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Bioenergy, Food Production and Biodiversity - An Unlikely Alliance?

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Introduction

The global demand for bioenergy is set to increase to a point where it may supply up to one third of global primary energy by 2050 (IEA 2012a). Current cultivation of biofuel and bioenergy crops has attracted considerable criticism due to their encroachment into areas traditionally occupied by food crops and natural and semi-natural ecosystems. Amongst the most notorious of these bioenergy crops are sugarcane, jotropha, ethanol maize, and palm oil, crops closely associated with biodiversity and habitat loss, water deficit, and perhaps most ironically, given their potential for greenhouse gas emissions reduction, negative impacts on carbon storage and sequestration (Martinelli & Filoso 2008; Fargione *et al*. 2008; Koh *et al.* 2009; Romijn 2011). In in the medium-term bioenergy demand is likely to be met by so-called second-generation (2G) lignocellulose crops, principally perennial grasses and woody trees (Somerville *et al.* 2010). Many of the problems associated with established first generation biofuel crops, which are often also food crops, could be avoided by cultivating 2G bioenergy crops on existing farmland. However, this option is often undesirable due to increasing food demand and the potential displacement of food crops (Godfray *et al.* 2010; Dauber *et al.* 2010; Gelfand *et al*. 2013). This conflict between land use objectives, the so-called 'food, energy, environment trilemma' (Tilman *et al.* 2009), raises concerns that increased demand for bioenergy crops will displace food production and/or cause further destruction of natural and semi-natural (so-called marginal) ecosystems. The problems of potential biodiversity loss and land competition with food production remain central to the debate surrounding the possible contribution that bioenergy crops could make towards meeting renewable energy and greenhouse gas emissions targets (Nonhebel 2012). Policy makers are left struggling with the problems that have dogged bioenergy cultivation for decades; where should 2G bioenergy crops be planted and what proportion of land should they occupy? Such questions raise doubts as to the viability of bioenergy as a major future energy source; a major recent report into bioenergy crop viability in the US concluded that economic and environmental uncertainty will strongly limit future deployment of 2G crops (Committee on Economic and Environmental Impacts of Increasing Biofuels Production 2011). However, this assertion relies on the old agricultural paradigm of large-scale cultivation of monocultures on existing agricultural land. Indeed, current policy advice largely ignores the potential to better manage bioenergy crops to reduce their impacts on food, biodiversity and ecosystem services and for strategic deployment of 2G bioenergy crops within the landscape so that they mitigate environmental damage and enable a more balanced use of limited land resources.

We propose two main strategies for managing bioenergy crops that could reduce their impact on food production and the environment, and at the same time may even boost biodiversity and food production via increases in ecosystem service provision (Table 1). The first of these is that *existing* bioenergy crops are managed to facilitate biodiversity and support ecosystem service providers (ESPs). When properly managed using well-designed agri-environment schemes, wildlife friendly farming practices can be successful in sustaining biodiversity (Ausden 2007; Carvell, *et al.* 2007, 2011; Whittingham 2011), but this approach is not widely applied to bioenergy crops at present. Our second proposal is that new bioenergy plantations are located in a more strategic way that considers landscape context and is sensitive to how they affect biodiversity and ecosystem services (Table 2). This involves planning the spatial arrangement of bioenergy plantations so that they interact positively with other landscape units. It also requires an understanding of how the impact of bioenergy crops on biodiversity and food security varies depending upon their biological and physical environmental context. We suggest that the strategic planting of bioenergy crops, relative to other land use packages, could mitigate environmental damage caused by other land uses, benefit ecosystem service provision, and in some cases boost arable productivity. Bioenergy crops could therefore make up a component of multifunctional landscapes in which limited land resources are used to meet the requirements and aspirations of a diverse community of users. To illustrate these points further we focus on three geographically distinct cases where these general principles could be applied. Our choice of these case studies is based upon literature availability, the extent (current or potential) of bioenergy cultivation, and the degree of conflict with other land uses within these regions. Land availability and competition between bioenergy cultivation and other land uses have received considerable attention elsewhere (e.g. Haughton et al 2009; Godfray *et al.* 2010; Dauber *et al.* 2010, 2012; Gelfand *et al*. 2013) and we do not discuss this issue at length here. Instead we focus on how a policy of targeted integration of bioenergy with conventional crops and other landscape features might facilitate biodiversity and ESPs. .

