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Combining Agricultural and Environmental Perspectives: Integrated Arable Farming Systems Research in the UK

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Abstract

Integrated Arable Farming Systems (IAFS) are attracting much current interest in the UK from researchers, policy-makers and farmers. This interest stems from increasing concerns about the environmental impacts of certain agricultural practices and the rising awareness of consumers about the way in which food is produced. Several rotational systems projects are underway in the UK. A primary aim of these projects is to show that different farming techniques, often associated with optimising or lowering the use of inputs, can be used in a variety of farming situations without reducing overall farm profitability, with secondary objectives associated with maintaining or improving environmental quality. Several of these studies involve the reduction of cultivation, fertiliser and pesticide usage which are often cited as the cause of environmental pollution. In many of the studies substantial reductions have been achieved in these areas leading to the suggestion that IAFS are "better" for the environment when compared to standard or conventional farm practices. In this paper, data is presented from the LINK-IFS project which suggest that although input levels are being reduced, the effect of this reduction in terms of impact on key environmental indicators is, to date, unclear. Discussions centre on the difficulty of making clear assumptions about the environmental benefits of IAFS based on a relatively short time series of data and the fact that, at least in the short-term, a reduction in the perceived causes of environmental degradation appears not to be mirrored by changes in key indicators of environmental quality.

Introduction

At a global level, but particularly in north-western Europe, the awareness of the environmental impacts of agricultural production has highlighted the need to find more sustainable farming practices (Park & Seaton, 1996). Integrated Arable Farming Systems (IAFS) are being put forward by some advocates as being more sustainable than current farming practice. Preliminary evidence from research in the UK suggests that profitability can be maintained providing yield suppression can be off-set by reductions in the use of crop growth factors (Jordan and Hutcheon 1994, Park *et al,* 1996).

A number of IAFS are being examined in the UK and Europe (Holland *et al,* 1994, Park *et al,* 1997) to evaluate their benefits in comparison with conventional farm practice. Several of these studies involve reducing cultivation, fertiliser and pesticide usage which are often cited as the cause of environmental pollution or degradation. In many of the studies, substantial reductions have been achieved in terms of the quantity of inorganic nitrogen fertiliser applied, the use of various pesticides (often referred to in terms of units) and the severity and frequency of cultivation used with respect to seedbed cultivation. These reductions are usually associated with changes in rotations and cropping sequences. These changes and reductions in the potential causes of environmental pollution and degradation would suggest that IAFS are somehow "better" for the environment when compared to standard or conventional farm practices. However, analysis of data from a number of the different experiments in the UK suggests that although reductions in inputs have been achieved in IAFS, this is not necessarily, at least in the short-term, leading to an unequivocal improvement in the environment, as measured by a number of key indicators.

In this paper, data is presented from a number of the LINK-IFS *(LINK-Integrated Farming Systems*) project sites which suggest that although input levels are being reduced, the effect of this reduction in terms of the impact on key environmental indicators is at best confusing and often counterintuitive. The LINK-IFS project is based on six agro-ecologically representative sites throughout England and Scotland (Figure 1). This rotational systems study was established in 1992 with the principal aim being to compare integrated and conventional rotations over a five year period. The basis of the experiment was a five course rotation at each site with crops chosen that were appropriate to the locality of that site. Comparisons were made on half or quarter fields (paired plots), one half managed as the integrated system, the second half managed according to the local conventional practice. Each course of the rotation was present in every year and there were therefore, at least five fields on which the experiment was conducted. In certain cases, additional fields and / or plots were used as replicates. Whilst the study concentrated on the practical feasibility and economic viability of the rotations it also took into account the level of input use and their environmental impact (see Ogilvy *et al*, 1994). Data relating to a number of "environmental indicators" has been recorded throughout the experiment, some of which is presented and discussed in this paper. Additionally, the difficulty of making clear assumptions about the environmental benefits of IAFS based on a relatively short time series of data are outlined.

