SESSION 10A

INTEGRATED FARMING SYSTEMS: ON FARM PILOT STUDIES IN EUROPE

Chairman & Session Organiser	S E Ogilvy *ADAS High Mowthorpe, Malton, UK*
Papers	10A-1 to 10A-3

Technology transfer of Integrated Farming Systems: a case study on transfer techniques, farmer responses and environmental consequences in Germany

A El Titi
Landesanstalt für Pflanzenschutz Stuttgart, D-70197 Stuttgart, Germany

ABSTRACT

Integrated Farming System (IFS) is identified as the most promising strategy able to meet the present challenges in European agriculture. Accordingly, major research emphasis is devoted to development and dissemination of IFS. In Germany, the Lautenbach project, 1977-1994, provided the evidence for feasibility of this approach under commercial conditions. Responding to Lautenbach, 15 arable enterprises (AKIL-farms), operating on ca 1200 ha of sloping or low lying land in the environmentally sensitive region of Bruchsal in the State of Baden Wuerttemberg, took up the initiative in 1988 to adopt IFS on their own farms, motivated by erosion control and reducing inputs. Different IFS prototypes were tested and improved on three pilot farms. In close co-operation with the State extension service, IFS technologies were transferred to farmers. The dissemination was based on two main schemes; the Bottom-up and Top-down approaches. On-farm demonstrations, interactive group extension, regular open-gate-offer, field-to-table approach and the evolvement into a regional marketing concept, highlight the bottom-up approach. In contrast, official regulations based on the "Bonus-Malus-principle", e.g. Water Vulnerable Zones, Nitrate and Pesticide Directives, Soil Protection law, Set-aside Option, Over-production Control and Landscape Management Option (MEKA Program) and the Preservation Directives for Landscape and Wild Species characterize the Top-down strategy. In addition, regular training offered for both extension officers and farmers, introduction of an AKIL-own label and a State logo for IFS products have strongly supported the dissemination. Nitrate leaching potential significantly declined in the last six years under the IFS fertilisation regime. Surveying the indigenous flora and fauna on AKIL farms revealed enhancement of endangered or extremely threatened wild species. The studies documented the considerable potential of regional farming communities to respond to environmentally safer, more sustainable approaches, so long as net farm incomes can be maintained profitably.

INTRODUCTION

Farming system research enjoys a wide appreciation in European agriculture (Vereijken, 1997). It is the logical response to shortfalls in the incoherent factorial studies by adoption of a complementary synthesis approach. This became evident when Integrated Pest Management (IPM) was introduced. The comprehensive approach in the Lautenbach Project (El Titi & Landes, 1990) was driven by IPM-implementation. However, even successful development of IFS under current farming conditions will not ensure successful dissemination of the system on its own. Commercial enterprises such as pilot farms for testing and improving IFS are required, therefore, as an essential link for IFS transfer. Since there is no recognized set of transfer methods and technologies for entire systems, efforts have been undertaken to evaluate different approaches to disseminate IFS technologies. The paper describes the methods used, evaluates their efficiencies and the environmental outcome of IFS implementation. It is a case study with a group of farmers which has run in the region of Bruchsal in Germany since 1988.

MATERIAL AND METHODS

Sites

The studies were conducted in the Kraichgau and Rhine valley regions. The Kraichgau is a hilly region with considerable elevation differences (326-98 NN). Parabrown, highly erodable soil reflects the prevailing soil type in the entire region. Through land reforms small field lots were consolidated into large field units, to fit the use of modern farm machinery. The annual precipitation average is 650 l/m^2, unequally distributed over the year, with heavy showers at few events. Erosion is a serious problem in the whole region, being aggravated by corn and other row crops. In contrast to Kraichgau, the region of the Rhine valley comprises the extended stream banks of the Rhine river. Sandy soils with fine gravel subsoils and a shallow water table are the main characteristics of the area. Land consolidation has resulted in destruction of hedgerows, scattered pome trees, with serious consequences for above and underground water flows. For both regions, there is a wide range of documentation on former native species of wild flora and fauna, soil mapping and forestry. The main crops grown are cereals, sugar beet, oil seed rape, corn, sunflower and forage peas.

The AKIL farmers

Motivated by erosion and farm income problems, 17 farmers with 1200 ha of arable land founded the AKIL farmer club in 1988. Their main intention was to adjust the IFS Prototype of Lautenbach to their specific farm conditions. Continuous testing and improving of the new prototypes was done between 1990 and 1996. The AKIL group established its own IFS Guidelines matching the IOBC/WPRS principles (EL Titi *et al.*, 1993). The AKIL guidelines were elaborated with the active contribution of the AKIL farmers. Measures were considered as adopted as long as they fitted the minimum guideline requirements. These included a positive or at least neutral impact on net farm income, adoption of a multifunctional crop rotation, a high soil cover index, moderate soil reserves of nutrients and occurance of endangered wild plant species on farmland. These parameters were applied to 15 AKIL and 30 non-AKIL farmers in the region to verify the adoption levels.

RESULTS

The technology transfer methods comprised two different approaches. These included:

Bottom-up approach

This is a voluntary approach, in which farmers are free to make up their own mind to adopt or to reject the IFS methods introduced to the pilot farms. The essential information is provided in written or oral form via the IFS consultant. Feasibility and profitability of the methods are the determining criteria. The guiding philosophy is that when convinced, farmers can convince others, leading to diffusion of methods and techniques. The following techniques were found to be effective:

On-farm demonstrations

The three pilot farms reflected the average farm in the region in size and structure. Visible or measurable IFS effects were displayed, e.g. effects of crop rotation on weeds and diseases, reduced soil tillage and soil cover on earthworms and erosion, IPM on farm net income were repeatedly demonstrated in the main crops. .Conventional references on 1-2 ha plots were found to be very helpful in demonstrating some specific effects e.g. minimum soil cultivation on erosion.

Group-Extension-Approach

Exchange of experiences among the AKIL farmers provided a most effective tool to build confidence and improve knowledge in IFS methods. Scope and quality of the information was supported by occasional intervention by experts. The interactive experience transfer is considered as insider information and was highly appreciated by the farmers. Six to eight meetings were organised annually, mostly during critical decision-making periods for the main crops. These meetings were extended to include non-AKIL farmers, who showed particular interest in some IFS aspects.

Open-gate offer

Both farming and urban communities were invited annually to visit the pilot farms, where e.g. new farm machinery, species diversity on the ecological infrastructure were displayed. Flowering field margins supported by photos, drawn or figured results, were integrated in natural boundaries with native wild species as a “show-pathway”. The Open-gate offer had a highly positive response.

Involvement of the regional market

The AKIL club took a collective initiative and offered wheat of guaranteed bread-making quality to regional mills. Contracts were made to regulate crude protein contents, varieties, quantities and price ranges. To respond to the identified regional market niche, the contracted mills extended the idea to customer bakeries. A regionally produced and processed wheat flour received a remarkable commercial interest in the region. A number of bakeries joined the AKIL club as full members. The positive response of the regional market has given AKIL pilot farmers more confidence and identification with their region. Furthermore, their efforts were honoured by an additional sale premium on their produce. The regional marketing concept has been most effective in motivating the pilot farmers, but also in inducing competition amongst other cereal producers in the surrounding areas. The latter responded by creating their own integrated farming clubs and establishing their own logos for their products. Some of them also sought unification with the AKIL club.

Field-to-table approach

The AKIL-farmers recognised the essential need to regain consumers' confidence concerning food, landscape and environmental safety. An AKIL logo was displayed on AKIL fields, farm buildings, grain and potato stocks, as well as on all food products from IFS fields. The logo has greatly helped to distinguish the AKIL pilot farms from all others. For the first time, local consumers attained the opportunity to supervise the production chain from field to table, to inspect where and how his (her) food is produced. The approach has stimulated competitiveness but has also enabled abuse of logos, due to the lack of legally binding IFS regulations.

Top-down-approach

The main feature of this approach is the application of legally valid regulations guiding farmers to meet pre-defined measures. A remarkable number of such legal regulations were available for use at the regional, national and EU levels and not just exclusively for the AKIL group. Some of these regulations, in particular those of the State of Baden-Wuerttemberg and EU-Commission, had a highly significant impact on the dissemination of IFS in the reported studies.

Water Conservation Zones/Nitrate and Pesticides Directives

The State Government of Baden-Wuerttemberg has put a regulation package into law in 1988 aiming at minimising groundwater contamination by agrochemicals (nitrate and pesticides). The Directives, known locally as SCHALVO (Anon., 1987), target restricting agrochemical inputs and organic manures at predefiined crucial periods to exclude leachable pesticides and excessive nitrate residues in Water Conservation Zones. Water Conservation Zones were legally determined according to the established hydrogeological maps for the whole state territory. In Water Conservation Zone I, all agricultural activities are forbidden, whereas those in Zones II and III are only restricted. The Water Conservation Zones are treated according to a Bonus-Malus Principle. State payments (up to 320 DEM/ha/year) compensate farmers for enforced restriction of inputs (mainly agrochemicals and manure) but, at the same time farmers are penalised, when they fail to meet the demands. Fields within SCHALVO areas are officially controlled by annual sampling of field soils and farm records inspection.

Since the AKIL IFS Guidelines meet the requirements for a minimal nitrate leaching risk, which is expressed in SCHALVO, as residues of less than 45 kg N/ha, in the 0-90 cm soil profile between 15 October and 15 November, there was neither a conflict nor a profit to draw from these Directives for the AKIL farmers. However, the Directives were found to be a valuable tool to motivate non-AKIL farmers. This was also true for leachable pesticides. All leachable compounds are excluded from the AKIL farming guidelines, and accordingly they meet the requirements of the legal regulations in the Water Conservation Zones.

Soil Protection Directive

This is a far reaching legal regulation applicable to different types of land uses, including agricultural use. It aims at sustaining soil fertility and productivity on farmland. It has an obligatory character in terms of farming methods. Husbandry techniques should not conflict with the objectives of this Directive for defined scenarios. On sloping fields for example, runoff and erosion must be maintained at the feasible minimum, to minimise contamination of water sources by agrochemicals. Minimal soil cultivation, multi-crop rotation, green manures, integrated nutrient management, are indispensable to meet the requirements of this Directive. Consequently, the directives encouraged farmers to adopt IFS.

Set-aside-Option

Set-aside as a EU-regulation provides an incentive to diversify crop rotations. Set-aside guarantees a prefixed revenue and is thus considered as a safe and valuable element of a multi-crop rotation. In binding soluble nutrients, set-aside is likely to provide additional profits in particular concerning nutrient losses from the system. In the region under consideration, AKIL and non-AKIL farmers responded strongly to this legal option supporting the diversification of the grown crop species. This is known to be one of the main obstacles on the way to convert the whole farm to IFS.

Overproduction and Landscape Management Option (MEKA Program)

The MEKA Program is a unique option offered to farmers by the State Government to encourage environmentally safer farming, to control overproduction and to maintain rural landscapes (Anon., 1992). The Program defines specific measures which a farmer may choose independently. The measures are described in an official leaflet indicating the required ranges and the related payment (point catalogue). Farmers can make a choice between different measures accumulating points up to a maximum value of 520 DEM/ha/year. There is a particular emphasis in this Program on minimal soil cultivation, integrated crop protection (only non-chemical methods), integrated nutrient management and ecological infrastructure. The MEKA Program has effectively supported dissemination of IFS not only in the region of Bruchsal but also over the whole state.

Landscape/Nature/Species Preservation

This is an additional option offered by the state government aimed at preserving wild plant species, maintaining specific habitats and establishing ecological corridors. A wide range of possibilities are included in this regulation and farmers can make a voluntary choice on a contract basis. The allocation of 0.04-0.10 of farmland for ecological infrastructure in IFS appeared to be a high threshold for IFS adoption on rented farmland. Both AKIL and non-AKIL farmers showed reservation against the introduction of hedgerows or corridors of wild plants on their farms.

Supporting complementary measures

Independent of the dissemination strategy followed, the following complementary measures were found to be the most supporting:

Training officers of the extension service

While facing day-to-day problems AKIL farmers have repeatedly underlined their urgent needs for strategic and technical advice on IFS. This type of interdisciplinary support differed fundamentally from that consultants were used to. Therefore, adhoc training courses in IFS were offered on both a regional and a State scale. Annual training courses in field scenarios using AKIL pilot farms as training grounds has accelerated the provision of knowledge. This offer proved to be extremely successful due to first multiplicator function. The employment of an IFS consultant for the AKIL group was found to be most successful and highly appreciated by farmers. The need for such IFS advisory experts must be emphasised, should the concept be disseminated to other EU regions.

Training of farmers

Even motivated farmers can hardly cope with all day-to-day decision-making in the first conversion years. Educating farmers on how to deal with IFS methods still needs improvements. In the region of Bruchsal, integrated crop protection and in particular decision-making on disease control, were found to cause major problems to farmers. The interactive exchange of experiences between farmers was so effective that IFS experienced farmers could offer such advisory services using their own fields as training grounds. This has enhanced farmers' confidence in IFS and motivated some non-AKIL farmers.

AKIL label

It can hardly be expected that IFS can achieve sufficient product quality to justify a trade label, unless the term "quality" is applied to environmentally safer and ecosystem-based farming. Therefore, AKIL farms used the production method as a quality criterium for their products. An AKIL label was contrived, giving farmers' greater confidence. The label also helped to improve of the image of farmers in the community. The award of an "Environment Prize" to the AKIL group in 1991 from the municipality of Bruchsal and the 1st Prize for Soil Protection from the Karlsruhe County Board in 1993 were more than symbolic acknowledgements. The AKIL farmers enjoyed guaranteed product sales to millers with a slight premium for wheat and rye. This presumably contributed to the expansion of the AKIL group to include more than 50 farms with more than 5000 ha in 1996.

State label

Alongside the AKIL label, the State Government has also established a label to certify both product origin and product quality, emphasising farming methods such as nutrient management, and ecological infrastructure. Farmers have to fulfil minimum farming requirements and accept on-farm inspections. Farms licensed to use this label get improved access to markets, with the possibility of better profits. However, no payments or other obligations are associated with it. When the participation conditions are really met, the conversion to IFS will be much easier. So, the State label has also supported the dissemination of IFS.

Effectiveness of IFS

Nitrate Leaching

Due to the adoption of IFS or at least the first nutrient management scheme, a decline of nitrate residues in the soil profile can be expected. To verify whether this would really reduce the nitrate pollution risk down to the legally required level of 45 kg N at 0-90 cm in the autumn, soils were sampled from a large number of fields with different crops, locations and treatments (17000-20000 samples/year between 1991 and 1996) (Anon., 1996). All sampled fields were located within the Water Conservation Zones. Farming and fertilisation patterns of the sampled fields corresponded with the AKIL IFS Farming Guidelines. The results obtained are summarised in (Figure 1).

The results clearly show a gradual decline in the nitrate contents over the sampling years, from 75 kg N/ha in 1991 to 29 kg N/ha in 1996. This means a reduction of more than 50% of the initial average contents in the soil profile. Since the sampling period is the most critical period for leaching, the available nitrate reserves in soil profile match the required official standards of 45 kg N/ha.

