ha/yr (including external cost) in O12.

4. SOIL FORMATION

Soil formation is an important ecosystem service provided by soil biota. Earthworms are the most important component of the soil biota in terms of soil formation and maintenance of soil structure and fertility. Earthworms bring between 10 and 500 tonnes/ha/yr of soil to the surface and it was estimated that soil biota aids the formation of approximately 1 tonne/ha/yr of topsoil. Under agricultural conditions it takes approximately 500 years to form 25 mm of soil, whereas under forest conditions it takes approximately 1000 years to form the same amount. Earthworms are also beneficial by maintaining soil nutrient levels by mixing the soil. Their activities bring sub-surface soil, providing nutrients in the plant root zone. In the current work, soil formation through the activities of earthworms was assessed by sampling their populations to provide an estimate of the quantity of soil formed/ha/yr.

Sampling was done during the spring as earthworm populations are generally highest at this time in New Zealand. The results are given in table 4.1. There were no significant differences between organic and conventional fields. However, earthworm populations increased significantly with the number of years the farm has been certified organic (Fig. 4.2).

4.1. Economic value of soil formation

The economic value of earthworms in soil formation in this work is presented in table 4.1. Mean earthworm biomass is 0.2g and on an average, one tonne of earthworms forms 1000kg of soil per hectare annually. The value of top soil in New Zealand is NZ$33.75 per ton. From these assumptions and economic information, the value of soil formation was calculated and is presented in Fig. 4.1.

Table 4.1 Earthworm populations, biomass, soil formation and their economic value in soil formation in selected organic (O1-O14), conventional fields (C1-C15) and conservation agriculture field (CA1). Highlighted rows indicate your fields' data.

Field type	Earthworm count (no./m^2)	Biomass (kg/ha)	Soil formation (kg/ha/yr)	Soil formation value ($/ha/yr)
O1	116	232	232	7.88
O2	212	424	424	14.41
O3	176	352	352	12
O4	28	56	56	1.9
O5	48	96	96	3.26
O6	240	480	480	16.32
O7	12	24	24	0.81
O8	84	168	168	5.71
O9	92	184	184	6.25
O10	**244**	**488**	**488**	**16.6**
O11	**108**	**216**	**216**	**7.34**
O12	**244**	**488**	**488**	**16.6**
O13	200	400	400	13.6
O14	44	88	88	3
C1	116	232	232	7.88
C2	104	208	208	7.07
C3	164	328	328	11.15
C4	116	232	232	7.88
C5	36	72	72	2.44
C6	76	152	152	5.16
C7	116	232	232	7.88
C8	104	208	208	7.07
C9	42	84	84	2.85
C10	**96**	**192**	**192**	**6.52**
C11	**184**	**368**	**368**	**12.51**
C12	**60**	**120**	**120**	**4.08**
C13	60	120	120	4.08
C14	148	296	296	10.06
C15	68	136	136	4.62
CA1	412	824	824	18.95

Comment: The population of earthworms was 244/m^2, 108/m^2 and 244/m^2 in O10, O11 and O12, respectively in organic fields and 96/m^2, 184/m^2 and 60/m^2 in C10, C11 and C12, respectively in conventional fields.
It was found that the population in O11, C10 and C12 were below the average of 125/m^2.