IAFS Techniques

Some of the methods in which an integrated arable farming system differs from what is generally regarded as conventional practice are discussed below, with examples from the LINK-IFS project. The defining of conventional and integrated practice has in itself, started to cause some concerns (Park *et al*, 1997), as lower world prices and a general heightening of environmental awareness has meant that "conventional systems" have evolved quite rapidly in the 1990's to what would previously have been thought of as a "lower input" or more "integrated" systems.

Changes in rotation : A primary aim of IAFS is to utilise different crop varieties and species which are likely to enhance soil fertility over a rotation, or reduce the inputs required over that time period**.** This can mean that a combinable rotation includes oilseed rape and a leguminous break, the aim being to provide the maximum opportunity for effective pest, weed and disease control during the rotation using cultural techniques as well as chemical applications. Additionally, growing spring crops in the rotation may help reduce the requirements for nitrogen fertiliser and pesticides.

Table 1 shows the conventional and integrated rotation at the Pathhead site which has substituted spring rape for winter rape in phase 1 of the rotation and spring barley for winter barley in phase 5. This was done with the primary aim of reducing inputs in the integrated system; additional advantages which have emerged include better slug control and reductions in the amount of soil nitrate residues available to be leached (Fisher *et al*, 1996).

The use of varietal resistance to disease as a means of reducing inputs is another important consideration within the rotation. For example, at the Pathhead site for the 1995 harvest, the relatively disease resistant wheat, Hunter, was chosen for the integrated system, whereas the fungicide responsive Riband, was chosen for the conventional system. Additionally, the growing of different varieties may allow market premiums to be obtained if climatic conditions are favourable.

Table 1. Conventional and Integrated Rotation at the Pathhead Site

Phase	Conventional	Integrated
1	Winter oilseed rape	Spring oilseed rape
2	Winter wheat	Winter wheat
3	Set-aside	Set-aside
4	Winter wheat	Winter wheat
5	Winter barley	Spring barley

Changes in cultivation : A number of cultivation techniques have been suggested as part of an IAFS approach to farming. These include non-inversion or minimum tillage to create the seedbed and the use of mechanical tools for weed control. Ploughing is an expensive form of land preparation but has benefits in terms of effective trash disposal, soil aeration and tilth creation. From an environmental perspective, some past research evidence suggests that cultivation has a deleterious effect on soil dwelling invertebrates (Edwards, 1984). Additionally, many cultivation processes are energy intensive and they emit previously stored fossil carbon to the atmosphere. Clear cultivation differences, represented in energy terms, between the conventional and integrated systems at the Boxworth site are illustrated in Table 2.

The rotation at this site is winter oilseed rape, winter wheat, winter beans, winter wheat followed by winter wheat in the conventional rotation, with linseed replacing the winter oilseed rape in the integrated rotation. Table 2 illustrates that in terms of energy use the integrated systems are generally most efficient. Similar results have been presented in other integrated experiments (Donaldson *et al*, 1994).

Reduction in inorganic fertiliser usage : A principal aim of IAFS is to reduce the amounts of fertiliser both applied and lost from the system. This has obvious direct implications for the farmer in that it will reduce input costs, but also has wider benefits in terms of reducing chemical contamination of both surface and groundwater (particularly by nitrate). Table 3 illustrates the reduction in nitrogen fertiliser that has been achieved at the High Mowthorpe site over the period of the rotation. The cropping sequence at this site is winter wheat (phase 1), set-aside (phase 2), winter oilseed rape (phase 3), winter wheat (phase 4) and seed potatoes (phase 5) in the conventional rotation, with spring beans replacing the oilseed rape in the third phase of the rotation on the integrated system.