Sweetening the pill of Brazilian sugarcane production

Our first example is more environmentally sensitive management of sugarcane (*Saccharum* spp.) plantations in Brazil. Presently, these provide around 17.5% of the nation's energy production (Ministry of Mines and Energy, Brazil 2013) and are managed intensively, thus imposing a range of negative environmental impacts including atmospheric pollution from the burning of sugarcane residues, soil degradation, and nutrient runoff into aquatic systems (Martinelli & Filoso 2008). These impacts could be minimised without loss of income and productivity by using altered field and landscape management practices; for example, by applying nitrogen fertiliser in the ammonium form that sugarcane prefers, instead of more environmentally mobile nitrates (Robinson *et al*. 2012). Furthermore, the use of buffer strips in sugar cane plantations could minimise soil erosion and the eutrophication of riparian habitats (Barling and Moore 1994), while simultaneously boosting biodiversity. Such strips might be placed along field margins and the edges of water bodies and could contain a range of species that provide multiple ecosystem services; e.g. native tree crop species such as candeia (*Eremanthus erythropappus*), a source of essential oils (Gries *et al.* 2011), and *Copaifera* spp., which produce copaiba resins with diverse medicinal uses (Veiga & Pinto 2002). In addition to providing economically valuable products these strips might also provide habitat for the natural enemies of crop pest species, e.g. the sugarcane borer moth (*Diatraea saccharalis*) (Oliviera *et al.* 2012) and predators of the disease carrying rodents that have proliferated under sugarcane expansion (Verdade *et al*. 2012). Such benefits may outweigh those of sugarcane displacement. Further economic and social benefits could be realised in the increased diversification and aesthetic appeal of the landscape. A similar proposal has been made for the incorporation of agroforestry strips between high conservation value areas and intensive oil palm plantations, and it is expected that such areas would benefit both biodiversity and rural communities (Koh *et al.* 2009). However, the scientific evidence base to support the planning of such multifunctional landscapes remains underdeveloped for most bioenergy crops.

Bioenergy and arable crop production - a European Union

Our second example focuses upon the strategic planting of 2G bioenergy crops into European arable landscapes. It is now widely established that 2G bioenergy crops can promote the abundance of numerous taxonomic groups in comparison with alternative, adjacent land uses such as arable, improved grassland, or fallow. Landscape-scale diversity might also be increased as different species are found in bioenergy plantations and cropland (Dauber *et al.* 2010; Rowe *et al.* 2011, 2013; Stanley & Stout 2013). Any measure that increases biodiversity and the abundance of wildlife in this intensively managed agri-environment is welcome, but we suggest that this higher abundance of organisms could also boost ecosystem service delivery both within the bioenergy crop and in surrounding farmland and that this may provide benefits to food production that may outweigh the cost of arable crop displacement. For example, the enhanced arthropod predator diversity and abundance that is found within bioenergy crop plantations (Rowe *et al.* 2013) can play an important role in herbivore pest control within the crop (Björkman *et al.* 2004). If bioenergy plantations were situated next to arable crops then the potential ‘spillover’ of spiders, beetles, hoverflies and various wasps could see significant boosts to this service in these surrounding land units. The relative increase in the abundance and diversity of hymenoptera and lepidoptera assemblages observed in and around bioenergy crop plantations (Haughton *et al.* 2009; Rowe *et al*. 2013) may also benefit crop pollination in adjacent farmland, an ecosystem service estimated to be worth > US$ 190 billion globally (Gallai *et al.* 2009). Similarly, weed seed predation by granivorous birds could be enhanced by the presence of bioenergy crops since they provide nesting and roosting sites for many bird species (Campbell *et al*. 2012). Crop pest butterflies are also less abundant in the field margins of bioenergy crops than in arable crop margins (Haughton *et al.* 2009). All these studies indicate that strategic bioenergy planting could simultaneously benefit biodiversity and food production. Indeed, where appropriate, bioenergy planting could even be integrated into agri-environment schemes, whereby payments are used to encourage environmentally friendly practices. Additionally, agri-environment elements could become integrated into policies that encourage bioenergy crop planning, e.g. the UK's Energy Crops Scheme (Natural England 2013). An example would be the deployment of short rotation coppice willow plantations as habitat corridors. These might complement existing features such as hedgerows and patches of semi-natural habitat in providing the connectivity demanded by contemporary biodiversity policy (Lawton *et al.* 2010).