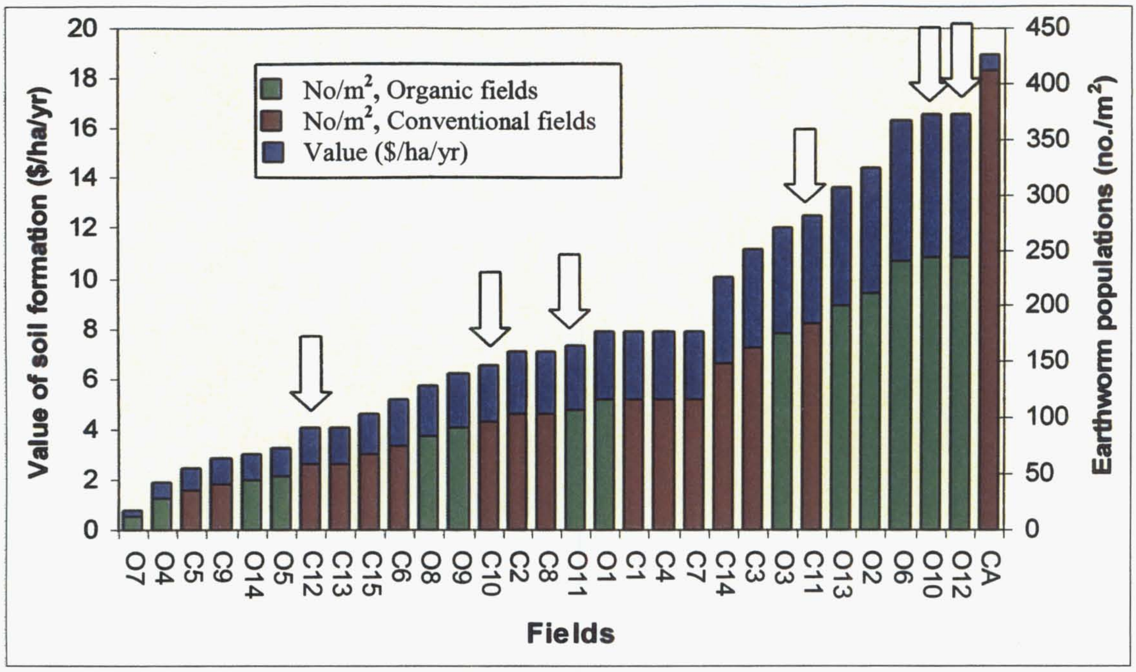

Fig. 4.1 Earthworm populations (no. /m²) and their economic value in soil formation ($/ha/yr) in selected organic (O1-O14), conventional fields (C1-C15) and conservation agriculture field (CA1). Arrows indicate your fields.

Comment: The economic value of earthworms in soil formation was $ 16.6/ha/yr, $7.34/ha/yr and $16.6/ha/yr in O10, O11 and O12, respectively in organic fields. And it was $6.52/ha/yr, $12.51/ha/yr, $ 4.08/ha/yr in C10, C11 and C12, respectively in conventional fields.

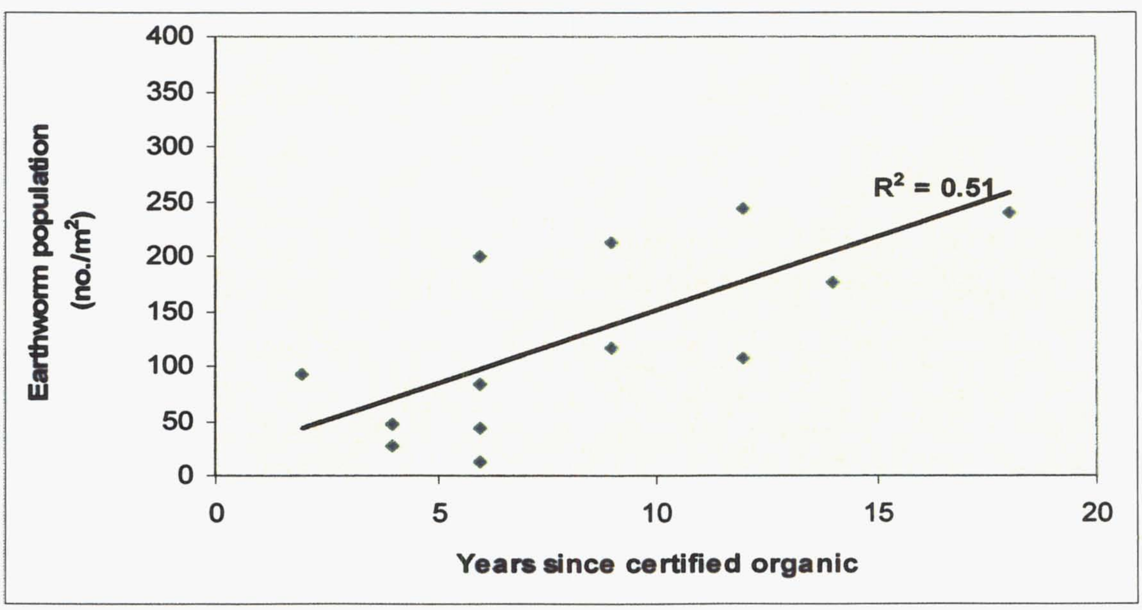

Fig. 4.2 Earthworm population (no. /m²) in organic fields in relation to the number of years since conversion to organic.