Table 2. Energy Use in the Conventional and Integrated Systems at Boxworth in 1995

Crop	CFP[1] Energy MJ ha^{-1}	IFS[2] Energy MJ ha^{-1}	CFP[1] Yield t ha^{-1}	IFS[2] Yield t ha^{-1}	CFP[1] Efficiency MJ kg^{-1}	IFS[2] Efficiency MJ kg^{-1}
W Wheat	18273	11151	8.67	8.81	2.11	1.27
W Wheat	21611	11549	8.66	6.36	2.50	1.82
W Wheat	16911	13737	9.30	5.66	1.82	2.43
WOSR/Linseed	21507	17712	3.43	3.68	6.27	4.81
W Beans	17883	12709	3.52	4.20	5.08	3.03
W Wheat	16497	10785	9.36	8.25	1.76	1.31

Notes: 1 - conventional rotation, 2 - integrated rotation

Overall, High Mowthorpe has achieved a 25% reduction in fertiliser use in the integrated rotation over four years, the aim being to reduce high nitrate residue in the autumn which runs the risk of leaching. These reductions have occurred primarily in phase 3 with the substitution of spring beans for winter oilseed rape in the integrated system, although reductions have also occurred on a number of occasions in the subsequent crops (phases 4 and 5).

Table 3. Nitrogen Fertiliser Usage (kg N ha^{-1}) in the Conventional and Integrated Rotations at High Mowthorpe

	1993		1994		1995		1996		Rotation	
Crop Phase[1]	CFP[2]	IFS[3]	CFP[2]	IFS[3]	CFP[2]	IFS[3]	CFP[2]	IFS[3]	CFP[2]	IFS[3]
1, 2, 3, 4	220	220	0	0	205	0	241	169	666	389
2, 3, 4, 5	0	0	219	0	238	247	0	156	457	403
3, 4, 5, 1	200	0	240	200	272	272	218	197	930	669
4, 5, 1, 2	220	205	151	130	230	230	0	0	601	565
5, 1, 2, 3	150	150	210	210	0	0	179	0	539	360
Total	790	575	820	540	945	749	638	522	3193	2386
Mean	158	115	164	108	189	150	128	104	639	477

Notes: 1 - crop phase starting in 1993 and going through to 1996, 2 - conventional rotation, 3 - integrated rotation

Reduction in pesticide use : A key component of the integrated approach is to reduce the amount of pesticide applied to crops. This may mean that some weeds are tolerated in crops or that a certain low level of disease is accepted. It has not been uncommon for some farmers to apply pesticides as an insurance measure although disease itself may only be present at low levels at the time of spraying. This managed disease programme is usually growth-stage dependent. IAFS techniques attempt to overcome such prophylactic practices via closer crop monitoring and the use of thresholds to make decisions on when to apply the appropriate fungicide. This can be a very successful approach in some instances. Pesticide loading can also be reduced via the selection of more disease resistant crop varieties or the use of more environmentally benign chemicals. This may result in lower quantities of pesticide being applied or may reduce the total toxic loading. Table 4 illustrates the pesticide units[1] applied in the conventional and integrated rotations for the Manydown site which has the same crops in both the conventional and integrated systems; winter wheat (phase 1), winter wheat (phase 2), spring barley (phase 3), peas (phase 4) and winter oilseed rape (phase 5).

Reductions in the number of pesticide units have been achieved mainly in the winter wheat phases of the rotation. Similar amounts were used in the spring barley phase and, against the general principal of integrated farming systems, greater amounts have been used in the pea phase of the IFS rotation. This was a function of the commercial farming nature of this particular site which meant that the site manager could not take the greater risk associated with the non-application of pesticides in the IFS rotation. Nevertheless, the overall number of pesticide units used has been reduced by 12%.

Table 4. Pesticide Use (Units) in the Conventional and Integrated Systems at Manydown