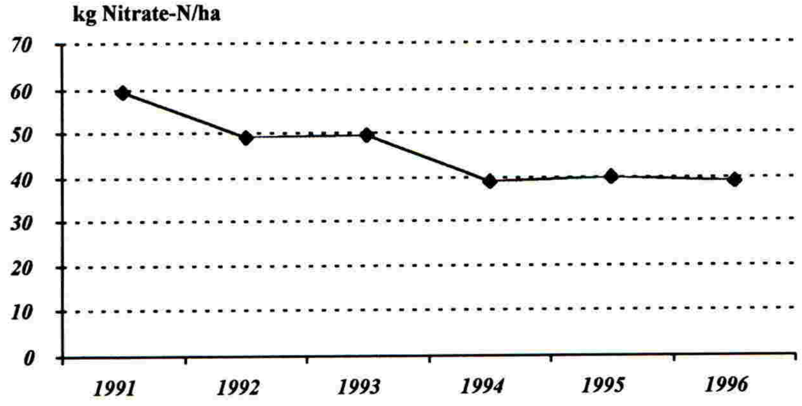

Figure 1. Mean NO_3-contents in soil profile (0-90 cm) in Water Conservation Zones (NAR) between 1991 and 1996 in Baden-Wuerttemberg.

Species diversity/ endangered plant species

Re-introduction or re-establishment of populations of endangered species cannot achieved, if the essential habitats are lacking. IFS contributes to the establishment of such environments. Therefore, effects of IFS on species diversity should be attributed to occurrence (or absence) of endangered or expired species and not necessarily to the number of the cosmopolitan species. For the region under study, there is sufficient documentation on botanical diversity and endangered species (the official Red List of Baden-Wuerttemberg) (Harms *et al.*, 1990) that can be used as references. A species survey of non-crop flora on both farmed and border land was conducted during the project period on seven of the 15 Pilot farms of the AKIL group documented a considerable re-occurrence of endangered species on IFS farmed land. The recorded species were classified according to their endangerment categories (Table 1). Depending on the specific habitat requirements of the species, IFS shows a remarkable potential to restore different native, but endangered or expired plant species. This finding underlines again the potential of the farming system to sustain agroecosystems.

Table 1. Wild plant species recorded in seven AKIL farms classified according to the different endangerment categories based on the official "Red List" of Baden-Wuerttemberg for endangered species.

Category	AKIL Farms							
	P1	P2	P3	P4	P5	P6	P7	Mean
a) Endangered spp (A3) agric. type	1	3	0	2	1	1	1	1.14
b) Spp to protect (A5) agric. type	3	3	4	3	0	3	4	2.86
c) Endangered other spp (A3)	1	0	2	1	0	1	0	0.57
d) Other spp to protect (A5)	0	0	0	1	1	0	1	0.35
Total species no/farm	5	6	6	7	2	5	6	5.29

DISCUSSION

Farming system research is seen as a logical development step to respond to the shortcomings of factorial research approaches. Even progressive farmers could hardly cope with the various and often contradictory demands of factorial results of the different agricultural disciplines. The classical way to adopt new technologies was either to adjust the technique or to modify the recommendation to fit their own farming conditions. This was the case for the application of pesticides and adopting new fertilizer strategies. However, the environmental, ecological and economic challenges require more comprehensive answers than factorial studies can provide. Multi-goal approaches characterise the type of research needed today. Hence, farming system research is increasingly covering the gap that has existed. It is a complementary approach to the existing factorial studies and not a competitive approach which can replace them.

The final step of the methodical way to IFS (Vereijken, 1997) implies dissemination of IFS. Traditional dissemination schemes are extremely inadequate for system transfer, unless a comprehensive interdisciplinary approach effectively replaces the narrow, isolated mono-disciplinary extension track. The classical specialisation of extension experts was found to impair or even to hinder the integration on the field, due to divergences in the recommendations. Under such conditions, farmers found that they themselves had to play the role of the different experts. The training background for the essential integrated advisor is still lacking. In our studies, the very first efforts have been undertaken to train the consultants in the new, integrated field. The main objective was to train the consultants in how to integrate the single IFS technologies with the commercial interests of the farm as a whole. Particular emphasis was devoted to methods on how to deal with the client, the IFS farmer, how to stimulate his interests for further IFS related progress. This would simply mean to re-define the role of consultants, should farmers be confident with IFS. Besides the scientific research input, extension services need innovation in extension concepts. The close co-operation between research teams working on development and the extensionists, while testing and improving IFS-prototypes, was appreciated by both involved groups. In our case, this helped to transfer the message to farmers. Extensionists are a supporting element. However, the objectives will not be met, if the potential farmers are not interested. Consequently, the perception of farmers for the specific farm problems on one hand and for the impacts of farming on the environment, agricultural resources and sustainability on the other hand, plays an important role in the dissemination task.

Regarding the dissemination concepts (Bottom-up/Top-down approaches) the more liberal and farmer-friendly approach is no doubt the Bottom-up approach. The responsible farmer has to keep in mind both own and society`s interests. This responsibility, however, will lose its effectiveness, if farm-income cannot be maintained at a satisfactory level. Although, the philosophy may be promising, it has its limitations, if farmers expectation on the income side are not met. If the profitability of the system is secured, farmers can be motivated to different types of IFS activities. The methods used were found to be effective and farmers responded positively to them. However, there are several IFS desired measures, that are costly with low or invisible productivity. Establishment of ecological infrastructure on farmland, for instance, involves expenditure with no direct monetary return. Water protection through environmentally safer farming technologies is likely to have long lasting consequences for the whole society, e.g. in respect to drinking water quality, unrenewable resources, atmospheric contamination. Limits cannot be exceeded, and consequently prevention and precautionary measures are enforced by the responsible authorities. The Top-down approach in its smooth form, as described in this paper, is a fair offer, farmers can react to it. Society pays those farmers forced to endure restrictions to their businesses.

Both dissemination (Bottom-up and Top-down) approaches are essential and act as complementary partners. Both of them would have been completely ineffective, if the knowledge of how to use IFS techniques was not available to farmers. Farmers as well as trainers are therefore indispensable for the realisation of IFS in different regions and localities. Farmers reactions to IFS will always be dependent on their personal motivations. The perception of a problem e.g. erosion can motivate farmers to seek solutions by themselves (bottom-up approach). Testing and improving of prototypes may provide an effective tool to stimulate farmers to perceive existing problems. Once they are involved, responses can be expected. In the case of the AKIL group in Germany, farmers even initiated a regional market for their own products and supported the dissemination directly and indirectly. However, farmers own efforts can be severely restricted by some of the essential demands of IFS. Multi-crop rotation is identified in our studies to be very important to achieve various IFS objectives. This is the case, especially when a new crop(s) requires additional financial investment. This possibility would be easier, if the European agro-policy would support such crop diversification. Set-aside was obviously successful, because of the payments associated with it. The fraction of leachable nitrate dropped back because of the Directives for ground water protection. The integration of agro-policy and farmers motivation is likely to be the driving power for an effective dissemination. Granting IFS a legal status would also support the dissemination by making the farming system worthwhile to adopt.

ACKNOWLEDGEMENTS

The author is indebted to the director of the agricultural office of Bruchsal, Prof Dr P Denzinger, to Prof Dr F Timmermann /LUFA-Augustenberg, Prof Dr Hoffmann /University of Hohenheim and the AKIL group /Bruchsal for their continuous support. The studies were partially funded by grants from the EU-Commission (C(92)-2433) and the Ministry for Landscape, Fishery and Agriculture, Baden-Wuerttemberg.

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Evaluation and testing of Integrated Arable Farming Systems on innovative pilot farms in the Netherlands

F G Wijnands, P van Asperen
Applied research for arable crops and field grown vegetables, P.O. Box 430, NL 8200 AK, Lelystad, the Netherlands

S R M Janssens
Institute of Agricultural Economy, P.O. Box 29703, NL 2502 LS, Den Haag, the Netherlands

ABSTRACT

In the Netherlands prototypes of Integrated Arable Farming Systems (IAFS) were developed on three regional experimental farms. To evaluate the perspectives of IAFS in practice, a co-operative research project between the agricultural extension service and several research institutes started in 1990. From 1990 till 1993, 38 pilot farms gradually converted to IAFS. The results showed that pesticide inputs can be substituted to the greater part by integrated crop protection and that integrated nutrient management reduces the N/P mineral fertiliser input, maintains the soil fertility and reduces the N surplus on the balance sheets. Economically, the pilot farms showed comparable or better results than the conventional reference farms.

INTRODUCTION

In the Netherlands, prototypes of integrated arable farming systems (IAFS) are being developed regionally at three experimental farms with region-specific crop rotations and cropping systems. The farms are located at Nagele (since 1979) in the Central clay area, at Borgerswold (1986-1995) in the North-eastern sand area and at Vredepeel (since 1989) in the South-eastern sand area, representing the major soil types in arable farming. (Wijnands & Vereijken, 1992).

IAFS aims at serving both ecological and economic objectives by substituting potentially noxious agrochemical inputs by both agricultural and ecological knowledge, labour and non-chemical husbandry techniques (Vereijken, 1992). The available IAFS prototypes consist of a coherent set of farming methods such as crop rotation, fertilisation (Vereijken, 1990), crop protection (Vereijken, 1989a; Post & Wijnands, 1993) and cropping strategies (Vereijken & van Loon, 1991; Vereijken, 1989b).

The methodology of designing, testing, improving and disseminating Integrated and Ecological Farming Systems for arable farming is elaborated in a four year European Union Concerted Action (Vereijken, 1994, 1995, 1996 and 1998). This methodology is called prototyping and can be characterised as a synthetic research/development effort starting off with a profile of demands (objectives) in agronomic, environmental and economic terms for a more sustainable farming and ending with tested, ready for use prototypes to be disseminated on a large scale.

Stimulated by initial results of IAFS (Vereijken, 1989b) the government in the Netherlands has adopted a policy of restructuring and sanitation of the national agriculture (Anon., 1990). In arable farming and outdoor horticulture, the pesticide inputs must be strongly reduced (50% in 2000 compared to 1985-1988) and mobile and persistent pesticides are to be removed from the list of registered pesticides (Anon., 1991). The volatilisation of ammonia must be strongly reduced (70% in 2000 compared to 1985) as well as N- and P-emissions into the North Sea (70% in 2000 compared to 1985). Besides, quality criteria for N and P in surface-(2.2 mg N/l and 0.15 mg P/l) and groundwater (11.2 mg $N\text{-}NO_3^-$/l) have been set. The use of organic manure is restricted in dosage (P-norm), timing and application techniques. Legislation including levies on surpluses on nutrient balance sheets is being implemented to restrict nitrate leaching to the groundwater and P-accumulation in the soil.

Consequently, the agricultural industry in the Netherlands has to adopt the quality of the environment as a major objective and has to integrate it with the conventional objectives of income and employment. The government considers such integrated farming systems as the best way to achieve a competitive, sustainable and safe agriculture. By 2000, 100 % of farmers should practise integrated farming (Anon., 1990).

However large scale introduction of IAFS can only be successful if region-specific knowledge on IAFS is available and the total farming community (farmer, advisors, teachers, industry, etc.) is sufficiently motivated for and, preferably by practical experience, familiar with (elements of) IAFS. Testing of the experimental prototypes with a pilot group of farmers is an indispensable first step to reveal the potential of IAFS in practice and to acquire the necessary knowledge to develop region-specific, safe and generally applicable variants of IAFS (Vereijken, 1992). Subsequently a co-operative project (1990-1993) between the agricultural extension service and several research institutes has been set up to introduce integrated farming into practice on an experimental basis (Wijnands, 1992). This paper will describe the results.

METHODOLOGY

Project set-up

In order to obtain sufficient diversity of soil, farm and management conditions, five pilot groups of about eight farms were formed in the major arable production areas of the Netherlands. These pilot farms gradually converted to IAFS supported by extension specialists. The farmers committed themselves by a contract to a fundamental and planned conversion (see agronomic demands in Table 1). The research program focused on evaluation of the performance of the system and the progress that was made at economic, technical end ecological levels. The starting position of every selected farm was elaborated for a three year period (1987-1989) preceding the project. As an actual reference, data were used from the national economic survey of arable farms. A detailed inquiry at the end of the project provided insight into the farmer's experiences. More details about the project, set up and management can be found in Wijnands (1992).

Characteristic of arable production regions

Farms in the Netherlands are in general small (30-60 ha). This urges farmers to grow financially valuable crops in short rotations needing high inputs. Most rotations consist of only three or four years. Cereals are financially less attractive but are needed as break crops (maximum of 25% in the rotation). Arable production is mainly concentrated on the South-western, Central and Northern clay areas, which are generally well drained and very fertile. Potatoes are the most profitable crop (25% of cropping plan), followed by sugar beet (20%) and vegetables such as onion, carrots and cabbage (25%). Consequently, beet and potato cyst nematodes can cause problems, forcing farmers to use regular soil fumigation as a curative or preventive measure. In the Central clay area, ware potato and in the Northern clay area, seed potato are the most important crops. In the South-western area, rotations are somewhat diversified by crops such as flax, poppies and pulses.

The South-eastern sand area is characterised by a high degree of mixed plant and animal production. Many farms developed an animal "factory farming" unit, based on high inputs of feed stuffs and maize monoculture. Most of the predominantly arable farms are very small and combine potato (25%) and sugar beet (20%) with vegetables (25%) for the canning industry. The region has a high surplus of organic manure, the most commonly used fertiliser-type. The farms in the North-eastern region have sandy or reclaimed peat soils where organic matter contents vary between 3 and 20% and weed pressure is very high. The area strongly depends on the growing and processing of starch potato with an average cropping plan with 50% potatoes, 25% sugarbeet and 25% cereals and other crops. The gross margin of sugarbeet is the highest, followed by starch potato. All other crops are far less profitable. The intensive potato growing is accompanied by intensive use of soil fumigants to control the potato cyst nematode problem. Wind erosion and nightfrost risks in spring are specific technical problems in this region.

RESULTS

General

When necessary, the farm-specific crop rotations were adapted to support the crop protection and nutrient management. Crop protection and fertilisation strategies and results will be discussed below. Results per region and on a national scale are arithmetic averages over the participating farms.

Weed control

The integrated weed control strategy aims at substituting or limiting herbicide use by mechanical weed control (hoeing and harrowing), the use of band spraying and the adoption of a low dose approach with contact herbicides. The latter enables a more field and year specific approach. New mechanical techniques were only gradually adopted. Especially, the (re)introduction of mechanical weed control in potatoes and cereals proved to be more difficult than anticipated, respectively due to the low costs of herbicides in potatoes and the low gross margin of the cereals. Dependent on soil type, weed pressure and crop, the possibilities to reduce the herbicide use differ. Potatoes and maize can technically be kept

Table 1. Agronomic demands for IAFS pilot farms.