Watering down the environmental impact of bioenergy crops?

Our third example centres upon the wide-scale concern that 2G bioenergy crops, in particular Miscanthus and jatropha, damage hydrological resources. Recent reports suggest detrimental effects on water supply following large-scale cultivation of perennial energy grasses such as Miscanthus, with water-use in the mid-western USA increased more than 50% compared with maize (VanLoocke *et al.* 2010; Le *et al.* 2011). The water-use footprint of 13 biofuel/energy crops was estimated by Gerbens-Leenes *et al.* (2009) and showed that Jatropha (a 2G crop) used more water than all of the 1G crops studied, including five times the water used by ethanol maize. However, these concerns rely on modelled data or inventories; blunt tools with which to determine future policy since there is very little experimental validation of model assumptions. These models also assume uniform cultivation across landscapes. This need not happen and plantations could be managed and sited to more effectively use limited water resources. Indeed, when spatial water use and variation in crop cover are incorporated into hydrodynamic models it is possible to identify less sensitive areas for *Miscanthus* cultivation and reduce predicted hydrological impacts (Gerbens-Leenes, *et al.* 2009). Experimental verification and wider identification of low impact areas, with regards to water and other land resources should enable prescriptions for the hydrologically and environmentally sustainable cultivation of *Miscanthus* and other bioenergy crops to be developed.

Barriers to success

At present these relationships remain hypothetical; studies of the environmental impact of bioenergy crops have focused largely on the response of biodiversity (Dauber *et al.* 2010; Fletcher *et al*. 2011; Wiens *et al.* 2011) and greenhouse gas emissions (Fargione *et al.* 2008. Romjin *et al.* 2011; Gelfand *et al.* 2013). By contrast most other ecosystem processes and services have received very little attention (but see Rowe *et al.* 2013). While the potential benefits of more strategic bioenergy crop planting and management are considerable several ecological and economic factors could limit the success of such schemes. Perhaps foremost amongst these is the potentially low cost-effectiveness of small and disparate bioenergy crops. The costs of managing and harvesting diffuse bioenergy crop plantations, and transporting the products, may well preclude their establishment (Dauber *et al.* 2012). Also, if biodiversity is to be maintained in such plantations then small-scale rotational management, as opposed to the clear felling of large areas, may also be required (Hanowski *et al.* 2003). Such practices are common in traditionally managed hazel coppice woodland in the UK (Ausden 2007), but their economic viability in bioenergy plantations is unknown.

The availability of suitable land may also limit the cost effectiveness of mixed bioenergy-food production landscapes (Dauber *et al.* 2012). It is clear that and the spillover benefits of bioenergy crop strips, as well as the price for bioenergy crop products would need to be considerable for bioenergy cultivation to displace food production in productive regions. At the other end of the spectrum, in less productive regions the extent of natural and semi-natural habitats is often greater and these habitats will typically contain far greater biodiversity than bioenergy plantations (Christian *et al.* 1997; Hanowski *et al.* 2003; Ausden 2007). These habitats may also provide ecosystem services to surrounding crops more effectively than bioenergy crops, thus limiting the benefits of bioenergy cultivation to the owner. Nevertheless, there are land use types, even within generally productive landscapes, that may be suitable. These include abandoned agricultural lands with low biodiversity value, marginal agricultural land and degraded sites colonised by invasive species, although all of these could also be targeted for agricultural improvement or ecological restoration (Haughton *et al.* 2009; Tilman *et al.* 2009; Nackley *et al.* 2013).