	1993		1994		1995		1996		Rotation	
Crop Phase[1]	CFP[2]	IFS[3]	CFP[2]	IFS[3]	CFP[2]	IFS[3]	CFP[2]	IFS[3]	CFP[2]	IFS[3]
1, 2, 3, 4	7.7	5.4	8.0	5.9	4.1	4.1	6.6	7.5	26.4	22.8
2, 3, 4, 5	10.2	7.8	5.00	4.5	5.1	7.1	8.2	7.3	28.6	26.7
3, 4, 5, 1	4.6	4.2	7.6	8.2	6.5	5.0	8.2	6.5	26.9	23.9
4, 5, 1, 2	5.9	6.5	6.2	4.4	9.3	7.6	6.7	6.4	28.0	24.9
5, 1, 2, 3	6.2	6.4	6.3	4.0	10.6	8.0	5.0	5.0	28.1	23.3
Total	34.6	30.2	33.1	27.0	35.6	31.8	34.7	32.6	138.0	121.6
Mean	6.9	6.0	6.6	5.4	7.1	6.4	6.9	6.5	27.6	24.3

Notes: 1 - crop phase starting in 1993 and going through to 1996, 2 - conventional farm practice, 3 - integrated farming system

Environmental Monitoring

A wide range of literature exists on the principle and practice of environmental monitoring and a comprehensive range of such indicators for farming systems have been suggested (Bockstaller & Giradin 1996, Vereijken 1996, DOE and MAFF 1995, OECD 1997). However, within the confines of particular research projects, only a limited number of environmental indicators can usually be chosen for base-line and continued monitoring due to practical, labour and financial constraints. The LINK-IFS project is no different in this respect, with only a restricted amount of data available through time which can be used for the

[1] A unit is the maximum amount, in grams, of an active ingredient recommended for arable crops. It assumes that the toxicity of all pesticides applied are equally deleterious to the environment.

purpose of monitoring change in the conventional and integrated rotations. The more influential of these indicators are outlined below :

Nitrate leaching : Controlling the leaching of nitrate from agricultural land has become a major environmental issue over the last decade (Addiscott *et al*, 1991). Nitrate contamination of ground water together with eutrophication of surface waters can be a problem in areas where high levels of fertilisers are applied. Additionally, the loss of nitrate has a direct cost to the farmer in terms of inefficient use of fertiliser. Nitrate residues present in the autumn, which represent inefficient crop uptake and / or over application of fertiliser, provide an indication of the nitrate nitrogen which is vulnerable to leaching during the following winter if not quickly utilised by the subsequent crop. Table 5 illustrates data on autumn nitrate residues for two contrasting sites. These are from soil mineral nitrogen samples taken at a depth of 90 cm. Samples were also taken at 30 cm and 60 cm in both the spring and the autumn.

Both Boxworth and High Mowthorpe have reduced their nitrogen fertiliser inputs in the integrated system by 15% and 25% (see Table 4) respectively. However, in terms of the residues available to be leached, Boxworth has greater amounts on the integrated system in both the years shown and, although High Mowthorpe shows an overall reduction in available residues over the three years shown, in 1995 the residues on the integrated system are greater, and in 1996 there is little difference between the two systems.

Table 5. Soil Nitrate Residues (kg N ha^{-1}) in the Conventional and Integrated Systems at Boxworth and High Mowthorpe

	1994		1995		1996		Rotation	
	CFP[1]	IFS[2]	CFP[1]	IFS[2]	CFP[1]	IFS[2]	CFP[1]	IFS[2]
Boxworth	-	-	62	85	121	159	183	244
High Mowthorpe	106	96	80	83	80	79	265	256

Notes: 1 - conventional rotation, 2 - integrated rotation

Beetle numbers : A range of indicators could be used to represent the effects of agricultural practice on habitats and biodiversity. Carabid beetles are relevant here because they are part of a complex food web which would suggest that if their numbers are high then the general environment for their survival and that of their prey must be suitable (see Cousins, 1985 on Eltonian Pyramids). Table 6 illustrates data on Carabid beetle and other invertebrate numbers for Manydown and Pathhead collected using pitfall traps filled with water and detergent which were set out for 10 day periods in the winter and 5 day periods during the summer for each crop's growing period. These were laid out in each field as two transects of five pitfall traps each spaced at 10 metre intervals and starting at 30 metres from a common boundary.

