The value of producing food, energy and ecosystem services within an agro-ecosystem

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Abstract

Agricultural ecosystems produce food, fibre, and non-marketed ecosystem services (ES). Agriculture typically also involves high negative external costs associated with, for example, fossil fuel use. Estimates were made, via field scale ecological monitoring and economic value-transfer methods, of the market and non-market ES value of a combined food and energy (CFE) agro-ecosystem that simultaneously produces food, fodder and bioenergy. Such novel CFE agro-ecosystems can provide significantly increased net crop, energy, and non-marketed ES compared to conventional agriculture and require markedly less fossil-based inputs. Extrapolated to the European scale, the value of non-market ES from the CFE system exceeds current European farm subsidy payments. Such integrated food and bioenergy systems can thus provide environmental value for money for EU farming and non-farming communities.

Media summary
Combined food and energy production can benefit the environment.

Key words
Food, bioenergy, ecosystem services

Introduction

Ecosystem services (ES) are the benefits humans derive from ecological processes and ecosystem function. By recognizing the value of ES we accept that our largely non-marketed ecological wealth underpins our marketed economic wealth. ES from agriculture have hitherto been assigned relatively low values (Costanza *et al*., 1997: Bjorklund *et al*., 1999) when compared with other terrestrial and aquatic ecosystems, partly due to lack of data. However, it is important to gain a more accurate estimate of the ES from agriculture as agro-ecosystems cover between 28% and 37% of the Earth's land surface and are divided about 70:30 between pastures and crops (DEFRA, 2005). Although agricultural ecosystems may have low ES values per unit area when compared with other ecosystems such as estuaries and wetlands (Costanza *et al*., 1997), they offer the best chance of increasing global ES via definition of appropriate goals for agriculture and the use of land management regimes that favour ES provision. Agriculture can be considered the largest ecological experiment on Earth with a large potential to damage global ES but also to promote them via ecologically informed approaches to the design of agro-ecosystems that value both marketed and non-marketed ES (Porter, 2003).

Coincidentally with the issue of ES from agroecosystems, there is a developing interest in using agricultural land for the production of biofuels (Tilman *et al*., 2006) such that their production is as sustainable as possible. Such a requirement invites the design of new systems of primary production that ensure a positive net carbon sequestration, are species diverse have low inputs and provide a suite of ES. This paper describes a novel combined food and energy (CFE) producing agro-ecosystem that meets the above requirements for sustainability by using non-food hedgerows as sources of biodiversity and biofuel. We have identified, quantified and valued ES from this new production system and refer to this concept as combined food, energy and ecosystem services (CFEES).

Materials and methods

The CFE system on which our work is based was established to create an agro-ecosystem that was a net energy producer, with the system producing more energy in the form of renewable biomass than consumed in the planting, growing and harvesting of the food and fodder. The bioenergy component is represented by belts of fast growing trees (willows, alder and hazel) that are planted orthogonally to fields containing cereal and pasture crops. Since its inception in 1995 the CFE system has been monitored for a range of ecological indicators that include biomass and crop yields, energy balance, carbon sequestration, nitrogen availability and biological control of pests. The biomass belts are harvested and chipped every 4-5 yr and the wood chips taken to a nearby commercial heat and power station for the production of heat and electricity. The CFE system is managed organically, meaning that biocides and inorganic nitrogen are not used.

We took a 'bottom-up' approach to estimating the ES of the CFE system, meaning that we measured field scale processes and states of the system and then translated these functional elements into monetary terms by using willingness-to-pay, value-transfer and avoided cost estimates. In spring and summer 2006 we made measurements and calculations of pest bio-control, crop and biomass yields, nitrogen fixation and mineralization, earthworm density and soil formation and insect pollination to obtain a 'snapshot' picture of the ES from the CFE system 11 years after it started.

