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Delivering Arable Biodiversity

Field margin management for nature within rotational grass fields at organic dairy farms

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Summary

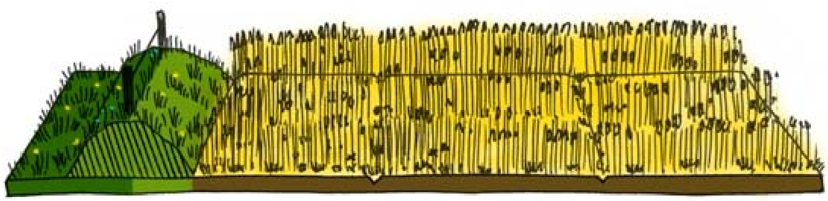
Organic farming is expected to show a substantial concern for nature quality. Examination of the nature plans of 10 organic dairy farms revealed that some of these farmers had no or only small areas with permanent grassland, and therefore lacked space for organisms belonging to such ecosystems. Therefore an option of 'flexible management of field margins' was developed. This option is that the outermost margins of the field are managed as permanent grassland with no manure and that some few metres into the field are managed as un-weeded crop with reduced manure. The 'flexible management of field margins' option provides space for flora and fauna associated with permanent grassland. As part of the cropping rotation system, the grassland plant species in these field margins are managed by grazing during years when the field has rotational grass, and with a pause in the grazing, allowing an opportunity for flowering, in years when the field is grown with cereals. The management option was presented to the farmers as a cartoon.

Key words: Permanent grassland, grazing, flowering, flexibility, nature plan

Introduction

Organic farmers are, according to their rules, expected to consider nature values (Hald, 1999, 2002). This is not always an easy task for many Danish organic dairy farms. According to the Danish organic rules dairy cows must graze outdoor at least 150 days in the summer period (Plantedirektoratet, 2006). Unfortunately, dairy cows are normally not able to produce the expected amount of milk by grazing merely on species rich and low productive natural meadows or commons since the forage quality is too low. Therefore, they graze on rotational grass fields that are re-sown after 3–4 years. When re-sown these fields are normally fertilised with slurry, sown with cereals or with cereals under-sown with clover and grasses of high productivity cultivated species such as *Lolium perenne* L. and *Trifolium repens* L. Some of these fields are also irrigated to maintain high productivity throughout the summer, and may be weeded mechanically post sowing. These highly productive re-sown grass fields contain only a small number of plant species other than the cultivated species, and therefore have a low nature value. In an examination of 28 fields with clover and grass it was found that on average 97% of the biomass was of cultivated species (Nielsen, 1995).

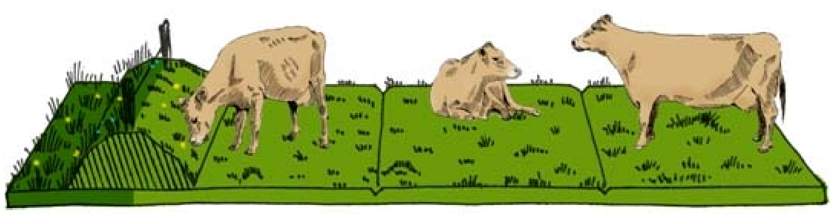
To improve the nature values and to utilise the management capacity of the grazing cows, we have developed a management option for the field margins of rotational high productive organic grass fields. The idea of flexible management of field margins developed as a solution to improve nature values on organic farms with no or small areas with permanent grassland.



Field margin:	Field:
Unmanaged Field margins: bank, road verge, field boundary, watercourse, small pond, etc.	Spring barley with under-sown clower-grass for next year grass field

Year 1 - Summer before new margin management.

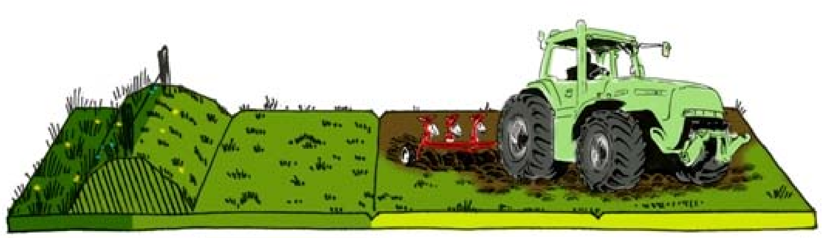
Field is cropped with under-sown cereal.