5. MINERALISATION OF PLANT NUTRIENTS

Organic matter breakdown carried by soil micro organisms and invertebrates 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.

Mineralisation of plant nutrients was assessed in 30 fields using bait lamina probes. These are strips of rigid plastic with a series of two mm holes (16) drilled into them. These are filled with gel comprising of cellulose, agar-agar, bentonite and wheat bran that matches to some extent the key constituents of dead plant material on or in the soil. The probes were inserted 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 measure of the rate of mineralisation.

The mean rate of mineralisation is calculated as the mean removal of baits and is given in Fig. 5.1.

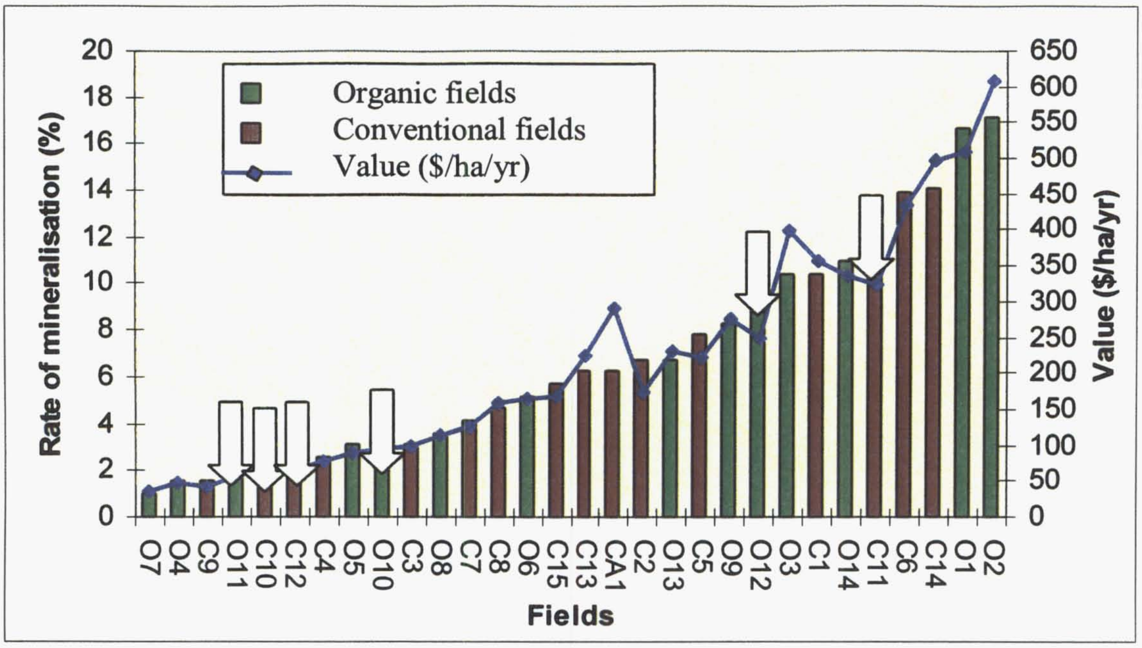

Fig. 5.1 Mineralisation of plant nutrients (mean per cent removal of bait) using bait lamina probes and economic value ($/ha/yr) in selected organic (O1-O14), conventional fields (C1-C15) and conservation agriculture field (CA1). Arrows indicate your fields.

Comment: Rate of plant nutrient mineralisation was lower than the average in all the fields except O12 and C11.