The data for Manydown and Pathhead show marginal differences in numbers which, overall, favour the integrated system at both sites. However, the information on Carabids and Linyphiidae at both sites is conflicting with higher numbers on the integrated in one year, with the reverse occurring in the following year. Staphylinidae at Pathhead appear fewer in number on the integrated, although at Manydown they appear greater in number. This is also the case for Lycosidae at Manydown, of which there are none in either rotation at Pathhead.

Holland *et al* (1996) conclude that, for Carabids only, the greatest effect on numbers was the differences between site location, as can be seen in the numbers given for the two sites above, and the type of crop grown.

Earthworm Biomass : Earthworms are recognised as important components of temperate edaphic systems (Edwards & Lofty 1982). They play a key role in trash burial, nutrient cycling, soil aeration and drainage. However, they are sensitive to a range of agricultural activity including cultivation, fertiliser and pesticide use. This suggests that changes in weights of earthworms per unit area can be used as an indicator of agricultural change. Earthworm numbers vary considerably depending on soil type, nutrient status (particularly related to pH) and agricultural practice. Table 7 presents data for both numbers and biomass from the two sites. Earthworm measurements were taken from two randomly selected areas of one square metre from within each plot. Pre-treatment earthworm samples were taken after the 1992 harvest but prior to the commencement of the conventional and integrated strategies. The second sample was taken after the harvest in he third year (1994/95) of the experiment.

At Boxworth, numbers and overall biomass have increased in both systems, although the greater increase occurs in the integrated system. At High Mowthorpe, the only increase is in numbers under the conventional system. There is a small reduction in biomass. In the integrated system at High Mowthorpe both the numbers and biomass are reduced, although the decline in numbers is only slight. It is also interesting to note that another site, Rosemaund, which has the same conventional and integrated rotations as High Mowthorpe, and similar management strategies in terms of cultivation practices and chemical use, shows the opposite situation with respect to earthworms. Numbers and biomass have increased on the integrated rotation, whereas there has been a barely perceptible change in numbers and greater reduction in biomass on the conventional system.

Table 6. Mean Number of Invertebrates Per Pitfall Trap Per Day in the Conventional and Integrated Systems at Manydown and Pathhead

	1993		1994		1995		Rotation	
Manydown	CFP[1]	IFS[2]	CFP[1]	IFS[2]	CFP[1]	IFS[2]	CFP[1]	IFS[2]
Carabidae	4.30	3.77	11.03	11.45	20.11	19.49	35.44	34.71
Staphylinidae	0.92	0.96	2.70	5.52	3.47	5.25	7.09	11.73
Linyphiidae	1.79	2.24	6.57	8.30	9.46	9.33	17.82	19.87
Lycosidae	0.14	0.15	0.36	0.42	2.20	2.71	2.70	3.28
Total	7.15	7.12	20.66	25.69	35.24	36.78	63.05	69.59
Pathhead	CFP[1]	IFS[2]	CFP[1]	IFS[2]	CFP[1]	IFS[2]	CFP[1]	IFS[2]
Carabidae	0.25	0.32	0.56	0.54	0.67	0.92	1.48	1.78
Staphylinidae	0.04	0.04	0.19	0.09	0.10	0.08	0.33	0.21
Linyphiidae	0.26	0.27	4.66	4.59	0.19	0.21	5.11	5.07
Lycosidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.55	0.63	5.41	5.22	0.96	1.21	6.92	7.06

Notes: 1 - conventional rotation, 2 - integrated rotation

Table 7. Earthworm Numbers (m^{-2}) and Biomass Changes (kg ha^{-1}) in the Conventional and Integrated Systems at Boxworth and High Mowthorpe

	1992		1994/95		Change		% Change	
Boxworth	CFP[1]	IFS[2]	CFP[1]	IFS[2]	CFP[1]	IFS[2]	CFP[1]	IFS[2]
Numbers	70	57	84	67	+14	+10	+20	+18
Biomass	1650	1280	1900	1730	+250	+450	+15	+36
High Mowthorpe	CFP[1]	IFS[2]	CFP[1]	IFS[2]	CFP[1]	IFS[2]	CFP[1]	IFS[2]
Numbers	11	11	19	8	9	-2	+80	-22
Biomass	770	1020	740	600	-30	-420	-3	-41