Crop rotation	- multi-functional to support crop protection and nutrient management
Nutrient management	- P/K input in balance with farm P/K output, as related to soil fertility status - P/K input based on organic manure, supplemented by mineral fertilisers - organic manure use aimed at maximum crop uptake and minimum emission - optimum use of green manures to prevent N leaching losses - moderate N fertilisation to support crop resistance against diseases, pests and lodging, to produce high quality products and to reduce N losses after harvest. - N fertilisation level adjusted for N from organic sources (manure, crop residues)
Crop protection	- maximum prevention based on broad-resistant/tolerant cultivars supported by seed treatments - use of monitoring and guidance systems for pest, disease and weed control - mechanical weed control, supplemented by band spraying - full-width chemical control of pests and diseases only as last resort, based on economic criteria - progressive exclusion of persistent and mobile pesticides, starting from an up-dated 'black list' for water-collecting areas

weedfree without herbicides. In cereals and pulses, harrowing reduced herbicide use strongly. The input in row crops was limited by band spraying and hoeing. On average, the herbicide input per farm dropped from 3.1 kg a.i./ha in the project and farm specific reference period 1987-1989 to 1.2 kg a.i./ha over the last two project years 1992-1993 (Table 2). A reduction of more than 60%. The reduction varied over the regions: from 30% in the North-eastern sand to 70% in the Central clay area. On the North-eastern sand and reclaimed peat soils, erosion and nightfrost risks limited the application of mechanical control. The reduced input reduced direct herbicide costs by some 100 NLG/ha.

Disease and pest control

The fungicide input on the farms in the Netherlands mainly concerns the prevention and control of potato blight (*Phytophthora infestans*). The integrated approach aimed at substitution of the commonly cropped cultivar Bintje (highly susceptible for potato blight) by more resistant varieties, a moderate N fertilisation level and a low dose fungicide approach in accordance with the level of resistance of the cropped cultivar. This consistent strategy was only gradually adopted in practice. It took some time to find good alternatives for Bintje within the existing market channels and obligations. In the last two project years, a new fungicide with a much lower active ingredient content became available: fluazinam. The pilot farms gradually substituted the dithiocarbamates and fentin acetate by fluazinam. In ware potatoes, the average use was reduced from 17.3 kg a.i./ha over 1987-1989 to 3.7 in 1993. For seed and industry potatoes, the figures are respectively 7.0 to3.9 and 10.6 to 9.8. In the Northeast (predominantly industry potato), farmers were reluctant to change to fluazinam because of the somewhat higher price and the low gross margin of industry potatoes.
Introduction of integrated crop protection in all other crops also resulted in strong reductions in fungicide use. At the farm level, the input reduced from 4.7 kg a.i./ha over 1987-1989 to 2.0 in 1992-1993 (Table 2). A reduction of about 60%. The reduction varied over the regions: from some 25% on the North-eastern sand to 70% in the South-eastern sand area. Insecticides played a minor role on the farms. The input was reduced based on a better justification of use

and when possible a low dose approach. At the farm level the input reduced from 0.3 kg a.i./ha over 1987-1989 to 0.1 in 1992-1993 (Table 2).

For soil born pests and pathogens a non-chemical control strategy was implemented aiming at minimum nematicide use. Intensive sampling methods were introduced followed by bio-assays to assess the most appropriate cultivar. The cultivar choice was adapted when necessary. Additional to that the crop rotation in the North-eastern sand region was widened to at least 1:3. Potato volunteer control was also improved. By the end of the project nematicides were generally only used on the North-eastern sand region. The need for nematicide use was strongly decreasing. Continued monitoring of nematicide input after the project period confirmed this. The average farm input (nationally) of nematicides was reduced from 14.4 kg a.i./ha over 1987-1989 to3.6 in 1992-1993 (Table 2). A reduction of about 75%. For Northeast Netherlands these figures are 48.8 and 18.8 kg a.i./ha. The reduction in direct costs for pesticide use for disease - and pest control amounted to 55 NLG/ha.

Nutrient management

The integrated nutrient management strategy was carefully planned over crops, fields and years Restoring the balance of in- and output of P and K over the crop rotation at a agronomic desired and environmental acceptable (risks of accumulation and leaching losses) level of soil fertility, was the first priority (Vereijken, 1990). Emphasis was put on the agronomic (N recovery) and environmental (N leaching and volatilisation) optimal use of organic manure. The N fertilisation aims at an optimal balance between quantity and quality, minimum losses and maximum utilisation. The N input is based on N mineral supply in soil in spring and crop and field specific aids like N windows, monitoring soil mineral N status and the N content of plant tissue, like the N content in petiole of potatoes. Minimum losses of N at farm level involves optimal green manure use and restricted N fertilisation in autumn and winter. The N fertilisation was gradually decreased to offer farmers the possibility of gaining confidence in the followed approach.

The P surpluses over 1987-1989 were unnecessarily high related to the soil fertility status of the soils. The adoption of integrated nutrient management led to a drastic reduction of the P overuse. The average surpluses on the nutrient balance on farm level for P_2O_5 and K_2O were respectively reduced by 55 and 10 kg/ha from 1987-1989 to 1992-1993 (Table 3). The largest reduction in P use occured in the two sandy regions where organic manure use often passed the stage of agronomical sound practices. Over the years, the use of K stayed more or less the same, again with exception of the two sandy regions. Mineral fertilisers were substantially replaced by organic manures (80% of P input as organic manure). The P use as mineral fertiliser amounts in all regions to only about 12 kg P_2O_5. Generally this substitution results in an increased input of N, however as a result of the moderate N fertilisation per crop the total N input decreases on average by 50 kg/ha, varying from 15 to 125 kg N/ha. The calculation of the N surplus comprises on the input side: wet and dry deposition, N fixation and N input in fertilisers, seeds and tubers and on the output side the export of crops or crop residues. The N surplus on the nutrient balance sheet decreased on farm level on average by some 45 kg/ha to 115 kg/ha.

At the farm level, the average residual soil mineral N (0-100 cm) after harvest of the crops exceeded 70 kg/ha (provisional NL norm to prevent unacceptable leaching losses) on

Table 2. Pesticide use (kg a.i./ha).

	Southeast sand			Northeast sand			Northern clay			Central clay			Southwest clay			Netherlands		
	87/89	90/91	92/93	87/89	90/91	92/93	87/89	90/91	92/93	87/89	90/91	92/93	87/89	90/91	92/93	87/89	90/91	92/93
herbicides	2,3	1,0	0,9	2,2	1,7	1,6	3,2	2,3	1,2	3,9	1,6	1,1	3,8	2,7	1,7	3,1	1,8	1,2
fungicides	5,3	3,4	1,6	4,1	4,1	3,2	4,3	3,2	1,7	5,5	4,7	2,0	4,2	3,5	1,9	4,7	3,9	2,0
insecticides	0,3	0,1	0,1	0,1	0,1	0,1	0,3	0,2	0,1	0,4	0,2	0,1	0,3	0,2	0,2	0,3	0,1	0,1
growth regulators	0,1	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,2	0,1	0,3	0,1	0,1	0,1	0,1	0,1	0,1
subtotal[1)]	8,0	4,5	2,5	6,4	5,9	4,8	7,9	5,7	3,0	9,9	6,6	3,3	8,5	6,5	3,8	8,3	5,9	3,4
nematicides	12,6	3,4	0,0	48,8	37,2	18,8	0,5	2,0	0,4	8,8	0,4	0,1	4,7	0,6	0,0	14,4	7,8	3,6
total	20,6	7,9	2,5	55,2	43,1	23,6	8,4	7,7	3,4	18,7	7,0	3,4	13,3	7,1	3,8	22,7	13,6	7,0

1) subtotal = sum of pesticide types above + pesticides againt slugs, rabbits and birds.

Table 3. Fertilisation: fertilisers input (kg/ha), share of organic manure in total input (%), export in produce (kg/ha), surplus on complete nutrient balance sheets (kg/ha) and recovery from total fertiliser input in product export (%).

	Southeast sand			Northeast sand			Northern clay			Central clay			Southwest clay			Netherlands		
	87/89	90/91	92/93	87/89	90/91	92/93	87/89	90/91	92/93	87/89	90/91	92/93	87/89	90/91	92/93	87/89	90/91	92/93
N-input	315	205	190	210	190	155	220	185	205	195	165	175	230	215	215	235	190	185
% organic manure	65	70	70	40	55	50	30	40	40	35	40	45	25	40	45	40	50	50
N-export	135	125	130	115	95	95	120	120	110	140	135	150	130	125	125	135	120	125
N-surplus	250	155	130	155	150	100	155	110	135	70	70	70	155	140	135	160	125	115
N-recovery	40	45	50	45	40	50	45	55	45	60	70	70	45	45	50	50	50	55
P_2O_5-input	180	100	70	125	85	60	115	95	85	125	80	75	105	75	75	130	85	75
% organic manure	80	90	90	55	85	85	50	75	80	50	75	75	45	80	80	55	80	80
P_2O_5-export	55	50	55	45	35	40	50	55	50	60	60	65	55	55	55	55	50	55
P_2O_5.surplus	130	50	20	85	55	25	65	45	35	65	20	15	50	25	25	80	40	25
P_2O_5-recovery	35	55	80	35	40	65	50	60	65	55	90	215	60	70	75	45	65	75
K_2O-input	290	180	170	185	170	155	150	145	170	100	115	120	145	150	145	175	150	150
% organic manure	75	85	85	40	60	55	30	35	50	60	60	60	45	65	70	50	60	65
K_2O-export	160	155	155	135	110	120	110	120	115	160	160	160	120	115	120	145	135	135
K_2O-surplus	140	35	20	60	65	40	45	35	65	-50	-35	-30	30	40	35	35	25	25
K_2O-recovery	60	85	90	70	65	80	75	85	75	175	155	255	100	80	80	100	100	125

respectively 77, 74, 87 and 18 (wet autumn) % of the participating farms for the project years 1990, 1991, 1992 and 1993 (Schröder, 1996). After harvest a number of cultural practices are still possible, ranging from manure application to green manure cropping. So the given data are only an indication that the potential N losses are still too high and deserve continued attention. The direct costs of fertiliser use were reduced by 80 to 185 NLG/ha, depending on the region.

Feasibility/farmers experience

The conversion process from conventional to integrated involves not only the farm (cropping technique) but also the farmer. Motivation, expertise and craftsmanship are indispensable for IAFS since it requires (1) careful planning of activities on farm, field and crop level; (2) flexible field- and year-specific management of inputs and interventions; (3) sufficient expertise concerning the monitoring and control of weeds, pests and diseases and the use of the necessary machinery and equipment. It is striking that farmers themselves specifically identified these areas as those in which they learnt most by participating in the project (Van Weperen *et al.*, 1998).

The IAFS approach was experienced as a more crop-oriented way of farming that was clearly more challenging for the professional skills of the farmer. Most of the participants felt the change to IAFS as a rewarding step forward, they became more "boss on their own farm" again and their work satisfaction increased. Participation increased their awareness of the agriculture-environment interaction and problems and made them realise that their former way of farming was not sustainable. This increased their motivation for integrated farming although the relatively low support from colleague farmers was demotivating (Van Weperen *et al.*, 1998). The comments of the farmers indicate that the shift to IAFS is a gradual learning process. The expertise needed for adopting IAFS techniques under a range of varying farm, soil and weather conditions, was at the beginning not always available. The required management skills could only be learned by practical experience. The project gave the farmers the opportunity to experiment with new practices under the guidance of the extension worker. While testing and implementing IAFS on their farm their expertise and craftsmanship increased. By increasing their knowledge and practical experience, farmers gained confidence in the IAFS approach, which reduced the initial risk inherent in the adoption of new technology and new cropping strategies. All farmers signalled an increased labour demand for the total farm management and operations. Apart from the amount of time required for learning, some of this extra time may be structural, especially with respect to planning and management tasks and field operations. Probably more sustainable farming requires a greater commitment and expertise on the part of the farmers.

Economic results

Comparison of the economic bookkeeping (LEI-DLO) of the pilot farms with a group of reference farms (network farm economic bookkeeping farms) shows that the profitability of the pilot farms was in general better than on the reference farms (Janssens *et al.*, in press). The position of the pilot farms compared to the reference farms was already better at the start of the project. There is no evidence that their relative position deteriorated during the project. The physical yields of most marketable crops were better on the pilot farms than on the reference farms with exception of winter wheat. In relevant crops, quality characteristics were

Table 4. Economic analysis of results pilot farms compared to a reference group (NLG/ha).

	Pilot farms (a)	Reference farms (b)	Analysis (a-b)
Financial Yield marketable crops	6060	5670	+400
Allocated costs:			
basic material	705	605	+100
fertilisers	200	270	-70
pesticides	385	525	-140
other crop related costs	135	100	+35
total			+75
Other costs:			
contractors work	650	620	minimal
machinery (nursery)	95	85	+20
labour	1885	1895	+55
Net farm profit			minimal

also better. The lower yields of winter wheat and the better quality characteristics of sugarbeet were an effect of the integrated strategy. The average financial yield of the marketable crops was 5-10% higher on the pilot farms due to the higher yield and better prices.

The integrated approach affected the allocated costs. The choice for more resistant and appropriate cultivars on the integrated pilot farms increased the costs of seeds and tubers in comparison to the reference farms by on average 100 NLG/ha (some 10-15 %). At the end of the project the difference became smaller due to the changing variety choice in potatoes at the reference farms initiated by changing legislation for potato cyst nematode control. The choice for more animal manure and a more focused strategy could reduce the input of mineral fertilisers. This initially led to some 100 NLG/ha (35%) lower fertiliser costs on the pilot farms. This difference decreased due to adaptations in the same direction over the project period on the reference farms. The reduction in pesticide input led to some 140 NLG/ha (26%) lower costs on the pilot farms. This difference increased during the project due to continuous innovation (reduction in use) on the pilot farms. The total of allocated costs resulted in some 75 NLG/ha benefit compared to the reference farms. The gross margin of the marketable crops was better on the pilot farms as a result of lower allocated costs and better financial yields. This benefit varied from 260 to 610 NLG/ha per region and amounted in average to 465 NLG/ha. This means on an average farm size of 58 ha a financial advantage of 15.000-35.000 NLG /farm/year. However, since the pilot farms always had a higher physical yield the difference in financial result cannot be fully attributed to the integrated approach.

The integrated approach might also affect the costs of machinery, labour and contractors work. Contractor costs didnot differ significantly. The labour costs are slightly higher on the pilot farms than on the reference farms. During the project period this difference increased. The pilot farms spent some 1-2 hours/ha more, mainly through hired labour for weed control. The costs for machinery were already initially higher on the pilot farms than on the reference farms. Over the project period, the difference increased by some 200 NLG/ha. However, this is partly based on investments in machinery that are not specifically integrated. At the start of the project the pilot farms had already invested more in crop nursery machinery (excluded field sprayers). Two thirds of the pilot farms had already a band sprayer against only one third on the reference farms. This ratio stayed unchanged during the project. Also the pilot farms invested more in modern long tine weed harrows and hoeing equipment. So as a result of the project, the pilot farms had more modern machinery for mechanical weed control and band spraying.

Table 4 summarises the economic analysis. The shift to integrated farming changed the pattern of costs. The available data show that the financial result was not affected by this approach.