5.1. Economic value of plant nutrient mineralisation

In this study, economic value of mineralised nitrogen provided by soil micro organisms and invertebrates is assessed using the mineralisation of organic matter data obtained from field experiments. The total organic matter content in the fields was estimated using the total weight of soil 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. The total amount of nitrogen mineralised was estimated and valued at the equivalent price of N/kg. Table 5.1 presents the value of mineralised nitrogen in each of the field.

Table 5.1 Rate of mineralisation of plant nutrients and estimation of its economic value in selected organic (O1-O14), conventional fields (C1-C15) and conservation agriculture field (CA1). OM (Organic matter). Highlighted rows indicates your fields' data.

Field type	Rate of mineralisation (%)	Bulk Density (g/cm^3)	Weight of soil/ha/10cm deep. (X 10^5 kg)	Total N (%)	Total OM (%) OM:N ~ 20:1	Total OM/ha (X 10^5 kg)	Mineralised OM/ha (X 10^3 kg	Mineralised N available/ha/yr (kg)	Dollar value of mineralised N @ $1.20/kg N ($/ha/yr)
O1	16.66	1.02	10.2	0.25	5	0.51	8.49	424.5	509.4
O2	17.18	0.93	9.3	0.32	6.4	0.59	10.13	506.5	607.8
O3	10.41	0.95	9.5	0.34	6.8	0.64	6.66	333	399.6
O4	1.56	1.02	10.2	0.25	5	0.51	0.79	39.5	47.4
O5	3.12	0.99	9.9	0.25	5	0.49	1.52	76	91.2
O6	5.2	0.99	9.9	0.27	5.4	0.53	2.75	137.5	165
O7	1.04	0.96	9.6	0.31	6.2	0.59	0.61	30.5	36.6
O8	3.64	1	10	0.26	5.2	0.52	1.89	94.5	113.4
O9	8.33	1.02	10.2	0.27	5.4	0.55	4.58	229	274.8
O10	3.12	0.97	9.7	0.27	5.4	0.52	1.62	81	97.2
O11	2.08	1.01	10.1	0.23	4.6	0.46	0.95	47.5	57
O12	9.89	1	10	0.21	4.2	0.42	4.15	207.5	249
O13	6.77	0.99	9.9	0.29	5.8	0.57	3.85	192.5	231
O14	10.93	1.03	10.3	0.25	5	0.51	5.57	278.5	334.2
C1	10.41	0.92	9.2	0.31	6.2	0.57	5.93	296.5	355.8
C2	6.76	1.08	10.8	0.2	4	0.43	2.9	145	174
C3	3.12	0.96	9.6	0.28	5.6	0.53	1.65	82.5	99
C4	2.6	1.01	10.1	0.25	5	0.5	1.3	65	78
C5	7.81	1.03	10.3	0.23	4.6	0.47	3.67	183.5	220.2
C6	13.93	1.01	10.1	0.26	5.2	0.52	7.24	362	434.4
C7	4.16	1.02	10.2	0.25	5	0.51	2.12	106	127.2
C8	4.68	0.96	9.6	0.3	6	0.57	2.66	133	159.6
C9	1.56	1.05	10.5	0.22	4.4	0.46	0.71	35.5	42.6
C10	2.08	0.94	9.4	0.3	6	0.56	1.16	58	69.6
C11	11.45	0.98	9.8	0.24	4.8	0.47	5.38	269	322.8
C12	2.08	0.98	9.8	0.27	5.4	0.52	1.08	54	64.8
C13	6.24	0.98	9.8	0.31	6.2	0.6	3.74	187	224.4
C14	14.06	1.02	10.2	0.29	5.8	0.59	8.29	414.5	497.4
C15	5.72	1.08	10.8	0.23	4.6	0.49	2.8	140	168
CA1	6.24	0.93	9.3	0.42	8.4	0.78	4.86	243	292

Comment: The rate of plant nutrient mineralisation and their economic value in O12 and C11 was higher than the average but lower in O10, O11, C10, and C12.