Field margin:	Expanded margin:	Field in rotation:
Grazed	Grazing and cut for silage	Grazing and cut for silage
	No manure	Possibly manure

Year 2, 3, 4 - Summer

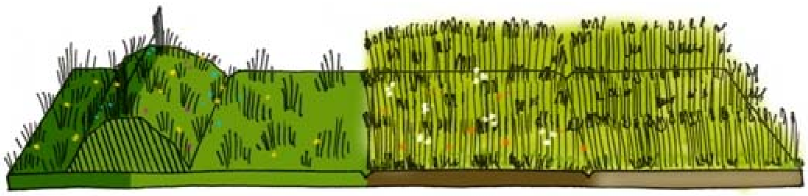
The field is grazed for three years before re-sowing. Notice the placing of the electric fence, which allows grazing of the field margin biotope without destroying it.



Field margin:	Extended margin:	Field in rotation:	
More space for different herbs after three years with grazing	Now permanent grassland No slurry No ploughing	Application of slurry and ploughing	
		Slurry half dose	Slurry full dose

Year 5, 6 – Spring. Application of slurry and ploughing.

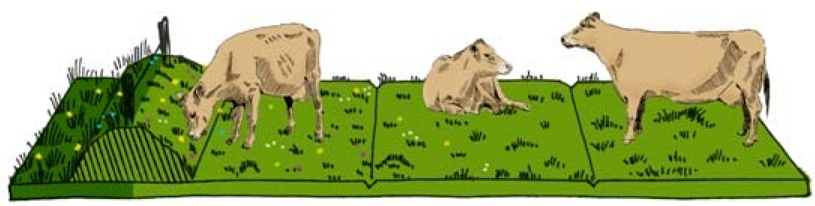
The three years of grazing is followed by two years of cropping with annual crops.



Field margin:	Extended margin:	Field in rotation:	
More space for different herbs after three years with grazing	Now permanent grassland with a pause in the grazing	Spring barley with under-sown	
		More weed species No mechanical weeding and reduced manure	
	Whole field for silage or wholecrop harvesting		

Year 5, 6 – Summer

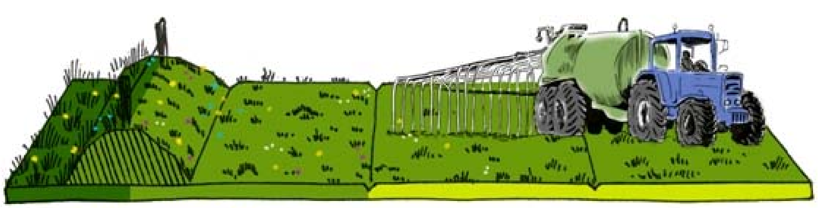
Annual crop. No mechanical weeding in the crop next to the extended margin.



Field margin:	Extended margin:	Field in rotation:
Grazed - Good living places for grassland species	Grazing Grassland species have established	Grazing More herbs have establish themselves
	Whole field is grazed	

Year 7,8, 9 – Summer

The field is grazed for another three years before re-sowing. The grassland species are now established in the extended margin.



Field margin:	Extended margin:	Field in rotation:	
Good living places for grassland species	Now permanent grassland	Application of slurry on field in rotation	
	No slurry No ploughing	Slurry half dose	Slurry full dose

Year 10 – Spring. Application of slurry, etc.

This management can now continue through the future years.

Fig. 1. Part of a cartoon explaining the option of ‘flexible management of field margins’ for farmers.

Materials and Methods

Assessments of nature plans at 10 organic dairy farms located on Zealand and delivering their milk to the dairy of Øllingegaard Mejeri were based on floral monitoring. These organic farmers had no or only small areas with permanent grassland on their main farm where the milking parlour was located and therefore the benefit for nature quality obtained from these cows was not very large. The heifers and dry cows mostly grazed on permanent grassland areas located far away from the milking parlour. The nature improving strategy we wished to provide to the farmers needed to be of low cost, easy to realise and include the grazing cattle at the farms. The plans should benefit grassland species including flora and insects as well as species belonging to the cereal fields, such as the food items for partridge chicks.