PERSPECTIVES AND CONSTRAINTS

In The Netherlands, the IAFS prototypes for arable farming, developed on experimental farms, were tested on a large scale on commercial pilot farms from 1990 to 1993. The conversion of the pilot farms to integrated farming was successful. The methods of the prototype were in general well accepted but had, eventually, to be adapted to farm specific situations. Some techniques proved to be immature and some region specific problems appeared to be quite different from those on the experimental farms. In these situations, solutions had to be found on an ad hoc basis. Additional research on these topics was initiated. The IAFS approach resulted in considerable reductions in the input of pesticides and restored the balance in P in- and output. With respect to N, the surpluses on the nutrient balance sheet were decreased, however the potential losses for N leaching were probably not adequately controlled. Further efforts are necessary in this respect and have been taken in the last years in the research programme of PAV. The IAFS approach had no negative influence on the profitability of the farm. On average, the pilot farms already meet the crop protection policy targets for the year 2000 (Anon., 1991) for all categories of pesticides. In a number of regions and for some categories, these targets were even exceeded substantially. A bottleneck remains for weed control in the North-eastern sand area where nightfrost and wind erosion risks hamper the full introduction of mechanical weed control techniques.

The project demonstrated that IAFS demands a farm-specific approach and showed how to adapt the general prototypes to farm specific conditions. However, the large scale introduction can only be successful when the agricultural community (farmers, extensions, education, trade) is sufficiently motivated for and familiar with (elements of) IAFS. This point of view was considered when setting up the pilot farm project in a larger context in which training courses for teachers and extensionists, promotion activities and study clubs of farmers were implemented (Wijnands, 1992). The pilot farm project gave face to the rather anonymous experimental farm integrated approach. Based on the experiences and gained knowledge improved farm and crop guidelines could be made (van Bon *et al.*., 1994). By the end of the pilot farm project, the pre-conditions for large scale introduction were fulfilled and the Arable Farming 2000 project started. In this project (1993-1995) 500 arable farmers participated to introduce (elements of) integrated farming on their farms, guided by the Agricultural Extension Service.

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A practical approach for Technology Transfer of Integrated Farming

C J Drummond
LEAF (Linking Environment And Farming), NAC, Stoneleigh, Warwickshire, CV8 2LZ, UK

ABSTRACT

LEAF (Linking Environment And Farming) was initiated seven years ago to encourage the adoption of Integrated Crop Management (ICM), and in the broadest sense Integrated Farm Management (IFM), by farmers and improve the public understanding of best farming practice. Although initially a three year project, the organisation is now well established and after seven years, supports a network of 26 Demonstration Farms throughout the UK, a number which is rapidly expanding. All these farmers are volunteers and are selected against specific criteria and trained in the most up to date information on IFM to ensure informed discussion between farmers and others. Monitoring is now being carried out on many of the Demonstration Farms to assess economic and environmental performance. There is also a network of Supporters who, as trained farmers, are further transferring the practical messages of IFM. This approach is widely recognised as an excellent way to encourage better practices and the adoption of IFM through peer pressure and visual, practical demonstrations.

INTRODUCTION

Farmers face many demands from all sectors of society, ranging from quality food production to environmental and social responsibility. Consequently, it is often difficult to know where to start and thus no attempt is made to even address an issue, particularly environmental improvement, since it is a perceived cost. However, there is much to gain from environmental management practices such as Integrated Farming, as the profitable rewards are often matched by better risk management with less impact to the environment, and a stronger assurance of safe, wholesome food. However, success in the adoption of such an approach is dependent on the messages and methods of technology transfer.

This paper examines the experiences of transferring a technology that is site specific, based on non-prescriptive techniques and is appropriate to a wide range of audiences, including farmers, the allied industry, the food sector, environmentalists and the general public.

For the LEAF organisation, this is the dissemination of Integrated Farming techniques through the use of Demonstration Farmers, and now through the development of complementary means such as 'Supporters', 'Audit Ambassadors' and training programmes.

TECHNOLOGY TRANSFER

When delivering a message or new technology, it is important that the message is clear, simple and consistent, and the audience is correctly identified (MAFF, 1997).

In the UK, technology transfer has tended to follow a traditional extension model, very similar to that identified in Ontario (Anon., 1994), in which information is perceived to flow in steps from researchers/developers through a recommending body, to public sector extension personnel or private sector sales representatives and then to farmers. In the past, the level of information available and the system that developed, suited the times and technology and was transferred very effectively. However, because technology is being developed or adapted at almost all levels of the system (i.e. researcher, extension, private sector and farm) and at a multitude of sources external to it, information flow is becoming increasingly multi-directional and less co-ordinated.

In addition, privatisation of extension and advisory services in the UK has diluted the impact of the technology transfer mechanism. Farms are becoming increasingly diverse and specialised, so that each farmer's informational needs are almost unique, in respect of both questions to be answered and the level of detail sought. Some farmers are looking for the specific information they need to implement a technology, while others still require a package of information complete enough for them to visualise how the entire system can be made to work, profitably, on their farm before they will try it.

In anticipation of these changing times, LEAF and its European partners, EIF (European Initiative for Integrated Farming), identified the need to develop practical messages for encouraging the adoption of Integrated Farming - economic farming systems that are also environmentally and socially acceptable. In particular, to develop systems that help farmers, who seem to be faced with an impossible set of demands, deal with the increasing complexity of food issues.

Furthermore, it was felt to be necessary to collaborate with an already long established infrastructure of support services in the UK. This structure, which is often not fully recognised, includes advisors, the industry and their agronomists, agricultural colleges and universities, research stations and membership organisations, including farmer and environmental groups.

So as one system erodes, a new method is developing which builds on key criteria and organisations involved. Furthermore due to increasing specialisation, new demands are being asked of the supporting information. More often than not in transferring detailed information, farmers remain highly dependent upon personal contact, such as their agronomist, as the preferred method of learning and as an information source. However, farmers are also very flexible when they want to find out more about an issue, they have become very diverse in their abilities to obtain, assimilate and apply information, and they will certainly be more selective about the format in which they will accept information. So the attention must also go to the supporting organisations and messages must be consistent, clear and concise, whilst being mindful of the amount of information now available and the level of detail being requested. This is certainly beginning to seriously tax the system for extending information, especially in an era when the number of personnel is being reduced at all levels within the system, and at a time when farmers really need support. Also there is a very strong element of competition from a range of organisations resulting in a dilution of effort and duplication of efforts.

Perhaps somewhat rudimentary in its initial approach, the idea of Demonstration Farms has been one of the best methods of technology transfer in a multi-disciplinary approach. They have been the backbone of the LEAF organisation on which other complementary techniques have been added. It was recognised very early on, that it would not be easy to transfer "packaged" systems, given the diversity and complexity of most farm operations, but farmers and the allied industry needed an approach that was flexible and relevant. Some of the experiences are detailed below.

PRACTICAL SOLUTIONS FOR PRACTICAL PROBLEMS

For LEAF, as has been highlighted, the technology to be transferred is IFM, with a varied target audience including:

- Agriculture sector - producers, agribusiness professionals, extension staff.
- Education sector - secondary and post-secondary teachers, students and consultants.
- Environmental special interest groups.
- Food sector - retailers, consumer groups.
- Government - MP's, MEP's, policy developers.
- The media - as a vehicle for technology transfer.

Having identified the technology, the audience and the methods, LEAF has had success in firstly introducing the concept of ICM and IFM to a broad sector of audience. This has principally been through a range of activities which are multi-disciplinary and include the following technology transfer modes:

1. Collaboration.
2. Publications and guidelines.
3. Demonstration Farmers.
4. Training and education.
5. Supporters.
6. Audit Ambassadors.
7. Links with researchers.

Collaboration

One of the most important features in the development of a new technology and its transmission is the need to collaborate. This is principally for two reasons, firstly to ensure that the technology is sound, and secondly to instill ownership from those involved. LEAF was set up with a management structure based on an advisory board and executive committee consisting of a range of organisations including farmers, farmer advisory and membership organisations, industry representatives, environmentalists, educationalists, researchers, consumer groups and the retailer sector. Although such a structure requires careful control, the rewards from co-ordinated views have been central in the development of a fully integrated approach that involves all the stakeholders and thus has a strong ownership from those involved. Basically it allows people to take action.

Publications and guidelines

After the initial discussions in the development of LEAF and ICM, the next stage was to develop procedures and overall guidelines for Integrated Crop Management and from these developed the LEAF Audit - a self assessment management tool to help farmers plan and assess their farming practices against the principles of ICM. These have been central to the development of ICM as a base line for farmers to 'make them think'.

Moreover the Audit has recently been developed on computer disc. This interactive software package offers farmers an opportunity to compare their current farm practices with IFM practices and also provides a unique, personalised feedback. This provides a comprehensive report on the farmers performance against IFM principles setting out suggestions for improvement, highlighting priority areas and establishing Targets for Actions. There is a performance profile giving an overview of the farmers overall adherence to IFM and a useful benchmark to assess the farmers' standards against others. The software package also provides access to advisory information including the Codes of Practice for Good Agricultural Practice and other guidelines and management tools to help farmers set their own policies and procedures. There are four years of data from the audit returns, and this has been invaluable in identifying areas in which the organisation can make improvement.

The Audit is sent to all members, and on average some 30-40% complete it annually and return it for analysis. In 1997, this totalled 350 farmers representing some 350 000 acres of land (LEAF, 1998a), 92% of the farmers had arable and 47% had field vegetables; the latter being a significant increase from the previous year due to the increased demands of the adoption of ICM systems and traceability in the retail trade. To date the livestock element remains relatively low with 26% having beef and 11% dairy, though it is expected that this will increase as IFM develops. The analysis of the returns identifies the areas where farmers are 'getting it right' and areas 'where there are concerns'. In particular, these areas include the need to:

- improve fire procedures and ensure emergency phone numbers are readily available
- improve record keeping
- investigate monitoring and diagnostic techniques
- monitor fuel and energy consumption
- obtain a soil map for the farm
- develop a waste management plan
- improve recycling of all waste products
- increase the number of staff meetings to discuss IFM and performance
- calibrate machinery more regularly
- bund fuel and mixing areas

The feedback returned to farmers has pointed them in the right direction to obtain help. LEAF has provided guidelines and developed plans and templates for farmers to adopt, not only for members but also, with support from the national farming press, other farmers.

Demonstration Farmers

Key to the success of LEAF is the involvement of highly motivated skilled Demonstration Farmers. To date there are 26 Demonstration Farmers which will be expanded to 50 over the coming years. Each farmer is selected against specific criteria as defined by the Audit, their location and communication skills. They have a commitment of five years to LEAF and host visits to a broad range of groups that are invited to discuss and learn more about a fully integrated approach. Their job is the hardest in terms of the varied skills required for a range of organisations such as the Womens' Institute, Friends of the Earth and those involved in the food and agricultural industry.

The Demonstration Farmers are by their nature, leaders and innovators, hungry for information and motivated by making their businesses succeed. To them, IFM seems the most logical way forward in terms of adopting an approach that is economically viable, environmentally responsible and practically achievable for the majority. They have a strong conscience and also believe that IFM will address their needs and the consumer's concerns. The selection procedure is exceedingly important to ensure the success of this method of technology transfer. The farmers are selected according to their farming practices, region, farm type i.e. vegetables, arable, fruit, mixed and also tenant/owner occupier etc. Size is also a consideration and all the farmers are involved in some level of research, development, monitoring or technical expertise. This is important to ensure that as procedures are adopted they are specific to the requirements of the farm site.

Even as times are becoming increasingly harder for the farming industry, the enthusiasm of the Demonstration Farmers provides peer pressure encouraging other farmers to adopt ICM techniques. As part of the transfer of information, extension materials in the form of farm brochures are supplied. These are designed to meet the needs of the general public but other supplementary information is supplied for specialist groups.

In 1997, there were over 380 visits to the Demonstrations Farms, the average number of people per visit was 15-20. This represented some 6400 people, a very significant number of targeted and invited individuals. It should be noted that these farms are not open farms and the range of group sizes may be from one for an MP, MEP or journalist to 80 for a Womens Institute group. The Demonstration Farms also receive a lot of press coverage in the national and local farming press.

Over the last three years financial case studies have been done to the assess the economic viability of IFM on an all arable and a dairy/arable farm. This has been extremely important in encouraging farmers to adopt IFM, since it is often perceived that environmental management costs and the studies show that better risk management saves money. Added to this, farmers are faced with the prospect of considerably reduced prices for produce throughout the case study period, reducing profits, whilst pressure on farming systems to take more account of the environment, animal welfare and food safety continues to increase. The case studies have compared the performance of IFM against the conventional farming situation and have consistently shown that adopting an IFM approach has financial, as well as environmental benefits (LEAF, 1998b), with increased profitability from 13 to 20% on the all arable farm over the three years.

Training and education

There are many players involved in farmer decision making. Indeed it is estimated for every farmer there are eight people employed in the associated industries. Thus training and education are fundamental to the transfer of new information. This is principally through different avenues.

Professional training

Advisers are the main messengers for new technologies on farm. Consequently, LEAF in association with BASIS developed an ICM syllabus which is now recognised by Government as a professional certificated course. This two day course is designed for advisers to ensure that there is consistency in the ICM message given by those visiting the farm. As the principals of ICM develop and more advisers are trained, then this course will become an integral part of the standard BASIS and FACTS courses.

Farmer training

Colleges and Universities are the starting point for many involved in the industry. An annual training course for college lecturers is held on a Demonstration Farm with updates from representatives of the industry together with research findings from ICM projects. The colleges use Demonstration Farms for student projects and walks. An ICM training pack for Colleges has also been developed and this is widely used throughout the UK, and is now being further developed as a European package - again extremely important to ensure consistent messages. Regular training is provided for farmers. ICM is not only a whole farm approach it is also a whole industry approach and training of farm staff is an essential part in ensuring it works. Training of those delivering the messages is also essential, and regular meetings are held for the Demonstration Farmers - an annual two day training event involving experts in the industry - including opportunities for exchange of ideas and receiving up to date information on IFM topics, and radio and TV training for all new Demonstration Farmers.

Supporters

The development of a group of supporters is currently being piloted. This initiative has been set up to capture the enthusiasm and commitment of many individuals who want to help promote the uptake of environmentally responsible farming systems. Supporters are farmers and non-farmers, willing to give their time on a voluntary basis to help support the network of Demonstration Farms and promote the Audit. The initiative is currently being piloted for a period of one year with 10 individuals, after which it is hoped that many more will want to get involved.

Audit Ambassadors

This initiative has been set up to ensure the wider uptake of the new Audit and encourage its completion on an annual basis. To help achieve this, a register of Audit Ambassadors has been established. The ambassadors will promote the use of the Audit to farmers and the wider industry and encourage its uptake. They are drawn up from the membership and include advisers, retailer technicians, trainers, merchants and motivated individuals who want to promote IFM.