Results

Local measurements of ecological processes in the CFE system and their valuation show (Table 1) that, of the three components of the CFE system (biomass, cereals, pasture), the biomass had the highest gross ES ha^{-1} ($US 1146), followed by the pasture ($US 1134 ha^{-1}) and crops ($US 998 ha^{-1}), respectively. Non-market ES make up 48%, 48% and 81% of the total ES of the three CFE components, respectively. When account is taken of the proportional areas of the pasture (45%), cereals (45%) and biomass (10%), the ES of the CFE system as a single unit is $US 1074 ha^{-1}, of which 64% are non-market. Using globally derived figures (1) and including multifunctional ES raises the gross value of ES from cropping agriculture from $US 92 ha^{-1} (1; comprising pollination ($US 14 ha^{-1}), biological control ($US 24 ha^{-1}) and food provision ($US 54 ha^{-1})) to $US 1866 ha^{-1} with the net value being $US 387 ha^{-1} lower than this ($US 1479 ha^{-1}) when external costs (8) are included. Thus, both locally and globally based calculations of ES from multifunctional farming point to a net value of ES from agriculture of between $US 1000-1500 ha^{-1} yr^{-1}. The largest contributions to multifunctional agriculture's ES come from the regulation of nitrogen turnover, food and raw material production and a contribution to landscape aesthetics.

Discussion

For global ES to maintain or even increase their current value, agricultural systems have to be designed with ES in mind (Foley *et al*., 2005) such that non-market ES contribute between 50-70% of an agroecosystems total ES value. The CFEES approach is an example of such a system but one that is more pasture based is also likely to offer high non-market ES as a proportion of its value. Converting conventional agriculture to CFEES agro-ecosystems could substantially and simultaneously enhance food, fibre, fuel and global ecosystem services production and sustainability. Future scientific challenges in this area need to examine and define, using a range of approaches, the properties of agroecosystems that provide ES as so-called service providing units, defined as the population unit that provides an ecosystem service at some spatial or temporal scale, and to evaluate how ES may change with time through climate change and other influences (Schröter *et al*., 2005) rather than by using simple 'snapshots' in time. A socially desirable future goal would be to develop further the notion of the energy neutral farming systems, as represented by the CFE system, towards farming systems that are greenhouse gas neutral in the sense that losses of carbon and non-carbon greenhouse gases are balanced by carbon sequestration.

References

Bjorklund J, Limburg K.E, Rydberg, T. 1999. Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: an example from Sweden. Ecol. Econ. 29: 269-291.
Costanza R *et al*. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253-260.
DEFRA UK. 2005. The Economic, Social and Ecological Value of Ecosystem Services. EFTEC, London.
Foley JA *et al*. 2005. Global consequences of land use. Science 309: 570-573.
Porter JR. 2003. Ecosystem services in European agriculture: theory and practice. Royal Swedish Acad. Agric. Forest., Stockholm.
Pretty JN, Ball AS, Lang T. 2005. Farm costs and food miles: an assessment of the full costs of the UK weekly food basket. Food Policy 30: 1-19.
Schröter D *et al*. 2005 Ecosystem service supply and vulnerability to global change in Europe. Science 310: 1333-1337.
Tilman D, Hill J, Lehman C. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science 314: 1598-1600.

Table 1. The monetary value of ecosystem services (ES) in pastures, cereals, biomass belts and the combined food and energy (CFE) system. The ES value of the CFE system was calculated based on the ratio of 45:45:10 as between pasture, cereals and biomass belts.

Ecosystem service	**Ecosystem service value $US ha^{-1} yr^{-1}**			
	pasture	cereals	biomass	CFE
Biological control of pests	13	0	12	7
N regulation: fixation and mineralisation	434	217	15	294
Soil formation	11	17	-	13
Food and fodder production	216	515	0	329
Raw material (biomass) production	0	0	600	60
Carbon accumulation	37	25	60	34
Hydrological flow	76	86	42	77
Aesthetics	262	138	332	213
Pollination	85	0	85	47
Total economic value of ES	**1134**	**998**	**1146**	**1074**
Non-market ES value (NMV)	**918**	**483**	**546**	**685**
NMV/ES value	**0.81**	**0.48**	**0.48**	**0.64**