The option comprises grazing management of the field margin biotope, establishment of a few metres of permanent grassland in the margin of the field, plus a marginal zone of the crop, which is not weeded mechanically in the following years when annual crops are grown in the field. The un-weeded zone of the crop, with reduced levels of manuring, should among others things benefit partridge. It is a comparable to the use in conventional farming of an un-sprayed crop edge.

Field margin management should be located at sites with the best botanical potential to obtain a good response of the effort. These sites were found from the nature plan: (a) the field should be included in the farmers grazing system, (b) some wild grassland plant species should be present in the field margin biotope and (c) the presence of nitrophilous species should be as low as possible in the field margin biotope.

Results and Discussion

The flexible management of field margins was presented for the farmers as a cartoon (Fig. 1) in order to better visualize the system. The width of the expanded margin may vary according to the local situation, size of machinery and other practical concerns. By using this management system the farmer can give some attention to the nature quality at the farm and the cattle are offered more varied roughage although the basic feed will be high quality clover and grass.

Acknowledgements

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A functional approach to modelling arable diversity

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Summary

This LINK project aims to model, and provide advice on, the strategies for maintaining biodiversity within arable systems whilst maintaining yield. Empirical approaches have begun and are being set up to describe the relationship between weed density and yield to a high level of precision and accuracy, and to identify functional types of weed and invertebrate species using multivariate analysis on functional traits. An Individual Based Model will represent biodiversity through functional types in order to predict the probable effects of management changes on ecosystem and biodiversity

Keywords: Modelling, advice, biodiversity, individual based model, yield

Introduction

Within a recently funded LINK project we aim to provide guidelines for managing arable crops in order to balance the potentially conflicting goals of biodiversity and crop productivity. We are interested in ecosystem functioning and its relationship with the diversity and composition of functional types of individuals in the system.

Firstly, the ecosystem itself has function. By this we mean that there are certain beneficial properties that emerge at the system level from the interaction between individual components of that system. Some of these properties are of benefit not only to the continuing existence of the ecosystem but also of economic benefit to the farmer. Such processes include nutrient cycling, water retention & biocontrol through maintaining stable natural enemy populations. The widespread use of crop-rotation within arable systems, particularly when used to reduce pest build-up, is an implicit recognition by the industry that the ecosystem "function" can benefit the economics of the farm.

Secondly, we explore the means by which diversity of functional types of species may be a simple way of representing overall biodiversity and its contribution to system function. For the purposes of this project, the ideal aggregation of species into different functional types is one such that *a*) the diversity of the functional types is strongly correlated with species diversity; and *b*) the functional grouping allows the creation of an arable system model that is simpler than representing all possible species but captures the important components of the non-crop ecosystem; and *c*) it is easily translated into practical methods for assessing the diversity and functionality of an arable system for non-ecologists.

Our approach is to examine in detail the relationships between the weeds, invertebrates and crop yield. Generally, arable studies of biodiversity tend to look at weeds and invertebrates *or* weeds and crop yield. Advice on optimal strategies for maintaining both crop yield and biodiversity must take into account all three components of the system. We have chosen not to consider non-invertebrate animals for reasons of simplicity. These relationships will be examined both empirically and also through the use of a process-based Individual Based Model which uses energy flow as the driver of interactions between individuals. This short paper describes our empirical approach to examining the relationship of yield to weed density, an empirical approach to categorising arable weed species into functional groups, the designs of analyses that have been started, and the structure of the individual based model.

Methodological Approach

A process-based IBM representing trophic relationships between functional groups in arable systems

A prime tool within this project is an Individual Based Model (IBM) based on an aggregation of species into functional types and the trophic relationships between these types. The functional approach has two main advantages over traditional taxonomic approaches: first, if the diversity or composition of 'types' successfully predicts biodiversity and system functioning, this approach will provide a better representation of the mechanisms involved, as the contribution of individual organisms is modelled directly; second, compared to representing all species, the functional approach should allow a more computationally tractable method of representing biodiversity in arable systems.

Diversity will be modelled through the representation of individuals, each of which will belong to one functional type. Each functional type will have a range of values for each of the functional traits described through a probability distribution of values for each trait. The model will include three trophic levels: producers, invertebrate consumers, and invertebrate secondary consumers.