A third problem is that the edge and connectivity effects of bioenergy crops that we propose may not be manifested and could even be negative. Instead of spilling over into neighbouring crops, many ESPs may remain in perennial bioenergy crops and seldom enter the arable crop (e.g. Christian *et al.* 1997; Hanowski *et al.* 2003). Some species of semi-natural habitats may respond the bioenergy plantations similarly, remaining within isolated patches of habitat and not using bioenergy crops as habitat corridors. Contact effects between bioenergy and arable crops might also be negative. For example, the emission of isoprene by short rotation poplar forests could potentially result in ozone formation with crop damage and human health impacts (Ashworth *et al.* 2013). The planting of poplar into areas of high potential ozone formation should therefore be avoided, thus limiting the potential coverage of these crops.

With respect to the more sustainable and wildlife-friendly management of bioenergy crops, challenges are likely to be similar to those for food crops; payments, and/or landscape scale crop benefits must be sufficient for farmers to adopt sustainable practices. Management practices also need to be coordinated at a landscape scale in order to benefit organisms with large ranges and limited dispersal. Such topics have been discussed elsewhere (e.g. Whittingham 2011 and related papers), and so we do not elaborate upon them here.

Setting research and policy agendas for sustainable bioenergy crop cultivation

To see if the potential benefits of the strategic cultivation and management of bioenergy crops can be realised, new research is required. Such research would contribute to the current drive to develop ‘sustainable intensification’ strategies that foster synergies between land use packages and attempt to reduce the trade-offs between the delivery of multiple ecosystem services within our limited land resources (Garnett *et al.* 2013). While the examples presented here illustrate our general points they also demonstrate that the trade-offs and synergies between bioenergy cultivation and the provision of other ecosystem services vary depending upon their geographic setting, as will the socially desired balance and prioritisation of multiple land uses. Novel landscape management strategies will therefore need to be developed at local-, national-, and global-scales (Garnett *et al.* 2013) but unfortunately few mechanisms are currently in place to ensure that land use policy and practice is developed in an evidence-based way. Such evidence is essential as most of the environmental damage caused by bioenergy cultivation has been a consequence of policy advancing ahead of a well-formulated scientific evidence base. For example, the original European Renewable Transport Fuel Obligation (2009/28/EC) mandated a target of 10% renewable energy in the transport sector by 2020. This policy was implemented with limited understanding of global land use implications and minimal sustainability criteria in place. As a result, it inadvertently encouraged widespread planting of food crops such as palm oil for biofuel production, the displacement of food crops and the destruction of natural habitats (Gilbert 2012). The recent 2012 directive (com 595) addresses this issue and promotes the use of non-food crops and residues with minimal indirect Land Use Change (iLUC). However, this is an unrefined approach that relies on biophysical and global economic modelling, and it has rarely been tested at the landscape-scale. We propose directed research that identifies new strategies for sustainable landscape scale 2G planting in which the cost to other ecosystem services is reduced or removed. This would likely require a combination of observational field measurements, large-scale manipulation experiments and spatially explicit simulation models. Once identified, such strategies can be implemented using policy mechanisms such as subsidy, law, and certification of produce.

Conclusions

If performed strategically, bioenergy crop cultivation and management need not be to the detriment of the environment, and could even boost biodiversity, ecosystem services, and by consequence increase crop yield. The research that is required to tell us if this is possible must bear eventual policy instruments in mind as these are likely to be as much a barrier to successful deployment as technical plausibility. The scientific and policy challenges in developing the resulting multifunctional landscapes are considerable. Nevertheless, the importance of such work is paramount given the prevailing societal desire to produce large quantities of food and energy in agroecosystems that are underpinned by a stable and biodiverse network of ecosystem service providers.