Links with researchers

Links with the research establishments have also been established to assist in the transfer of information on IFM. In particular this has been through the Integrated Arable Crop Production Alliance (IACPA), a group that brings together seven leading UK organisations, including LEAF, working in the area of IFM and ICM in arable crops (IACPA 1998). IACPA members are working together to ensure:

- that a representative range of common cropping problems are addressed in their research.
- the exchange of literature and research and development findings on a regular basis so that unnecessary duplication of work can be avoided.
- a faster and more effective dissemination of all the important results.

The benefits

One of the things essential for the spread of technologies is benefits to the main stakeholders. Some of the benefits from the LEAF approach are as follows:

The Demonstration Farmers

- an opportunity to give something back to the industry.
- involved at the forefront of the development of IFM.
- an opportunity to debate the issues facing farmers with those who have not been exposed to the complexities of farming before.
- first hand access to government officials to discuss policy and concerns.
- debate with farmers on their experiences of what works and does not.

Members

- through the Audit a review of their whole farm enterprise and ability to demonstrate their commitment of care for quality food production and the environment.
- better risk management and performance through carrying out the Audit.
- involved in the discussions and development of IFM.

Supporting Organisations

- an opportunity to keep ahead of the market.
- promote the professional integrity of their business.
- help their farmer clients meet the future challenges of the industry.

Agriculture as a whole

- the encouragement of farming practices that balance economic viability and environmental responsibility and which meet the requirements of their customers and in the broader sense, encourage a better public understanding of farm practices.

The General Public

- an inside knowledge of how farmers are addressing their concerns about the environment and an assurance of safe, quality food.

Does it work?

It is increasingly evident that such a multi-disciplinary approach does work - but measurable targets are always required. The number of groups going to visit a Demonstration Farm and those carrying out the Audit are measured. These numbers are increasing rapidly and it appears that those adopting the IFM approach are finding it increasingly rewarding. Where there is a true understanding of an issue, it is carried out more effectively. Without a doubt payments and the market place can drive these issues forward but again that development must not be diverted from technology transfer or else there is no ownership by the person adopting the technology and no depth of understanding.

CONCLUSIONS

For all technology transfer the following key points are essential:

1. Information must be presented in ways that will allow potential users to assess the impact of a change in technology on their production system and the environment.
2. An effective alternative to direct contact with experts must be developed to transfer detailed information to clients.
3. The technology transfer system must ensure that the best available information is widely accessible in formats that will facilitate widespread usage.

For LEAF and the transfer of information of IFM, this includes a multi-disciplinary approach involving collaboration, Demonstration Farms, training and advice, Supporters and Audit Ambassadors, adopting a non-prescriptive approach to allow individuals to identify how IFM fits their business.

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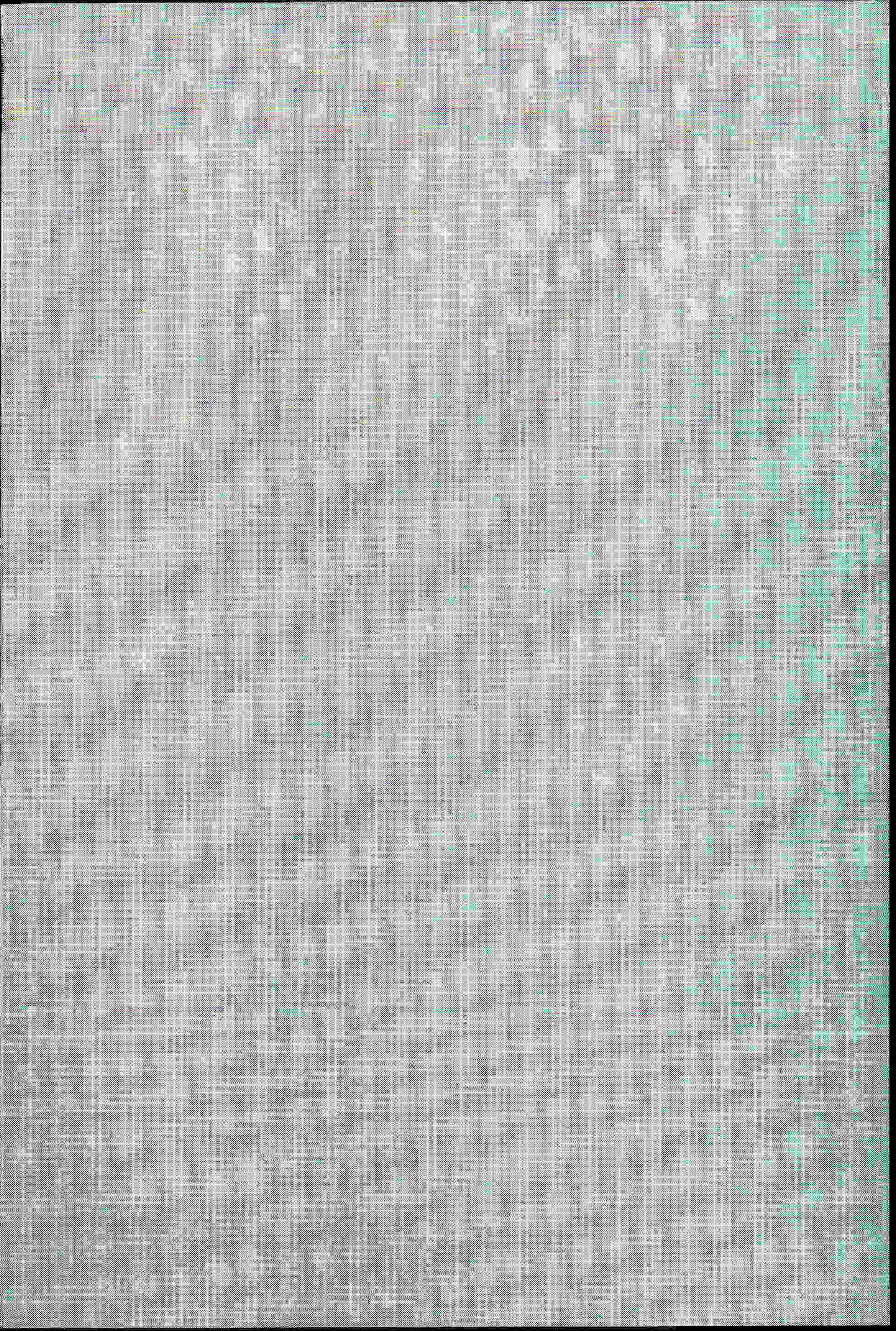
SESSION 10B

PRECISION IN CROP PRODUCTION: BENEFITS AND COSTS OF ADVANCED TECHNOLOGIES

Chairman	R J Cook *Ministry of Agriculture, Fisheries and Food, London, UK*
Session Organiser	Professor W Day *Silsoe Research Institute, Bedford, UK*
Papers	10B - 1 to 10B - 3



Precision Agriculture: vive la difference

P C Robert
Precision Agriculture Center, University of Minnesota, Saint Paul, MN 55108-6028, USA

ABSTRACT

The refinement of farm input use and the adoption of improved technologies is a continuous process in agriculture. However, farming in the American Midwest reached another milestone in the 1980s with the advent of controlled crop production processes based on information technology. Better awareness of soil and crop condition variability within fields developed from better field investigation methods including soil survey, soil sampling, aerial photograph, and crop scouting. This identified potential benefits of management within fields by zones rather than whole fields for increased profitability, sustainability and environmental protection. At the same time, the microcomputer became available and made possible the acquisition, processing and utilization of spatial field data and novel farm machinery with computerized controllers and sensors. The potential benefit of precise management - in space and time - of all cropping practices is now being demonstrated. But, today, precision agriculture is still in its infancy and requires much research and development before becoming the agricultural system of the 21st century.

INTRODUCTION

The new agricultural system called site specific crop management (SSCM) or precision agriculture is the start of a **revolution** in natural resource management based on **information technology**: it is bringing agriculture in the digital and information age. It has been compared to the " just-in-time" concept in manufacturing (Searcy, 1995). But it can also be seen as an **evolution**: more precise management (control) of soils and crops made possible by more precise information and new technologies. The definition I proposed years ago was:

> *Precision Agriculture is an information and technology based agricultural management system to identify, analyze, and manage site/soil spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment.*

DEVELOPMENT OF THE PRECISION AGRICULTURE CONCEPT: BETTER SPATIAL INFORMATION FOR BETTER MANAGEMENT

The basic principle of adapting soil and crop management to specific local conditions is not new. However the continuous increase in field and farm size and bigger machinery moved producers away from small scale field variability. From the mid 1970s, a greater awareness of the potential benefits of better farm record keeping procedures and understanding soil and crop input needs developed progressively in the Midwest of the United States. Cochrane (1993) indicated that "farming in America began to cross another watershed in the 1980s.... in which the steps in the production process will be fully integrated and the entire process strictly controlled. The essence of this mature industrial age of agriculture is **control** - control over the input of resources into established processes or into new and improved technological processes."

Indeed, in the late 1970s, CENEX, Farmers Union Central Exchange, Inc., and the computer company Control Data Corporation, both based in the Twin Cities, Minnesota (MN), started a joint venture called CENTROL - Farm Management Services (Fairchild, 1988). The objective was to use more information on soil and crop conditions for each field during an entire growing season to improve management and farm profitability. CENEX developed a network of Agricultural Consultant Services while Control Data was responsible for information management and the development of farm databases. An important outcome was a much better awareness of soil and crop variability within field and potential benefits of management within fields by zones rather than whole fields. This resulted in the decision to build a spreader capable of changing the blend and rate of fertilizer on-the-go. The project was initiated in the early 1980s by SoilTeq, Waconia, MN. The first prototype was finished in 1984, and the first commercial VRTs (Variable Rate Technology applicator) were used in 1995 by CENEX in Renville, MN and Quincy, Washington State.

At the same time, the Department of Soil Science, University of Minnesota (Robert & Anderson, 1987) had started the digitization of Minnesota USDA-NRCS (previously named Soil Conservation Service) county soil surveys and developed a soil survey information system (SSIS) for easy access of the data. Application software based on the SSIS data base were developed and one of them, "Soil Sampling Recommendations", was used by CENTROL consultants to group soils with similar important soil properties for crop growth in three categories when soil samples were taken for analysis. Aerial color photographs and grid sampling techniques were also used. Results of these soil samples taken by soil conditions in Minnesota in the mid 80s (Larson & Robert, 1991) confirmed clearly the zonal variability of soil nutrient levels within fields.

Other examples of initiatives around the mid 1980s introducing more intensive crop management were the MEY clubs and the Test 20 program. The MEY - Maximum Economical Yield - clubs promoting soil and plant sampling and analysis, record keeping, on-farm experiment, and the implement of new technologies were started throughout the Midwest. The Potash Phosphate Institute (PPI) created a network of clubs. An agri-consulting company in Illinois, Top-Soil, initiated several MEYs and started some soil grid sampling within fields.

Precision agriculture is information technology, and we have stressed the importance of better information and the developing awareness of within field spatial variability from the mid 70s. New technologies, particularly the microprocessor, made the development of the concept feasible. The microcomputer has been the most significant technological innovation during the 80's in American Agriculture (Holt, 1985). Microcomputers made possible the development of farm equipment computers and controllers, the production of site specific management maps using GIS, the electronic acquisition and process of spatial field data to build farm geographic record keeping systems, the positioning of machines using GPS, and the development of the first sensors. In the future, real-time sensors will be playing a key role in the development of precision agriculture. In 1984, the American Society of Agricultural Engineers ranked the development of sensors for data collection and control systems on the highest engineering research priority for Agriculture (ASAE, 1984). The grain yield sensor has already become an essential part of precision agriculture. Presently, the number of grain harvesters equipped with a yield sensor is approaching 20,000 units. Yield maps have an essential role in the development of precision agriculture. They reveal to farmers common occurrences of large variability within fields as a result of natural conditions, field management, and machinery.

VARIABILITY WITHIN FIELDS

Two principal kinds of variability within fields concern SSCM: variability in space (spatial) and time (temporal). A third kind, predictive variability, has been mentioned by Blackmore & Larscheid (1997). It "describes the differences between what was predicted for management purposes and what actually happened. It can arise from many factors such as the weather, the expected yield and the prices for the coming year". This relates more directly to managerial decisions.

Spatial variability within agricultural fields has been well documented by USDA-NRCS soil surveys, soil sample analyses, and crop yield measurements taken by weigh wagons or truck load scales. County soil surveys at a 1:20,000 scale show clearly that individual fields have in general several soil types with contrasting characteristics. Also, crop-free low altitude vertical or oblique aerial photographs or satellite images can show variable patterns of surface colors or gray tones within fields, corresponding to variable soil conditions. Another kind of indicator is the soil productivity index, which indicate relative differences in productivity between soils due, in most instances, to soil physical and chemical properties. The CER index when used for land assessment shows clearly the variability of soil map unit productive capacity within fields. Common variability of the CER index is greater than 20, in a scale ranging from 0 to 100, indicating significant differences in soil productivity. Crop visual condition can also be an indicator of soil variability. In southwest Minnesota, for example, soybean fields in the spring may show a mosaic of irregular yellow patches due to high pH/$CaCO_3$ in the topsoil of some soil-landscape units. This is called iron chlorosis and results in substantial yield losses.

The spatial variability of different soil properties varies in size and shape. Common soil physical properties such as texture, available water, and permeability are usually following closely the pattern of the landscape or microrelief, while soil chemical properties such as soil nutrient (N, P, and K) have irregular and independent spatial patterns.

Table 1. Variability of soil characteristics in SSCM projects (Wollenhaupt *et al.* 1997); CV is the coefficient of variation and spatial range is the range parameter of the semivariogram.

Soil characteristic	CV (%)	Spatial range (m)
Soil pH	8 - 14	20 - 132
Organic Matter	21 - 41	112 - 114
Soil NO3-N	28 - 58	40 - 275
Available P	39 - 157	68 -145
Available K	31 - 61	-
Yield	8 - 29	70 - 700

Temporal variability, differences in soil conditions and crop growth during a growing season or from year to year, for specific sites within fields is, at this moment, a great challenge to precision agriculture management. It has been mentioned by several authors (Porter *et al.*, 1996) that the variability in crop conditions or yields for a field may be greater on a temporal rather than a spatial basis. The main reason for the temporal variability is weather-driven, particularly through changes in soil water content. Often, soil water content is more important than nutrient availability. Yield maps clearly show greater yields than average for well drained soil conditions on a wet year and lower yields for the same site within the same field on a dry year. In Minnesota and most of the Midwest, farmers' response to rainfall uncertainties, particularly excess water in depressional zones with high productivity potential is to install subsoil artificial tile lines. A prime use of yield maps has been to identify zones requiring additional drainage. Another common scenario is that some zones within a field always have higher yields than the rest of the field while absolute yields may go up and down from one year to another.

SPATIAL VARIABILITY AS A RESULT OF NATURAL CONDITIONS.