One method for defining functional types is to use existing theories of important functional traits to categorise species (plants and invertebrates). This is appropriate as it deliberately focuses on the traits that are already considered important in determining the function of the ecosystem as a whole. We have also gathered published data on weed species to use within a multivariate approach for categorising weed species and this is discussed below. Dependent upon this multivariate analysis, the functional categorisation will probably consist of approximately 20 functional types of plant and approximately 30 functional types of invertebrates. This categorisation will be finalised with reference to the multivariate analysis described above, analysis of data from the FSE trials (Squire *et al.*, 2005), and published analyses (Storkey, 2006). There are two sorts of traits that an individual carries: (a) physiological traits that are common to all individual invertebrates and plants and which are necessary within the model to allow the individual organisms to grow, reproduce, disperse and die. Their value depends upon the functional type but are not used to *define* the functional type (e.g. number of seeds/eggs per organism); (b) traits that, in addition to allowing the organism to exist also define the functional type of the individual. Amongst the plant traits that define functional type are monocot/dicot; annual/perennial; rate of development. The latter trait type will influence the former through empirical associations between functional type and those former traits.

The processes of growth, reproduction, dispersal and death are dependent (amongst others) upon competition and trophic interactions and constitute the broad cycle that occurs for each individual but there will be a high level of detail modelling how the different functional types interact with one another. As an example, we are creating a food preference matrix for all functional types describing the likelihood of predation between functional type pairs. At this level of detail we do not always find published estimates for the parameters required. In such cases expert opinion and sensitivity analyses will allow us to estimate the importance of the gaps in the parameter-requirements of the model. Sensitivity analyses will also allow a level of model-assessment since we have data that show the effect of specific management changes on weed and invertebrate populations within certain arable systems (oil seed rape, maize & beet) (Squire *et al.*, 2005).

Model assessment will be carried out by testing results against existing datasets and known patterns of abundance. In particular the model results will be assessed for spatial patterns of functional types ("species accumulation curves") (Rosenzweig, 1995), rank abundance curves (Magurran, 1998), the relationship between crop yield and weed biomass, the relationship between weed biomass and invertebrate biomass, the relationship between weed biomass and invertebrate diversity (Squire *et al.,* 2005), and the relationship between weed diversity and total (weed and crop) primary production.

Relationship between weed density, diversity and crop production

Within current "conventional" agriculture, the density of weeds tends to be very low (e.g. < 1% of annual dry matter was weeds in the recent GM Farm Scale Evaluation trials (Squire *et al.,* 2005)). The relationship between weed density and crop yield is normally derived from experiments and tends to be described for weed densities much higher than those normally found in the field. The experimentally induced relationship between crop weight or crop yield and weed density is frequently described using a rectangular hyperbolic equation (Cousens, 1985).

An important consequence of the widespread use of this empirical model is that the estimate of the slope at low weed densities is steep and depends upon the fit of the model over the *full* range of experimental weed densities. Whilst the hyperbolic curve above is commonly used we have found examples of either linear or sigmoidal curves (Klem, 2003) being used to describe the competition relationship. At the low end of weed density, the shape (and slope) of this curve is particularly important for understanding the trade-off between biodiversity gains and yield losses, both potentially associated with weed density.

Sigmoidal curves such as those of (Klem, 2003) are counter-examples (to the hyperbolic curve) but this is not sufficient to discard the rectangular hyperbolic relationship which is frequently reported. They do at least justify a questioning of the universality of the hyperbolic curve. Importantly the observation that most of the variation in biodiversity in conventional arable systems is associated with variation in weed biomass at low levels of weed density means that it is important to represent the relationship as accurately as possible. We have set-up a trial of winter wheat to examine the relationship between weeds and crop yield and weeds and invertebrates (abundance and diversity) at "typical" and reduced herbicide levels. The crop data will be collected in August/September 2007. In this way we hope to describe the relationship. A second experiment will use the classic competition-study approach of manipulation of weed density through the addition of weeds to a weed-free system (as opposed to removal through herbicide application) in small experimental units (1 m^{-2}) of spring barley where we focus on the low end of weed density.