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References

Ashworth K, Wild O, Hewitt CN (2013) Impacts of biofuel cultivation on mortality and crop yields**.** *Nature Climate Change,* **3**, 492–496.

Ausden M (2007) *Habitat Management for conservation.* Oxford University Press, Oxford.

Barling RD & Moore ID (1994) Role of buffer strips in management of waterway pollution: A review. *Environmental Management*, **4**, 543-558.

Björkman C, Bommarco R, Eklund K, Höglund S (2004) Harvesting disrupts biological control of herbivores in a short-rotation coppice system. *Ecological Applications,* **14**, 1624-1633.

Ministry of Mines and Energy, Brazil (*2013*). *Brazilian Energy Balance*, *Final Report*. Ministry of Mines and Energy, Brazilia.

Campbell SP, Frair JL, Gibbs JP, Volk TA (2012) Use of short-rotation coppice willow crops by birds and small mammals in central New York. *Biomass & Bioenergy,* **47**, 342-353.

Carvell C, Meek R, Pywell RF, Goulson D, Nowakowski M (2007). Comparing the efficacy of agri-environment schemes to enhance bumble bee abundance and diversity on arable field margins. *Journal of Applied Ecology,* **44**, 29–40.

Carvell C, Osborne JL, Bourke AFG, Freeman SN, Pywell RF & Heard MS (2011) Bumble bee species' responses to a targeted conservation measure depend on landscape context and habitat quality. *Ecological Applications,* **21**, 1760–1771.

Christian DP, Collins PT, Hanowski JM, Niemi GJ (1997) Bird and small mammal use of short-rotation hybrid poplar plantations. *The Journal of Wildlife Management*, **61**, 171–182.

Committee on Economic and Environmental Impacts of Increasing Biofuels Production (2011). *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy*. National Research Council National Academy. National Academy Press, Washington D.C.

Dauber J, Jones MB, Stout JC (2010) The impact of biomass crop cultivation on temperate biodiversity. *Global Change Biology Bioenergy,* **2**, 289-309.

Dauber J, Brown C, Fernando AL *et al.* (2012). Bioenergy from "surplus" land: environmental and socio-economic implications. *BioRisk* **7**, 5-50.

Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P (2008) Land clearing and the biofuel carbon debt. *Science,* **319**, 1235-1238.

Fletcher RJ, Robertson BA, Evans J, Doran PJ, Alavalapati JR, Schemske DW (2011) Biodiversity conservation in the era of biofuels: risks and opportunities. *Frontiers in Ecology and the Environment,* **9**,161–168.

Gallai N, Salles JM, Settele J, Vaissiere BE (2009) Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*, **68**, 810–821.

Garnett T, Appleby, MC, Balmford A *et al.* (2013) Sustainable intensification in agriculture: premises and policies. *Science,* **341**, 33-34.

Gelfand I, Sahajpal R, Zhang X, Izaurralde RC, Gross KL, Robertson GP (2013) Sustainable bioenergy production from marginal lands in the US Midwest. *Nature*, 493, 514-517.

Gerbens-Leenes PW, Hoekstra AY & van der Meer TH (2009) The water footprint of bioenergy. *Proceedings of the National Academy of Science U.S.A.,* **106**, 10219-10223.

Gilbert N (2012) Palm-oil boom raises conservation concerns. *Nature,* **48**, 14-15.

Godfray HCJ, Beddington, JR, Crute IR, *et al.* (2010) Food Security: the challenge of feeding 9 billion people. *Science,* **327**, 812-818.

Gries L, Almeida S, Macedo R, Barlow J (2011) Evaluating the impacts and conservation value of exotic and native tree afforestation in Cerrado grasslands using dung beetles. *Insect Conservation and Diversity*. **5**, 175-185.

Hanowski JM, Niemi GJ, Christian DP (2003) Influence of within plantation heterogeneity and surrounding landscape composition on avian communities in hybrid poplar plantations. *Conservation Biology*, **11**, 936–944.