Soil and landscape spatial variability are the result of both natural processes and soil/crop management practices. Natural spatial variability results from complex geological, geomorphological, and pedological processes. **Landscapes** result principally from a variety of historical erosion and deposition processes. Although the general form of the landscape was shaped before agriculture started, today's intensive, sometimes excessive, agriculture practices may still result in substantial erosion and deposition events slowly but progressively changing field microrelief and particularly soil characteristics such as soil productivity. Landscape positions in association with related soils, also called soilscapes, are key information elements in precision agriculture, informing the selection of soil sampling sites, nutrient management, and yield map interpretation. Directed sampling using soilscape information reduces the number of samples and results in more accurate maps. A systematic grid sampling procedure may miss important locations within fields. Several kinematic DGPSs already provide centimeter accuracy in elevation and allow for rapid development of a digital elevation model for agricultural fields.

Soil types are the result of five forming factors: parent material, biota, climate, topography, and time. They are variable in time and space and explain most general soil characteristic variability. Initially the concept of precision agriculture was called "farming by soil types". However, USDA-NRCS soil surveys at a scale of 1:20,000 were found insufficiently detailed for precision agriculture, particularly for spatial management of fertilizers. Soil survey mapping units may contain as much as 25 % of inclusions, that is soils with very different soil characteristics. In Minnesota, a soil survey scale of 1:5,000 has been found appropriate for precision agriculture. Presently, computer-based methods are developed to rapidly and efficiently create a 1:5,000 scale applied soil survey for precision management.

SPATIAL VARIABILITY AS A RESULT OF FIELD MANAGEMENT.

Management-induced variability, particularly for highly productive soils, can be significant. Soil fertility variability within a field, especially nitrate nitrogen, but also phosphorus and potassium, is generally not correlated with the soil-landscape. In a soil specific management study in Lyon county, Minnesota (Robert *et al.*, 1991), anhydrous ammonia was applied in a corn (*Zea mays* L.) field by soil survey map units and by soil N fertility map units. The soil base map was the standard 1:20,000 soil survey. The soil nitrate fertility map was prepared from nitrate nitrogen test values on a 60 m grid. Nitrate nitrogen levels were kriged to generate the contour map

(Burrough, 1991). The resulting map delineations show substantial differences and applications according to the grid based map resulted in higher net returns.

The rapid development of yield mapping has unveiled many relationships between yield variability within parcels and soil/crop management. The most common sources of variability are: historical practices - ownership, subsoil artificial drainage, manure application, land use (e.g., pasture, woodland, farmstead), land fill, loading zone, spill, and terrain leveling; past year practices - machinery problem and poor calibration, scheduling of practices(e.g. split timing within a field, inadequate soil conditions, poor weather), inadequate products (e.g. type, timing, placement, rate), labor (e.g. different machine operator, different field scout).

VARIABILITY AS A RESULT OF PROCESSES

The standard indicator of crop variability, success or failure, is the crop yield and the associated net return. For some crops, crop quality is already the reference. Examples are sugar content for sugar beets, protein content for wheat, and size and shape for potatoes. Crop quality, with its associated added value, will become in the future a primary indicator as a result of precision management, but at this moment, yield is generally the common reference. Yield mapping is becoming in the Midwest, particularly for corn and soybeans a primary tool for crop management. There will be about 20,000 yield monitors by the end of 1999 and a large proportion is used in the Midwest. Their value has been well documented (Robert *et al.*, 1995, 1996, 1998). Yield sensors are presently developed for a variety of farm products (e.g., sugar beet and sugar cane, potato, cotton, peanut, hay, vegetables, orchards and vineyard). Yield maps, with all their imperfections, are a most valuable record for future management, a wonderful educational tool, and a great challenge. Yield variability is the result of a variety of reasons such as: soilscape properties, crop growth processes, cropping practices, and weather. The most common reasons include soil available water, soil drainage characteristics, soil depth, soil nutrient availability, pest infestation, and problems with farm machinery during tillage, planting, application of fertilizers, spraying of crop protection products, and harvesting. A good farm record keeping system is essential to help determine the causes of yield variability.

Processes and properties that are responsible for crop yield variability are multiple and complex (Mulla & Schepers, 1997). Among the essential processes and properties are: photosynthesis and root respiration - radiation, temperature, pest type and density, and plant disease; water uptake - precipitation, evapotranspiration, temperature, soil available water, soil water potential, soil compaction, leaf area index, weed pressure, and plant disease; nutrient uptake - soil nutrient availability, nutrient placement and timing, soil organic matter content, pest density, plant disease; crop phenology - planting date, depth, seed variety, and temperature; grain filling - yield, protein, starch, and oil content, soil available water and drainage status, and soil type.

VARIABILITY AND WEED POPULATION

Weed population varies in space and time. The aggregation of weed seeds and seedlings has been observed across agricultural landscapes in many studies, even in most uniform natural conditions, and despite uniform field management (Cardina *et al.*, 1996; Mortensen et al., 1993). Changes in the weed density and composition are associated with landscape position and soil properties. Soil and crop, weather regime, and weed population dynamic are also important factors that influence weed species distribution and density (Baudry, 1993; Johnson *et al.*, 1997). Khakural *et al.* (1998) found that weed populations were significantly aggregated within fields, with large areas free or with very few weeds. The most common weed species were foxtail (*Setaria* spp.), smart weed (*Polygonum* spp.) and pigweed (*Amaranthus* spp.) Broad-leaf weeds were concentrated in less than 20 % of the field while 80 % of the parcel was weed-free. Grass weed density was medium, more than 4 weeds per 0.304 x 0.304 m, in 35 % of the parcel area while low grass weed density was measured in 65 % of the parcel area. The distribution of broad-leaf weeds, and to a lesser extent grass weeds, were closely related to soilscape characteristics.

Preliminary results suggest that weed scouting and spot applications of post-emergence herbicides can reduce their use by more than 50 %. Similar results have been found in others studies for different weeds, crops, and regions (Christensen *et al.*, 1998; Maxwell & Colliver, 1995; Mortensen *et al.*, 1995; Stafford & Miller, 1996).

VARIABILITY AND INSECT POPULATION

Insect population variability in space and time exhibits dramatic and very dynamic changes in density and genetic heterogeneity. Fleischer *et al.* (1997) suggest that the spatial variability is caused by the interaction between population dynamics, population genetics, and the biotic and abiotic environment. These interactions occur rapidly at rates that are closely tied to temperature with resulting variation within field scale or landscape scale. Generalizations about causes of insect population variations are difficult because insect behavior varies dramatically among species. However many populations have similar processes governing their spatial distributions and genetic structure in time: immigration, colonization, reproduction, emigration, and mortality. Important potential results of the introduction of precision integrated pest management (PIPM) are a reduction in inputs, and more importantly for some cases, a reduction in insect resistance to crop protection products. PIPM could preserve within field susceptible populations, reduce insecticide resistance, and preserve natural enemies (Midgarden *et al.*, 1997). Fleischer *et al.* (1997) found in their work on Colorado potato beetle that PIPM reduced by about 45 % the use of products and insect resistance by about 25%.

CONCLUSION

In summary, a better awareness of within field variability of soil/site/crop conditions, new technologies and the capability to electronically acquire, process, and utilize spatial agricultural information has developed into Precision Agriculture. Progressively, it will mature into the system of the 21st century. Today, it is still in its infancy, and only some pieces of the puzzle are already available. Agricultural history shows that any significant technological enhancement of agricultural management took much development, education, and time before used by a majority of producers. It took, for example, more than 30 years to see tractors fully utilized. A similar course should be expected for precision agriculture, a system requiring many new tools and skills. However it seems feasible that new technologies, including new learning processes, will facilitate and accelerate its implementation and adoption. Precision agriculture - information technology - is the agricultural system of the future because it offers potential benefits in profitability, productivity, sustainability, crop quality, food safety, environmental protection, on-farm quality of life, and rural economic development: vive la difference.

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Precision Agriculture – new technologies

B J Legg, J V Stafford
Silsoe Research Institute, Wrest Park, Silsoe, Bedford, MK45 4HS, UK

ABSTRACT

The future evolution of precision agriculture depends on technological advances in navigation, sensing, decision support, equipment control and system integration. New technologies for navigation and equipment control have been developing fast, and further advances can be anticipated. Development of sensing has been relatively slow, but satellite imaging seems likely to be one of the more cost effective in the near future. Often, however, sensors do not give sufficient information to define optimal crop treatments. Better decision support, probably based on crop models, is needed if robust treatment maps are to be produced automatically. Fully integrated systems with common communication standards are also essential.

INTRODUCTION

Spatial variability of crops has been appreciated by farmers for centuries, but the emergence of precision agriculture as a novel approach to crop management has been one of the most dramatic developments in recent decades, and it offers the potential to transform agriculture! The implementation of precision agriculture has been made possible by the 24 hour availability of global positioning systems, both the US GPS and Russian GLONASS systems. Coupled with yield monitors, this has enabled the production of yield maps. It seems likely that we will also, in due course, be able to map crop development and pests and diseases. It should, therefore, be possible to optimise crop inputs, such as fertilisers and pesticides, for each point in the field giving increased profits coupled with reduced chemical use and environmental benefits. This product of the IT revolution is thus likely to gain immediate public approval, and be far less controversial than many of the products of the biological revolution!

Although the term precision agriculture is widely interpreted as applying only to within-field spatial variability, a more complete definition would be "applying the right treatment in the right place at the right time". This definition includes the need to choose the correct treatment, and recognises that timing is critical for many agricultural operations. Indeed for many pesticides, timing is more important than dose, or even the choice of chemical. Other research communities are developing decision support systems for conventional agriculture (Brooks, 1998), but in this paper we will argue that decision making for precision agriculture must not just be *supported*, but must be *automated* if it is to become acceptable to the vast majority of farmers. It is essential, therefore, that the precision agriculture and decision support communities work together.

ESSENTIAL TECHNOLOGIES

Navigation

In-field positioning is required in order to map the sensed soil and crop factors and for the control of application equipment. The use of the US Global Positioning System (GPS), which is based on a constellation of 24 satellites, is almost universally used as a positioning system for precision agriculture, although the Russian GLONASS system is finding some application. The position resolution required depends on the operation under consideration, varying from perhaps 30m for variable fertiliser application right down to 0.1m for row crop planting. For spot sensing and establishment of a sampling grid within a field, GPS position can be computed in static mode repeatedly to reduce the error. However, positioning of field vehicles requires reliable positioning resolution in dynamic mode with, perhaps, 0.5 s updates.

Table 1: The GPS configurations with position resolutions and costs.

GPS technique	Source of differential signal	Resolution, m	Cost, £k
Standard positioning service	-	100	0.2 - 0.5
Differential GPS	local dedicated base station	2 - 5	2 - 3
Differential GPS	free wide area service	2 - 5	1 - 2
Differential GPS	subscription wide area service (e.g. Landstar)	1 - 3	1 - 3 plus 0.5 - 1 annual fee
Carrier phase smoothed GPS	subscription service	< 1	1 - 3
'On-the-fly' kinematic GPS	local base	< 0.1	> 5

GPS pseudo-range position computation with differential correction attains a position resolution of the order of 2-5 m. The problem with such position computations is that they are subject to an error distribution with tails extending from sub-metre accuracy to ten or more metres. To achieve such position resolution, the GPS receiver must be locked into a constellation of satellites well positioned across the sky. In practice, satellite switch-over as satellites move below the elevation mask of the receiver, obscuration of satellites by trees and buildings, and multi-path reflections lead to significant degradation in position resolution. The resolution is, of course, also dependant on the availability of dependable differential corrections. Thus the method of transmitting correction signals to the mobile receiver is a consideration for agricultural applications. The lack of reliability in positioning resolution has serious implications for real time dynamic positioning of application equipment within the field. Serious positional error will lead to the treatment map that controls the applicator providing positionally misplaced information.

In order to improve the reliability and accuracy of positioning for precision agriculture, both enhancement of GPS with other positioning information and the use of on-the-fly kinematic GPS may be considered. Enhanced GPS requires the integration of other positioning information available on the field vehicle such as speed and heading, using techniques such as Kalman filtering and forward error estimation (e.g. Stafford and Bolam, 1996). However, for accurate and reliable positioning, kinematic GPS may have more potential. In contrast to 'pseudo-range' position computation which uses a binary code transmitted by the satellites, kinematic GPS measures phase shift in the carrier transmitted by the satellites and can achieve sub-metre or even centimetre positioning accuracy. Current GPS receivers incorporate several enhancements to improve accuracy and reliability. These include carrier phase-enhanced pseudo-range computation, full 'on-the-fly' kinematic GPS, integration of other positioning information such as speed and heading and combined GPS/GLONASS receivers. The latter takes advantage of the benefits of both systems.

Differential operation is essential for agricultural applications to compensate for both the deliberate downgrading of the GPS signals and other error sources such as atmospheric refraction. Wide-area differential services are now provided (on a licence fee basis) via side-band encoding of commercial FM stations and by communication satellites. A free service based on coastal beacons has also recently been established in the UK by the General Lighthouse Authority.

Sensing

At the heart of precision agriculture is the collection, manipulation and use of information. Whilst some systems such as yield monitoring and remote sensing are currently available, no systems yet exist for the automatic measurement of soil chemical or physical properties or water content, or of weeds or crop pests and diseases. Some of these factors can be measured by soil sampling, though this is relatively expensive. In other cases, a pertinent factor may be deduced from a surrogate factor that is more easily sensed, e.g. soil organic matter content from soil colour, or a propensity for certain weed species or ground-borne pests from soil texture or pH.

Variable rate treatments may be undertaken with real-time sensing; they may be based on historically collected information or on a mixture of the two. Real-time sensing and control involve measurements of some crop or soil characteristic as the tractor moves through the field, and a control algorithm to vary the treatment given. An example is the system developed by Hydro-Agri (Precisio-N) using a spectral reflectance sensor on the front of a tractor to vary the application of fertiliser. Experimental machines have also been developed for primary cultivation (Scarlett, 1997), where the draft force indicates the need to adjust engine power, transmission or plough setting, and for secondary cultivation (Stafford & Ambler, 1990), where the tilth is measured using imaging or ultrasonic sensors and the intensity of cultivation is adjusted accordingly.

Table 2. Status of soil and crop sensors.

Property	Technique	Development stage	Resolution	Cost
Soil sensors				
Organic matter	soil colour by fibre optics	commercial	cm	L
Water content	electrical conduct. / capacitance	research	cm	M
pH	ISE / ISFET	research	cm	H
Avail. nitrogen	ISE / ISFET	research	cm	H
Texture	EM induction	commercial	m	L
Potato cyst nematode	ELISA	research	cm	H
Crop sensors				
LAI	Vegetation index	commercial (satellite/aerial)	1-10 m	L
Ground cover	NDVI	commercial (satellite/aerial)	1-10 m	L
Weed patches	aerial imaging	research	0.5 m	M
	near-ground imaging	research	0.01 m	H
Crop colour	Spectral reflect.	commercial (satellite/tractor)	0.1-10 m	L
Grain yield	mass or volume flow rate	commercial	20 m	L
Grain quality	NIR absorption	prototype	20 m	H

Crop sensors

It has been argued that the crop is the 'best sensor of its own environment' and thus measuring crop condition by some means should provide the best means of assessing its requirements. Such sensing may be undertaken from satellite, aerial or ground-based (on tractor) platforms.