A multivariate approach to functional aggregation of species

A common method which we are currently employing for aggregating species within the plant component of our arable system is multivariate clustering of existing data to see what clusters of species are found when their traits are analysed (Gitay & Noble, 1997). Using existing data (Squire *et al.,* 2005) and an online database (Peat & Fitter, 2006) we selected 105 arable taxonomic groups, (usually at the species level) and 40 traits. The first stage of analysis is to discard taxa and traits optimally to reduce the proportion of missing values and make the analysis tractable. We will then use a dissimilarity matrix to determine clusters and this can be compared to the mechanistic approach described above, as one means of functional-type validation.

Discussion

Since the 1920s, agricultural intensification has caused a decline in the diversity of arable plants and associated fauna (Marshall *et al.*, 2003), and has had a detrimental impact particularly on non-target species that are present at moderate or low abundance (Brenchley & Warington, 1933; Roberts & Chancellor, 1986). This loss of biodiversity has important implications for system function including pest and disease control, nutrient retention, hydrological processes, detoxification, microclimate regulation, invasion resistance and productivity (Altieri, 1999; Knops *et al.*, 1999; Petchey *et al.*, 2002). In addition, the modelling studies of Tilman *et al.* (1997) and Norberg *et al.* (2001) showed that productivity (as a measure of system function) increases asymptotically with biodiversity and that the effects of biodiversity on productivity and nutrient retention increase with interspecific, and in particular phenotypic, differences in resource requirements. There is in ecology generally an emerging consensus that ecosystem function is truly important for providing “services” and furthermore that biodiversity contributes to this ecosystem functioning as is demonstrated by recent high profile meta-analyses (Cardinale *et al.*, 2006; Worm *et al.*, 2006). Within the arable industry, however, it is less obvious that these properties of systems are yet accepted intellectually or applied.

Although biodiversity-system function relations are rarely tested explicitly in arable systems, many studies have demonstrated a positive association between the abundance and diversity of primary producers and associated herbivores, predators and parasitoids (Siemann *et al.*, 1998, Koricheva *et al.*, 2000; Haddad *et al.*, 2001; Hawes *et al.*, 2003). Two complementary hypotheses have been proposed to explain these relations between plant and insect diversity. The “resource concentration hypothesis” suggests that herbivores are less likely to find, and remain on, their hosts in mixed stands of vegetation and that the complex habitats typical of polycultures reduce the potential for dominance by specialist herbivores. The “natural enemies hypothesis” is based on the assumption that complex habitats provide a greater diversity of prey and microhabitats, allowing increased stability of generalist predator densities. Specialist predator populations are also more stable due to greater availability of host refuges and alternative food sources. This means that under both scenarios, faunal diversity is lower, herbivore load higher and outbreaks more frequent in simple monocultures than more diverse polycultures or weedy mixtures (Root, 1973; Powell *et al.*, 1985). Diversity in the weed assemblage therefore has the potential to enhance system function by stabilising pest and beneficial natural enemy populations through provision of a greater range of microhabitats and sustained resource availability throughout the growing season.

Practically, the existence of rotation systems within the UK arable sector is a demonstration that, for disease and pest prevention purposes at least, there is an implicit recognition of the contribution ecosystem function provides to productivity and profitability. Whilst there are currently moves towards “environmentally sensitive” farming methods, much of this is motivated by WTO economic philosophy, recent over-production within Europe and a public desire for maintenance of biodiversity for its aesthetic value. Our interest is also in the contribution of diversity to system function and to provide a tool for maximising diversity with minimum loss of production.

Where, as in this case, there is a paucity of data describing the whole system, a synthesis of published reductionist data describing components of the system, is, we believe, the most likely way in which we can represent the key functional processes (e.g. energy capture and cycling) and biodiversity and hence make useful predictions for the industry and wider public.

Once tested, the model will then be used to examine the consequence of management changes on functional diversity both for weeds and invertebrates and on the crop productivity. As described here, even the basic empirical relationship between weed density and crop productivity is not yet fully described. Using such results together with the system model it should be possible to provide guidelines on management changes most likely to enhance biodiversity and sensible and practical measures of functional biodiversity. As biodiversity becomes a more relevant policy objective within agriculture it is likely that these results will be of interest to policy-makers, regulators and agri-businesses.

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