Haughton, AJ, Bond, AJ, Lovett AA *et al.* (2009) A novel, integrated approach to assessing social economic and environmental implications of changing land use: a case study of perennial biomass crops. *Journal of Applied Ecology*, **46**, 315-322.

IEA (2012a) *Bioenergy – a Sustainable and Reliable Energy Source- Main Report.* International Energy Agency, Paris.

IEA (2012b) *Technology Roadmap. Bioenergy for Heat and Power*. International Energy Agency, Paris.

Koh JP, Levang P, Ghazoul . (2009) Designer landscapes for sustainable biofuels. *Trends in Ecology and Evolution,* **24,** 423-438.

Lawton JH, Brotherton PNM, Brown VK *et al.* (2010) *Making Space for Nature: a review of England's wildlife sites and ecological network.* DEFRA, London, UK.

Le PVV, Kumar P, Drewry DT (2011), Implications for the hydrologic cycle under climate change due to the expansion of bioenergy crops in the midwestern United States. *Proceedings of the National Academy of Sciences U. S. A.*, **108**, 15085–15090.

Martinelli LA & Filoso S (2008) Expansion of sugarcane ethanol production in Brazil: environmental and social challenges. *Ecological Applications,* **18**, 885–898.

Nackley, LL, Lieu, VH, Garcia BB, Richardson JJ, Isaac E, Spies, K, Rigdon, S, Schwartz DT

(2013). Bioenergy that supports ecological restoration. *Frontiers in Ecology and the Environment,* **11**, 535–540.

Natural England (2013) *Energy Crops scheme Establishment Grant Handbook*, Natural England, Worcester.

Nonhebel S (2012) Global food supply and the impacts of increased use of biofuels. *Energy,* **37**, 115–121.

Oliviera RF (2012) Ant diversity (Hymenoptera: Formicidae) and predation by ants on the different stages of the sugarcane borer life cycle *Diatraea saccharalis* (Lepidoptera: Crambidae) *European Journal of Entomology* 109, 381–387.

Robinson N, Vogt J, Lakshmanan P, Schmidt S (2012) Nitrate paradigm does not hold up for sugarcane. *PLoS One,* **6**, e19045.

Romijn HA (2011) Land clearing and greenhouse gas emissions from Jatropha biofuels on African Miombo Woodlands. *Energy Policy,* 39, 5751–5762.

Rowe RL, Hanley ME, Goulson D, Clarke D, Doncaster CP, Taylor G (2011) Potential benefits of commercial willow short rotation coppice (SRC) for farm-scale plant and invertebrate communities in the agri-environment. *Biomass & Bioenergy,* **35**, 325-336.

Rowe RL, Goulson D, Doncaster CP, Clarke D, Taylor G, Hanley M (2013) Evaluating ecosystem processes in willow short rotation coppice bioenergy plantations. *Global Change Biology Bioenergy,* **5**, 257-266.

Somerville C, Youngs H, Taylor C, Davis S, Long SP (2010). Feedstocks for lignocellulosic biofuels. *Science,* **329**, 790-792.

Stanley DA & Stout JC (2013) Quantifying the impacts of bioenergy crops on pollinating insect abundance and diversity: a field scale evaluation reveals taxon-specific responses. *Journal of Applied Ecology*, **50**, 335–344.

Tilman D, Socolow R, Foley JA *et al.* (2009) Beneficial biofuels – the food, energy and environment trilemma. *Science*, **325**, 270–271.

VanLoocke A, Bernacchi CJ & Twine TE (2010) The impacts of Miscanthus×giganteus production on the Midwest US hydrologic cycle. *Global Change Biology Bioenergy*, **2**, 180–191.

Veiga VF & Pinto AC (2002) O GÊNERO *Copaifera* L. *Quim. Nova,* **25**, 273-286.