In the longer term the most attractive approach is to use remote sensing from satellites. Some services already exist using Landsat or Spot images with a resolution of 10-30 m using, typically, 6 spectral wavelengths in the visible and near infrared. Such images only provide information on crop 'colour' and hence must be interpreted in conjunction with ground truth data. They are costly, and are frequently unavailable due to cloud cover, a problem that we are particularly sensitive to in the UK! Matra Marconi Space are promoting the 'XStar' project in which they propose to launch two new satellites devoted mainly to agricultural applications. These will have 20 m resolution, and offer superspectral data with 10 bands in the visible and near infra red. These will give basic biophysical data such as leaf area index, leaf chlorophyll content, level of brown pigments and soil brightness and, using crop models and empirical approaches, will allow the estimation of nitrogen stress, yield prediction, soil organic matter content, and risk of fungal attack and lodging. The accuracy of these estimates is being assessed in a European wide project, PAAGE, between now and the proposed launch date of 2002-2003.

Although these satellites do not eliminate the problem of cloud cover, their orbit times are 4 days compared with every 16/26 days with current systems and the chances of obtaining regular images are that much better. In addition, we may be able to use SAR (synthetic aperture radar) images from satellites such as ESR2, which can penetrate clouds. The reflected image is sensitive to surface structure and moisture content but still requires interpretation as with the visible and near infrared images.

In principle, everything that can be measured from a satellite can be measured even better from an aeroplane, and model aeroplanes have been used very successfully (Stafford & Bolam, 1998), while others have mounted cameras on reconnaissance aircraft. In the long run, however, mini satellites could be dedicated to agriculture and launched for as little as £1.5M, and as these cover a wide geographical area and have an expected life of up to 10 years it is unlikely that sensing from aircraft would be able to compete.

Tractor-mounted sensors may be very attractive. At present, factors such as crop colour, crop density and weed patches can be detected (Stafford and Benlloch, 1997), and as spatial resolution can be as high as 1mm, there is future potential for individual weeds, insects, or diseases to be identified. Another possible method for obtaining crop images could be through the use of autonomous vehicles (Hague et al, 1997). Such vehicles could be small, lightweight, and comparatively low cost, and provide 24 hour surveillance. Information gathered could be transmitted directly back to the farm complete with video images allowing expert identification of features that cannot be resolved automatically. It is unlikely, however, that autonomous vehicles will be sufficiently robust for commercial sale for at least 5 to 10 years.

Soil sensors

The major intrinsic sources of field variability are aspect and soil properties. Aspect, including such characteristics as slope and proximity of buildings or trees, can be found from survey maps but more detailed within-field surveying, which can now be undertaken with GPS to mm resolution may be required. On the other hand soil properties, which include water holding and transmission properties and nutrient holding capacity, are very difficult to measure. It may be possible to deduce some soil properties from crop growth and yield maps but it seems likely that soil sampling and analysis will always be beneficial. Many commercial companies offer a soil sampling service, and will measure a wide range of physical and chemical properties plus the presence of key pests and diseases, such as potato cyst nematodes. Geostatistical analyses indicates that sampling of some factors should be on a very fine grid (<1 m for available nitrogen) but that would be prohibitively expensive, so most use coarser grids of 20 - 100 m. It would therefore be very attractive to measure soil factors by non-contact tractor-mounted sensor systems. However, the only system commercially available is for deducing organic matter content from soil colour (Case-Tyler) although research is on-going into soil nutrient, soil water content, pH and texture sensors. Detailed soil texture/series maps provide the farmer with very useful crop management information. A possible means of deriving these from yield maps - and thus at acceptable cost - has been demonstrated by Lark et al (1998) who used a fuzzy clustering approach to regionalise a field on the basis of a sequence of yield maps.

Generating the treatment map

At present, there are no generally agreed approaches to generating treatment maps. Most are heuristic, rather than being based on any rigorous analysis. A more rigorous approach, however, faces two significant problems. The first is that our knowledge of variation within the field, is both incomplete and subject to error. The second is that optimal treatment requires knowledge of not only the present state, but also of the likely future weather and incidence of pests and disease. The result is that heuristic approaches, even if based on expert views, cannot be optimal for all circumstances. Better progress can be made by using yield variations over several years to deduce intrinsic, but difficult to measure, soil properties (Lark et al., 1998).

Similar problems occur through the season as measured properties, such as spectral reflectance, are subject to error and may not give an accurate measure of critical crop properties. As Rawlins (1996) concluded, an alternative approach would be based on a model of crop growth. All field measurements are then checked against the model and used to calibrate it so that its predictions correspond to the observed spatial variability. The model could also be used to estimate the likely response of the crop to proposed treatments, and so that a map of optimal treatment could be derived. This is exactly the approach adopted by recent decision support systems (Brooks, 1998) and, although these are currently based on uniform field treatments, they could be extended to spatially variable applications.

Spatially variable treatment

Variable application requires a treatment map, and a vehicle navigation system, as input to a control system that drives the variable application mechanism. The spatial resolution of the application system must match that determined for the treatment map. In the case of agricultural sprayers, conventional equipment has sufficient spatial resolution but insufficient turn-down ratio without resorting to injection metering systems or compound systems such as in the SRI / Micron patch sprayer (Miller and Paice, 1997). However, for plant scale application of pesticides, new techniques for precision application need to be developed.

Further development is also required for granular fertiliser spreaders (e.g. Bergeijk et al, 1997), though a more attractive approach may be to use liquid fertilisers through a modified patch sprayer. As soil pH sensors are developed, there may also be a requirement to improve the spreading accuracy and spatial resolution of lime spreaders. Although seedbed tilth sensors have been developed at the research level, precision seedbed cultivators can probably not be developed until there is better understanding of the seedbed cultivation process.

SYSTEM INTEGRATION

The principles of precision agriculture can be applied to virtually every farm operation. It is not surprising, at this early stage, that the various systems are not well integrated. In an ideal system (Figure 1 maps of all the sensed field properties would be received by a central GIS database; the farmer would review these maps and make any necessary changes or adjustments; optimal treatment maps would be generated for the farmer's acceptance or modification; and these maps would be delivered to the tractor computer which would be able to check, calibrate, and control the equipment attached to the tractor.

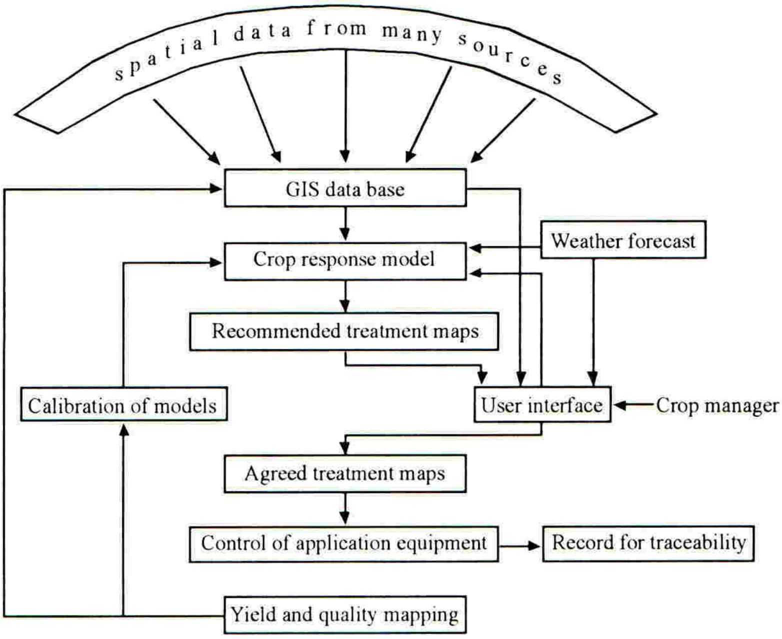

Figure 1. Integrated decision and control system for precision agriculture.

Commercial systems do now offer a treatment map 'shell' so that application maps can be generated if a suitable strategy has been devised. For example, the Massey Ferguson 'Fieldstar' system can be used to produce application maps as well as providing a 'standardised' data communication network (partly based on the German DIN 9684 standard) for control of application equipment. For weed control, variable dose sprayers are becoming available commercially, but there is as yet no easy way to generate maps of weed distribution to control the sprayer. Widespread uptake of the technology is unlikely before these gaps have been filled. The situation is more advanced where spatially variable information is obtained from soil samples; organisations offering this service produce treatment maps that are compatible with commercial application equipment.

At present, there is no check that the operator has put the right chemicals into the sprayer tank. In the future equipment will take chemicals directly out of their original packaging, having first read a smart label and ensured that the correct product has been supplied. The application rate could be checked using appropriate flow meters and, as application continues, the computer might also check that safety restrictions, relating for example to windspeed thresholds or proximity to hedges and water courses, are being observed. This would give real benefits to the producer who supplies the supermarkets and has to produce evidence of environmental and safety compliance.

As already indicated, the generation and transfer of large amounts of information is at the heart of precision agriculture. Thus standardisation in the method of transfer of information is essential so that systems from different manufacturers can 'talk' to each other. ISO11787 relates to the form of data and is a published standard. ISO11783 defines transfer of data over a data bus on and between mobile equipment such as field vehicles and implements. It is, however, still only a draft standard and so some manufacturers use the German DIN 9684 on which the ISO standard is partly based.

Precision agriculture is a powerful crop management concept, but its full potential can only be realised when a fully integrated approach has been developed and all aspects of crop management are included.

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Precision in practice – will it be cost effective?

D K Brightman
Brightman Farms, Gaydon Hill Farm, Gaydon, Warwick, CV35 0HQ, UK

ABSTRACT

A personal view of the potential for precision farming based on experience on a heavy land arable farm. Information on current practice and historical knowledge are used to assess the potential for increased precision in yield measurement and the application of cultivations, drainage, fertilisers and pesticides.

INTRODUCTION

The recent review of the potential of precision farming by Sylvester-Bradley *et al.* (1997) gave a thorough assessment of the technical aspects and highlighted the lack of economic data available to establish cost effectiveness. This paper is therefore a personal view based on past experience gained on the family farm in Warwickshire since it was purchased in 1964 and an assessment of the likely uptake of new technology in the future.

CURRENT FARM PRACTICE

The farm currently comprises 243 ha of which 227 ha are suitable for arable cropping (harvest 1998 figures). The arable area is used entirely for autumn-sown combinable crops (wheat, oilseed rape and field beans) and rotational set aside, which is managed, mainly for weed control purposes, as naturally regenerated green cover. This area is divided into 24 fields ranging in size from 0.5 ha to 26.3 ha with 7 fields less than 5 ha and only 5 fields larger than 15 ha. The majority of fields now have a full under-drainage with porous back-fill and ditches on 2 or 3 sides, but some fields have only a skeleton drainage system, a single header drain for mole drainage purposes, or no drains at all. Four fields only have a slight slope, the remainder being moderately to steeply sloping.

Soil texture is fairly uniform with 19 fields being classified as clay, one as clay loam, one as sandy clay loam and three as predominantly clay with small areas of either clay loam or sandy clay loam. The majority of the soil has a natural pH of between 6.0 and 8.0 with high potash levels but requiring regular inputs of phosphate to maintain soil indices. Only two fields require infrequent additions of lime and potash.

Cleavers (*Galium aparine*) and black grass (*Alopecurus myosuroides*) are the main weed problems with cranesbill (*Geranium dissectum*) and herbicide-resistant black grass usually being the only reasons for additional herbicide inputs. Seed rates are generally high at 400 seeds/m^2 to provide plenty of competition for black grass. Fungicide and insecticide use is low, which is attributed to a policy of nil insurance applications, a rigid rotational policy and a low density of arable crops in the direction of the prevailing wind due to large military and industrial sites. Due to high soil strength and avoidance of excessive or early nitrogen applications, growth regulator inputs are limited to only very weak strawed varieties or very exposed sites, although there was significant lodging with the severe weather conditions prior to 1998 harvest.

Yields expressed as clean dry tonnes sold off the farm (at or below normal commercially accepted moisture contents) divided by areas registered for Arable Area Payments Scheme (AAPS) are given in table 1 in the current rotational sequence.

Table 1. Crop yields (t/ha) in normal rotational sequence.

Crop	Harvest Year 1996	1997	1998[4]	Mean
Oilseed Rape	3.77	3.91	2.8	3.5
First Wheat	9.44[2]	8.89	8.0	8.8
Field Beans	3.86	4.16	-[5]	(4.0)
First Wheat	9.80	7.78[2]	7.7[2]	8.4
Second Wheat	8.53	8.35	4.2[2, 3]	7.0
Third Wheat[1]	Set aside	7.79	7.2	7.5

1. Third wheat is replaced by set aside as necessary to meet AAPS or other requirements.
2. Bread-making variety of lower yield potential.
3. Yield affected by black grass infestation.
4. Estimated from combining data – crop not sold yet.
5. Not available at time of going to press.

Clearly yields are affected by season, variety choice, rotational position and weed infestation. Drier years always result in better yields because of reduced water-logging, resulting in a longer growing season and more timely applications which in turn lead to improved performance of plant protection products, particularly herbicides. 1976 was the only year when some crops died before ripening and this was mainly the later harvested bean crop.

The uniformity of the physical characteristics of the farm (particularly the soil type), and the low level of fungicide, insecticide and growth regulator inputs suggests that there may be little opportunity to repay any investment in greater precision of application. Investment in the form of more intensive sampling and monitoring, or equipment to automatically vary applications according to maps generated by Global Positioning Satellite (GPS) technology or otherwise may be better spent on improved drainage. However a more detailed look at past experience may suggest some rather less apparent opportunities.

LESSONS FROM PAST EXPERIENCE

The Enclosure Awards for Gaydon Parish were signed and sealed in 1759. This document reveals that the present farm consists of parts of at least eight holdings that existed in those days. Many of the hedgerows established at that time divided 'four horse land' from 'six horse land'. This was a reference to the number of animals needed to pull a single furrow and perhaps the first attempt at precision farming. Where these boundaries have been removed, knowledge of their original position would probably be of great significance to modern precision farming. The holdings supported many different land uses, some of which continued until comparatively recently and consideration of their possible lasting effects may give a clue to the value of greater precision (figure 1).