7. CONCLUSIONS

The current study was designed to assess the consequences of arable farming on the provisions of ES at the field level in Canterbury. This study demonstrates that arable farming is both a consumer and a provider of the three key ES. Rates of ES were observed to be generally higher on the organic fields studied. This could be attributed to the fact that organic farmers utilize natural biological control services for the suppression of pests. Conventional farmers do not depend on these natural services as shown by low levels of background biological control on their fields. However the soil formation by earthworms and mineralisation services provided by soil micro and macro fauna were found to be severely damaged in both the organic and the conventional systems.

There is thus a great potential to improve these nature's services on arable farms using the principles of ecological engineering to enhance biological control, conservation agriculture, zero or no tillage practices etc. An understanding and appropriate utilization of ES can thereby ensure the long term sustainability of arable farms.

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D16 GARDENING Saturday, August 20, 2005

Worms worth millions to Canterbury

Steve Wratten

What on earth

What's a worm worth? Not a question vegetable gardeners ask very often as they prepare beds for spring sowing and planting. While waiting for the snow last Saturday (it didn't), I forked and limed beds (and composted the weeds) in readiness for planting my already-sprouted liseta and swift early potatoes.

As I dug, I turned over some cloddy clay concretions; not many, though, as I had been using the pile-it-on principle for years — lots of organic matter in the form of dung, compost and pea straw.

I expected to see lots of worms as a reward for my soil-improvement efforts. I didn't expect native New Zealand worms, however. Those in our farmland and gardens are entirely European and Australian imports.

There were a few worms, mainly the common Australian species, Aporrectodea, which are large and greyish, with a pink saddle. That structure means they were reproductive adults and were soon to deposit a mini time capsule of eggs in the soil. This would guarantee a future worm population if I knew how to nurture them better.

The low numbers were a disappointment and I wondered why — and whether or not it mattered.

I knew that worms were important in some way; after all, Charles Darwin's last book was about earthworms — The Formation of Vegetable Mould Through the Action of Worms. Aristotle, too, knew a thing or two about worms when he called them the intestines of the Earth.

We know that worms take plant material into the soil and therefore help it to decay and release its minerals for our crops to use. By doing this, they add organic matter to weathered rock, and the two then become soil.

But how much does it matter as we prepare the garden for spring? We can buy all the fertilisers we need, surely? So can farmers.

However, seen the petrol price lately? There's talk of peak oil, after which global supplies start to decline. Many commercial fertilisers such as urea are made from oil or other dwindling resources. How can the worm help?

Harpinder Sandhu, an agricultural expert at Lincoln University, but originally from the Punjab in India, tells me that water levels in that region are dropping by 25cm a year due to the high demands of Green Revolution crops which need high inputs of water and fertilisers. Echoes of Canterbury, perhaps?

Harpinder is motivated to find out what value we can place on more natural methods of farming, in other words, what's a worm worth?

He counted worms in 30 Canterbury paddocks (organic and conventional) and put the farms in order of worminess.

The winner was Kowhai Farm, the Heinz Wattie's organic farm at Lincoln University. The second highest was a nearby no-tillage (but high-herbicide) farm.

Just shows that "sustainable growing" has many meanings. Organic farming is certainly good for worms — but you have to wait a bit.

Harpinder then attached a dollar value to the worms, based on their soil-formation services. If all the arable paddocks on the Canterbury plains were as poor in living organisms as was Harpinder's worst paddock, the creepy-crawly value would still be $6 million a year for the arable land on the plains.

If all Canterbury arable farmers boosted their soil organism levels to those of the best paddock, the annual value of the living things would jump to $100m. Worth thinking about as we increase our urea and oil imports and build still more suburban housing developments on good soils.

So, as I took a chance with my first sowing of greenfeast peas (my favourite), in a limed, well-drained, sunny spot, I thought of that other worm, the one on political leaders' TV debates, and wondered how much thought was being given to maintaining the natural capital of our farmland, worms and all.

Politicians are under pressure from all quarters, of course, so I thought of Shakespeare, who knew a worm's worth, and who wrote in Hamlet: "A certain convocation of politic worms are e'en at him."

Steve Wratten is professor of ecology at Lincoln University.

Worms: boosting soil organism levels and saving the cost of oil-based commercial fertiliser