Notes: 1 - conventional farm practice, 2 - integrated farming system

Discussion

The data presented in this paper suggests that the sites included in the LINK-IFS study are certainly achieving reductions in nearly all instances with respect to inputs into the integrated rotations when compared to the conventional rotations. Other work has reported that the profitability of these systems, at least to date can be more or less maintained under lower input regimes (see Park *et al* 1996). However, analysis of environmental data obtained after 4 growing seasons does not clearly reflect this reduction in inputs. Rates of leaching of nitrate from farming systems is known to be variable and often associated with a time lag. For instance soil type, rainfall, cropping and amount of soil disturbance can all have an effect on the movement of nitrate in soils. Thus, measured leaching will be a compound effect, dependent on these variables (see Figure 1). Clearly, the rate of leaching of nitrate will be strongly influenced by these factors. However, this does not easily explain the differences found between the conventional and integrated rotations at each site which may be more readily explained by localised variations in soil type, topography and organic matter content as well as differences in the amounts of crop residues being returned in each rotation. With respect to crop residues, it could be argued that the lower yields often achieved on integrated rotations means that less organic material is being returned to the soil. This may have a knock-on effect in that less free nitrate is bound up by decomposing materials in the short-term leading to a higher potential rate of leaching on the integrated rotations. This needs to be set against the slightly higher rates of nitrogen usage on the conventional rotations.

Results of the beetle monitoring are even more difficult to interpret. Number of beetles trapped will depend on many different factors from major influences such as soil type and permanent habitat availability, to more seasonal factors such as weather patterns, availability of food, the coarseness of the soil surface and vegetation cover. Given such a complex set of variables it is perhaps not surprising that the experiments to date have not illustrated any clear trends between the conventional and integrated rotations. For instance, the use of herbicides to control weeds may well be expected to reduce the amount and diversity of surface vegetation with knock on effects in terms of food supply for predatory beetles. However, the use of a harrow-comb on integrated systems to control weeds may well not only remove weeds but also disturb the soil surface across which the beetles move.

Similarly, with earthworm numbers it is clear that a large number of variables interact to influence their numbers. Research has shown that earthworm populations are effected considerably by a number of agricultural practices (Edwards, 1984). The spatial distribution of populations in a field can also vary. Thus, it is again perhaps not surprising that no clear trends between the conventional and integrated rotations exists. Ploughing, which is seen as the standard primary cultivation on the conventional rotation has been shown in past research to have a larger deleterious effect on earthworm populations than direct drilling and minimum cultivation. However, the type of cultivation adopted on some of the integrated rotations is perhaps even more damaging to earthworm population than the plough. For instance, a one pass cultivator and drill can be regarded as giving the soil (and thus the earthworms) a short sharp shock, rather than a more gentle plough, press and drilling pass.

Conclusions

This paper has presented evidence to show that IAFS are certainly capable of reducing some of the inputs into farming systems, many of which are often perceived as being detrimental to the environment in general. This has led to the claim that integrated arable farming systems are generally more environmentally friendly. However, substantive evidence based on short-term environmentally oriented monitoring does not always confirm these claims. Indeed there are many instances in which data from the LINK-IFS experiments could be used to show the opposite is true. This may well be regarded by some as counterintuitive, although a more systematic approach can be employed in many of the cases to analyse why such results are achieved. Part of the reason for the emergence of this confused picture is likely to be due to the compounding of a number of factors, which is inevitable in this type of rotational systems project. Additionally, the short time period over which monitoring is available (at least in agroecological terms) is liable to confuse rather than clarify issues. Climatic variation over the period of the experiments has been extreme which is likely to have implications for the more general conclusions that can be drawn from the research study.