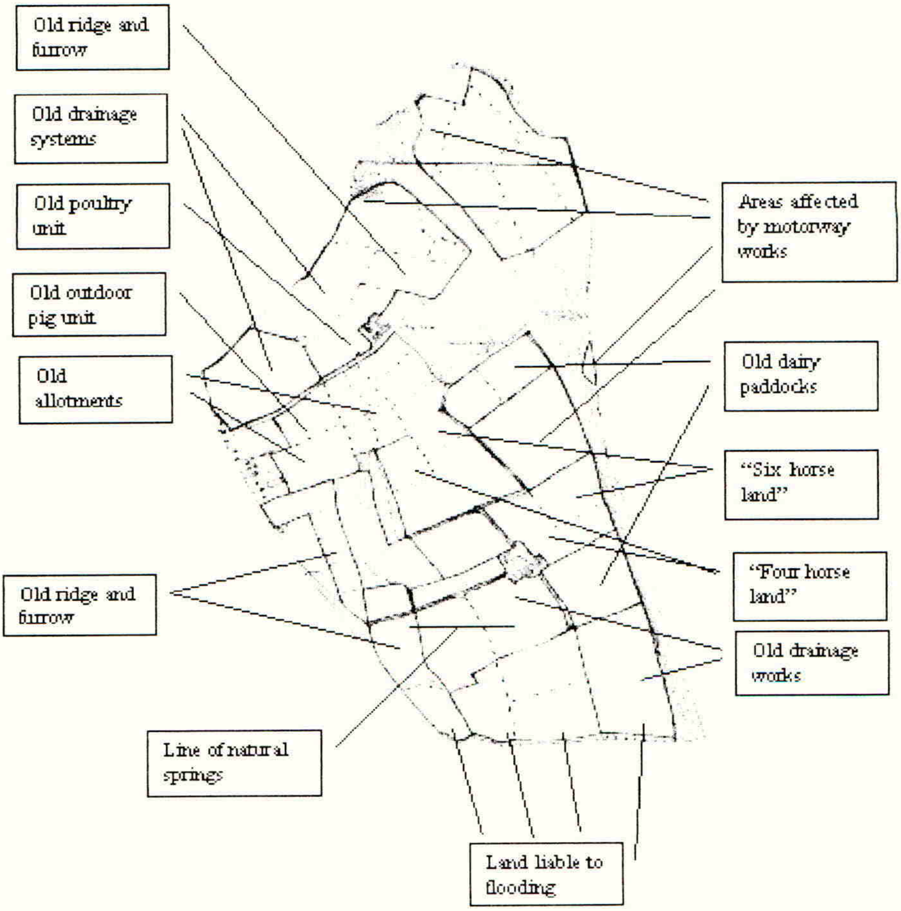

Figure 1. Map of part of Gaydon Hill Farm showing historical features which may be of relevance to modern precision farming.

During the nineteenth and early twentieth century, several fields had under drainage installed by hand in the form of "horse shoe" shaped clay tile drains. The plans, if there were any, of these drains have long since been lost, with the earliest records only going back to 1947. Where these drains have been unearthed recently, some, mainly on steeper slopes, have been found to be still working. Some were installed to drain natural spring lines. Occasionally failure of these old systems has been found to be the cause of waterlogged patches, which probably reduce yield. It would be extremely difficult to trace all the areas that were slightly wetter or drier than average without complex surveying. However, because of the critical effect soil moisture content has on yield and the high cost of land drainage, it may be cost effective to patch drain only the worst areas, if these could be detected at reasonable cost.

Another type of early drainage used in several parts of the farm was ridge and furrow, which was also used to provide dry areas for animals to stand. Most of these have been levelled now for cropping, but the effects of this on soil texture and structure, and occasionally on the crop, are still visible. The effects are on too small a scale to be allowed for using current application equipment, but greater precision of soil and crop monitoring may indicate the benefit of variable application in this situation.

Several fields that are close to farm buildings used to be used as dairy paddocks and again these tend to have higher organic matter and improved workability compared to the more outlying fields. Cultivation is usually reduced on these areas and there is some evidence of reduced performance of residual herbicides. Herbicide policy could be altered on the basis of organic matter content where this was known or could be measured cost effectively.

Other areas were once used for allotments, an outdoor pig unit and free-range poultry. These have all had long term effects on soil characteristics. For example the poultry unit used old sheds with limestone floors. The area now exhibits high pH, high phosphate indices and a tendency for manganese deficiency in crops. These areas are already treated differently as much as practically possible but more sophisticated application technology could allow further input optimisation.

Finally, the construction of the M40 motorway through the farm in 1988 resulted in the amalgamation of several fields and the removal of some hedgerows (these were more than replaced in terms of area by planting on the motorway embankment and the average size of fields was not increased). However more mixed soil types now occur in one field, since motorways are no respecters of the number of horses it takes to plough a field, and old hedges tend to leave higher organic matter and more weeds (and often appear to be the source of herbicide-resistant black grass). Currently no allowances are made for these small variations but precision technology could show some benefit from doing so.

The above discussion indicates that there are potential opportunities and limitations for new technology to improve input optimisation, but an investment decision would require appraisal of individual costs and benefits.

NEW TECHNOLOGY

The agriculture industry is constantly being told to be efficient, competitive and sustainable and the government is now trying to define what sustainable means. Whatever the definitions, research and new technology are essential parts of achieving this goal and the government should continue to play a leading role in facilitating the development and uptake of technology. At present the industry has a greater problem with economic sustainability than it has ever had with environmental sustainability and the former must be addressed if the necessary investment is to be made in technology which could then improve both. However, I believe that the use of pesticides (and genetically modified crops) is sustainable. Trials such as the Boxworth Experiment and SCARAB which followed it, as well as the Brimstone Project, have shown very few long term effects of pesticides on the environment and certainly fewer than many commonly accepted technologies. Indeed an EU review (Eyre Associates, 1997) of pesticide legislation recently expressed the view that:

> "The overall picture which is concluded from the sub-report is that farmers expenditure on Plant Protection Products provides very large economic benefits, as well as significant and real environmental and social benefits, which need to be balanced against any costs or losses which they may cause."

On our farm, a consultation on the feasibility of organic farming concluded that investment in an animal enterprise would be necessary but, even if this was viable, grass weed problems and reduced output would lead to bankruptcy before conversion was completed. It would be disastrous if public opinion rather than scientific fact led to the restriction or taxation of pesticides or other technologies which are the foundation of our current efficiency and competitiveness.

This does not mean that we should not be constantly looking for means to reduce agriculture's impact on the environment. The recent trend towards integrated farming is being supported by the whole industry. However there is evidence from the TALISMAN and IFS projects that the more extreme forms of integrated farming involve higher risk and may not be economically justified. A recent consultation within the NFU suggested that many farmers believe that they are using integrated techniques *to the extent that it suits their own business*, and are looking to the next generation of technology to improve their environmental performance. Computerised decision support systems will help to fine tune inputs when they become widely available, but many are looking forward to automated variation of applications as the means to improve efficiency, competitiveness and sustainability.

IMPROVEMENTS IN PRECISION

When I returned to the family farm in 1982, nitrogen policy was "six bags for wheat, five bags for barley" (expressed in cwt/ac of 34.5% N, this is 260 and 217 kg N/ha respectively). This was based on the assumption that what wasn't used for yield would improve quality. When MAFF (1984) published their recommendations, these amounts appeared to be high for the yield levels being achieved, and allowances for the end use of the variety and the rotational position appeared to offer potential savings. Also at this time growth regulators were being strongly recommended and usage was routine with occasional split or duplicate applications. We decided to purchase a weighing device to fit to the combine so that we could measure plot yields accurately (this device weighed on emptying not continuously so yield mapping was not a possibility). A series of trials was started using three levels of nitrogen with or without growth regulator. These were based on what was thought to be optimum levels for yield plus or minus 50 kg N/ha, with an additional 50 kg N/ha applied to improve the quality of bread making varieties. The choice of the mid-value varied according to the yield potential of the variety and site and previous results.

These trials were obviously not very scientific but did allow certain conclusions to be drawn. Seasonal effects on yield were far greater than nitrogen or growth regulator effects but there was some interaction between season and nitrogen requirement. Prediction of the likely yield potential and nitrogen requirement in any one season proved impossible. Differences between individual fields were also dependent on an interaction with season, so requirements could only be based on average season and soil type. Price of nitrogen and grain did affect optimum application rates but differences were small. Optimum yield of barley following one or more wheat crops averaged 6.7 t/ha from an application of 150 kg N/ha without growth regulator.

Optimum yield of wheat could also be achieved without growth regulators but varied according to variety and rotational position. In general, first wheat after beans required 20 kg N/ha more than first wheat after oilseed rape, but in second wheat the reverse was true for varieties with the same yield potential. Third wheat did not respond to such high levels of nitrogen input. This season, nitrogen inputs will vary from 190-250 kg N/ha with the aim of achieving yields of 8-10 t/ha. It is interesting (and somewhat gratifying) to note that ADAS advice subsequently began to include similar variations in recommended nitrogen rates.

Similar trials have also been conducted on seed rates and phosphate requirements and are currently concentrating on fungicide inputs. However one lesson that has been learnt from conducting these trials is that, even with simple field scale trials, the design, analysis and interpretation have to be precise in order to gain maximum reliability. I have often been criticised for not including negative controls in my trials although I'm still not sure what zero fertiliser or fungicide application means in practice when the base level of nutrients and disease resistance varies with soil and variety. All too often I see trials with all the control plots at one end of the field or hear comments about one variety yielding more than another when trials results show that there is no significant difference. Greater precision in trial work will be essential if greater precision in practice is to be achieved.

FUTURE DEVELOPMENTS

Yield mapping is now a commercial reality, the question is whether it is cost effective. I am encouraged by the fact that simple yield measurements have already improved the precision of inputs on my farm but discouraged by the fact that I cannot distinguish between individual fields. It seems unlikely that yield mapping alone will allow greater precision of inputs on less than a field scale without very intensive sampling to establish the reasons for yield variations. I already know from my simple yield measurements that headlands generally yield less than the rest of the field (up to 35% less in some cases). However, the decision about whether to use less inputs or more is not an easy one so they continue to be treated the same as the rest of the field. Historical information could be useful to guide the sampling process but this could, and probably should, be done to a greater degree without yield mapping. What would be useful is prediction of yield potential at an early enough stage to vary husbandry.

Attempts to establish the theoretical maximum yield in the past have generally been proved wrong eventually. Even the most sophisticated decision support systems do not presume to predict yield potential. The best hope would appear to be in the direction of predicting crop potential from some physical measurement of the plants such as leaf area index. This would then have to be correlated to an indirect measure such as spectral reflectance if the system was to be sufficiently automated to produce maps cost effectively. However, mapping of yield or even potential yield would not justify the investment in GPS technology unless it could be used to produce treatment maps that would result in reduced treatment costs or increased output value.

Automated variation of applications also involves investment in equipment. It must be shown that automation will justify costs by increasing margins over and above that which can be achieved manually. With comparatively uniform soil type, it is unlikely that automatic variation of cultivation or seed rate, although theoretically possible, would be justified. The strong connection between yield and soil moisture status suggests that automated detection of moisture availability or excess could be a useful guide to yield potential or drainage requirements. This connection would have to be proven on areas of less than a whole field to be justified. The technology already exists to measure and map soil moisture status and compare this with yield maps but I am not aware of any reliable trial results as yet. Although the mapping process would only need to be carried out once (with modifications if corrective action is taken), it would probably need a degree of automation for detailed application to large areas. If the connection between soil moisture and yield can be proven on a sufficiently detailed scale, this may provide a means of varying inputs according to yield potential.

In the case of variable fertiliser applications, it would seem unlikely that investment could be justified for lime or potash, but nitrogen and phosphate are both significant input costs and, provided treatment maps could be generated at reasonable cost, variable application could be justified. Automated detection of leaf area index or chlorophyll content would seem to offer reasonable prospects of producing treatment maps for nitrogen. In the case of phosphate (and potash) recent work has been done at Rothamsted to improve the prediction of optimum requirements using tissue analysis. If this could be combined with a means of automated detection then prospects for automated variable application of nutrients would be dramatically improved, compared to intensive soil sampling and analysis.

Pests and diseases do, of course, occur in patches. The difficulty here is to predict where the patches are going to be sufficiently early to allow effective control. The only significant attempt to do this in the past has been the spraying of headlands only, to try and reduce the cost of controlling summer pests of oilseed rape which tend to invade from the edges of the field. While this has been agronomically effective in some years, the economic benefit has been negated by the introduction of 6m buffer zones to protect water courses, applied to the most cost effective products. This kind of treatment depends on prior knowledge of the nature of the infestation and will continue without more sophisticated technology, but the number of problems of this nature are very limited. More reliable thresholds, prediction systems, and dose response information for pests and diseases, combined with computerised decision support systems will hopefully improve the precision of treatment on a field scale. There have been suggestions that fungicide dose could be varied according to crop density within a field. Automated detection of high crop density would then trigger higher fungicide doses (and possibly lower herbicide dose due to improved crop competition). This possibility is worthy of detailed investigation but its reliability will depend on the influence of other factors affecting disease (and weed) infestation.

Herbicides represent the biggest single variable cost on the farm and arguably the biggest potential saving. Patch spraying weeds by marking patches with canes prior to spraying (e.g. herbicide-resistant black grass), defining areas to be sprayed according to tramlines or physical features already in the field, or manually controlling the sprayer during application (mainly for control of wild oats or couch) have all been attempted. While all of these techniques improve the cost effectiveness of herbicide use in the short term, they all result in a greater number of escapees which may lead to more herbicide use in future years. The most successful patching technique has been the spraying of couch regenerated in cereal stubble, prior to ploughing in winter beans in October. The production of reliable weed maps could be of enormous benefit in guiding herbicide applications, both in financial and environmental terms. Experience to date suggests that this will have to be automated to be widely applicable and I fully support the current LINK funded research which is trying to establish the feasibility of achieving automated detection of weeds and application of herbicides.

Precision of application of all fertiliser and pesticides is important for both economic and environmental reasons, whether on a field scale or on smaller units. Well trained operators and well maintained equipment are important in achieving this, but over regulation in this area could increase costs with little benefit. There is a danger of diverting resources from the development and uptake of new technology which would be of greater benefit. Reducing non-target effects by, for instance, controlling spray drift, must be done without reducing efficacy. Spray delivery systems, including boom stabilising devices, should be independently assessed for both safety and efficacy, and I applaud the efforts of the British Crop Protection Council in this difficult area. In future it will be desirable to have a standard application unit for precision detection and application. While standard tramline widths will be useful initially, greater savings could possibly be made with units down to say 6m wide. Precision of detection and control of application on smaller units would increase complexity and costs with little additional benefit. EU proposals to limit boom sections to smaller sizes are not helpful in this respect.

CONCLUSIONS

There is much research and practical interest in greater precision in crop production. Knowledge of variation in soil characteristics, historical features and yield performance will be of value in targeting this effort to the most responsive areas. Major progress will be made if automated detection of soil moisture, nutrient status, and crop and weed density can be reliably achieved. This information will probably need to be combined with computerised decision support systems in order to translate the information gained into meaningful treatment maps to facilitate variable treatment either by manual or automated equipment. The four functions of detection, decision, application and recording must all remain capable of being conducted manually or automatically and either independently or in an integrated system. This will help to maintain flexibility and allow producers to adopt elements gradually to suit their circumstances. While detailed records of precision applications will facilitate compliance with assurance schemes, such detail should never be made a requirement for assurance of commodities which will lose their identity as soon as they are harvested. Records need only demonstrate good agricultural practice has been applied to the crop as a whole. Costs are not known at present, but on our farm the biggest benefit is likely to come from weed mapping. Whether this will justify automated patch spraying equipment remains to be seen. Variable phosphate application will probably follow and eventually we will have to map yields to try and assess the benefits. We have replaced both the sprayer and the combine in the last two years. I would hope that patch spraying and yield mapping will have demonstrated their value by the time this equipment is next due for replacement. Expenditure will always have to be assessed in comparison with the known benefits of improved drainage.

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