Verdade LM, Gheler-Costa C, Penteado M & Dotta G. (2012) The impacts of sugarcane expansion on wildlife in the state of São Paulo, Brazil. *Journal of Sustainable Bioenergy Systems,* **2**, 138-144.

Whittingham MJ (2011) The future of agri-environment schemes: biodiversity gains and ecosystem service delivery? *Journal of Applied Ecology* **48**, 509-513.

Wiens J, Fargione J & Hill J (2011) Biofuels and biodiversity. *Ecological Applications,* **21**, 1085–1095.

Table 1. Generalised land use scenarios for arable and bioenergy crop management at the within-crop scale.

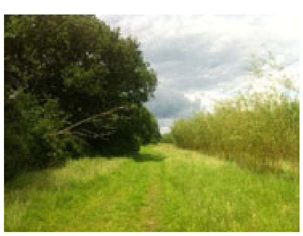
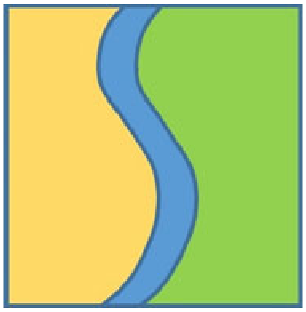
Land use		**Management practices**	**Biodiversity**	**Ecosystem services and disservices**
Intensive arable cropping system		*High inputs of biocides and fertiliser *Absence of field margins and other landscape features *Regular tillage	Low abundance and diversity of pollinators, natural enemies and other ESPs	*High nutrient runoff to surrounding ecosystems *High agricultural productivity but often unsustainable *Soil degradation *Low carbon storage * High GHG emissions
Environmentally sensitive arable cropping system		*Low inputs of biocides and fertiliser *Maintenance and planting of landscape features *Encouragement of within-crop biodiversity	Intermediate abundance and diversity of pollinators, natural enemies and other ESPs	*Intermediate nutrient runoff to surrounding ecosystems *Lower agricultural productivity but sustainable *Intermediate carbon storage *Intermediate GHG emissions
Intensive bioenergy cropping system		*High inputs of biocides and fertiliser *Absence of field margins and other landscape features *Displacement of food crops *Bioenergy food crops	Intermediate abundance and diversity of pollinators, natural enemies and other ESPs	*Removal of natural and semi-natural ecosystems *Nutrient runoff *Disease carrying organisms *Low carbon storage * Very high GHG emissions
Environmentally sensitive bioenergy system		*Novel landscape features and management practices that encourage biodiversity *2G non-food perennial bioenergy crops	High abundance and diversity of pollinators, natural enemies and other ESPs	*Greater aesthetic appeal *Very low GHG emissions *High carbon storage *Low nutrient runoff

Table 2. Generalised land use scenarios for bioenergy crop management at the landscape scale.

Landscape arrangement		**Management practices**	**Biodiversity**	**Ecosystem services and disservices**
Spatially distinct intensive agriculture and bioenergy plantations		*Large scale monocultures planted for industrial convenience with little consideration of environmental impact *Geographically separate systems *Conversion of natural and semi-natural habitat	*Absence of habitat corridors *Lack of habitat heterogeneity *Low local and landscape scale diversity and ESP abundance	*Alteration of local hydrology *Low GHG emissions *Low aesthetic appeal *Soil degradation *Nutrient runoff
Strategically planted and spatially mixed arable and bioenergy systems		*Side by side planting of complementary land packages *Avoidance of bioenergy planting in environmentally sensitive areas *Native crop species planted within bioenergy areas * Bioenergy crops form habitat corridors in food crops and buffer strips alongside water bodies	*Higher biodiversity of bioenergy patches supplements low diversity arable patches * Landscape scale habitat heterogeneity and diversity *High ESP abundance in both crop types.	*Multifunctional landscape in which ecosystem services are maximized e.g. planting of water demanding crops on wetter areas only * Provision of pollinator and natural enemy control in arable crops by neighbouring bioenergy crop ESPs. *Higher aesthetic appeal *Reduced soil degradation *Reduced nutrient runoff