Whereas high quality research exists to illustrate the effect of pesticides on earthworm numbers, little or no research under controlled conditions exists to look at the compounded effect of changes in fertiliser, pesticide and cultivation on earthworm populations. It would seem sensible to undertake this type of research in more traditional scientific experiments alongside rotational experiments such as the LINK-IFS. In short, rotational systems experiments are perhaps best utilised as a mechanism for measuring agricultural output from a known set of inputs in a range of different agroecological zones. It appears that their suitability for unravelling the compounded effects of a variety of agricultural practices on key environmental indicators is, at best, poor. The benefits of these types of field scale rotational systems for the demonstration of practical farming methods and input/output relations is clear. However, if the aims of such experiments are to learn more about agroecological processes at this level, it may be necessary to be a little less ambitious with respect to the variables being investigated.

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References

Addiscott, T. M., Whitmore, A. P., Powlson, D. S. 1991. *Farming, Fertilisers and the Nitrate Problem*. CABI : Wallingford.

Bockstaller, C. & Girardin, P. 1996. *Use of Agro-Ecological Indicators for the Evaluation of Farming Systems*. European Society of Agronomy 4th Congress, 7 -11th July, Veldhoven, The Netherlands.

Cousins, S. H. 1985. Ecologists build pyramids again. *New Scientist*, 4th July 1985, 50-54.

Department of the Environment & Ministry of Agriculture, Fisheries and Food 1995. *Rural England. A Nation committed to a living countryside.* Cm3016 HMSO: London

Donaldson, J.V.G., Hutcheon, J.A. & Jordan, V.W.L. 1994. Evaluation of energy usage for machinery operations on the development of more environmentally benign farming systems. *Aspects of Applied Biology*, 40, 87-91.

Edwards, C. A. and Lofty, J. R. 1982. Nitrogenous fertilisers and earthworm populations in agricultural soils. *Soil Biology and Biochemistry* 14:515-521.

Edwards, C.A. 1984 Changes in agricultural practice and their impact on soil organisms. *American Journal of Alternative Agriculture*, 2, 148-152.

Fisher, N.M., Richards, M.C. and Drysdale, D. 1996. The contribution of spring crops to integrated crop rotations. *Aspects of Applied Biology*, 47, 343-349.

Holland, J. M., Frampton, G.K., Cilgi, T. and Wrattan, S. D. 1994. Arable acronyms analysed - a review of integrated arable farming systems research in Western Europe. *Aspects of Applied Biology* 125:399-438.

Holland, J.M., Drysdale, A., Hewitt, H.V. and Turley, D. 1996. The LINK IFS project : the effect of crop rotations and cropping systems on Carabidae. *Aspects of Applied Biology,* 47, 119-127.

Jordan, V.W.L. & Hutcheon, J.A. 1994 Economic viability of less intensive farming systems designed to meet current and future policy requirements : 5 year summary of the LIFE project. *Aspects of Applied Biology,* 40 , 61-68

Ogilvy, S. E., Turley, D. B., Cook, S. K., Fisher, N. M., Holland, J.M., Prew, R. and Spink, J. 1994. Integrated farming - putting together systems for farm use. *Aspects of Applied Biology* 40(1):53-61.

Organisation for Economic Co-operation and Development. 1997. Environmental indicators for agriculture. OECD, Paris.

Park, J. and Seaton, R. 1996. Integrative research and sustainable agriculture. *Agricultural Systems* 50:81-100.

Park, J., Bailey, A.P., Keatinge, J.D.H, Rehman, T., Harris, D. and Tranter, R.B. 1996. An analytical framework for appraising integrated arable farming systems. *Aspects of Applied Biology*, 47, 317-327.

Park, J., Farmer, D.P., Bailey, A.P., Keatinge, J.D.H., Rehman, T. and Tranter, R.B. 1997. Integrated Arable Farming Systems and their potential uptake in the UK. *Farm Management Journal* 9(10) 483-494.

Vereijken, P. 1996. *A methodological way of prototyping integrated and ecological arable farming systems in interaction with pilot farms.* Proceeding Abstracts 4th European Society of Agronomy Conference, 7-11th July 1996, Veldhoven, The Netherlands.