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PROCEEDINGS
OF THE 6th MEETING
OF THE FULL MEMBERS

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CONCLUSIONS

AND RECOMMENDATIONS

CONCLUSIONS AND RECOMMENDATIONS of the 6th Full Members Session - Bologna, EIMA Show, November 6-8, 1995

50 Experts from **24 countries** attended the meeting - held under the auspices of CIGR - discussing a general subject on "A*n appropriate agricultural mechanization in the various world regions*". The subject was subdivided into three main topics:

1.1 - Methodologies for the identification of the optimum mechanization levels;

1.2 - Technological levels needed in the various agricultural areas;

1.3 - Role of High Technologies to contribute to the machine design and operations.

The meeting reached unanimously the following

Conclusions and Recommendations

1.1 METHODOLOGIES FOR IDENTIFICATION OF OPTIMUM MECHANIZATION LEVELS

Three key-note reports by **E. Audsley** (UK), **P. Jannot** (F) and **G. Castelli** and **F. Mazzetto** (I) were presented. Each summarizes the advances in modelling of mechanization management in the three countries.

On the basis of a wide-ranging discussion, the members drew the following main **conclusions**.

The use of computer-based mechanization modelling can significantly contribute to the identification of optimum mechanization strategies. The up-to-date research results on the subject show that the sector has greatly progressed in terms of both methodology (acquisition and transfer of data, identification of the various modelling techniques, definition of goals) and availability of appropriate computer programs.

The application of model-based systems will allow improved organization of farms in terms of crops grown and more rational use of farm equipment. This offers potential economic gains through improved efficiency of production.

For effective diffusion at farm level of the various models, it is necessary to overcome constraints such as:

- the difficulty of making available reliable farm data;
- the lack of education of farmers in the use of modelling technologies for decision making;
- the lack in several countries of effective extension services;
- the difficulty of demonstrating the effectiveness of the results from the use of appropriate models.

Taking into account the above considerations, the following research priorities are identified:

- improved modelling methodologies incorporating factors such as risk, environmental impacts and other unquantifiables;
- automated data collection from machines engaged in real farm operations;
- interactive models for machinery management.

In developing farm model-based systems, due regard should be given to the following factors:

- for each agricultural region representative data must be collected and analysed on depreciation of tractors and other machines, repair costs, work rates, consumption of fuel and other energies, timeliness penalties from agronomic experiments, and environmental impacts;
- acceptability to the beneficiaries such as farmers, contractors and co-operatives with machinery sharing arrangements;
- flexibility of use;
- ability to identify and control risks;
- compatibility with environmental requirements;
- in harmony with standards relating to machines and agricultural practices.

1.2 **TECHNOLOGICAL LEVELS NEEDED IN DIFFERENT AGRICULTURAL AREAS**

Four key-note reports were presented covering the industrialized countries, south-asian, central and east-european and latin-american countries, respectively.

On the basis of the report presented by **J.K. Schueller** and **W.A. Stout** (USA), the Club Members **recommend** that the highly industrialized countries develop their mechanization policies to reduce production costs, improve product quality, safeguard workers' health and safety and protect the environment (soil, water, air). Taking into account the growing role of contractors, the members agree on the need to develop two main mechanization strategies, one to be used by contractors and machinery-sharing companies and one to be used directly by farmers.

These goals could be achieved through:

- **for tractors**: the optimization of tractor-implement combinations; low ground pressure high efficiency tyres and tracks; light weight design; the reduction of engine emissions; the reduction of energy losses; continuously-variable transmissions; mechanical front-wheel drive systems; suspensions for improved ride comfort; and sensing and control elements;
- **for agricultural machines**: precision farming technologies based on global positioning systems; technologies for tillage; innovations which reduce specific energy inputs and emissions; new machinery for biomass and other industrial crops; machinery with improved performance; sensors and related algorithms to control performance; systems to minimize operator exposure to chemicals and to other health and safety risks.

These technologies are often too expensive for one manufacturer. The Club members, therefore, underline the need to support research co-operation and technology transfer between research institutes and/or the industrial sector.

The key-note report presented by **G.Singh** (India) underlined the development of indian agriculture over the last 45 years. At present, India is self-sufficient in food production through the increased use of high-yielding varieties and irrigation as well as the increase in power made available for agriculture through rural electrification and the introduction of locally manufactured tractors and other machines. By the year 2000, however, the total population of India will reach 1 billion, the agricultural area is subdivided into more then 105 million farms with an average size under 2 ha; the efficiency of use of the key agricultural inputs is still low and about 70% of total cropped area is dryland with low and variable crop yields.

Taking into account these major issues, the members recommend the local development of appropriate mechanization, with particular reference to the technologies for:

- environmental conservation;
- improvement of produce packaging and handling;
- development of rural agro-processing, including aquaculture and the utilization of agricultural wastes;
- rationalization and development of modern irrigation systems driven by renewable energy sources.

The development of agricultural extension services and contractor services are crucial to achievement of these objectives.

On central and east-european countries, the members, on the basis of the key-note report by **P. Kic** (CZ), recognize the general difficulties of the various countries in transforming the centrally-planned economies into market economies. These difficulties have produced an economic recession in both the industrial and agricultural sectors within the former COMECON area, with the result that the agricultural machinery industry has drastically reduced its production. The present situation in the various countries is greatly different but there are some common characteristics, namely, the large numbers engaged in agriculture and the small farm size of a few hectares, despite, the continued existence of large cooperative farms.

The drastic reduction of industrial production in the last four years and the decrease in purchasing power of the farmers has limited introduction of appropriate mechanization and good farm management. Once the opportunity for the development of contractor services and shared machinary use was demonstrated, some small manufacturers and dealers were able to service the immediate agricultural needs. Joint ventures between local manufacturers and well-established international companies could continue this trend.

On the basis of this approach the members **recommend** that industrialized countries should promote the transfer of appropriate technologies to increase yields, decrease losses and improve environmental protection. Without resolution of the issue of land ownership, the development of cooperation between eastern and western manufacturers will be inhibited.

The key-note report presented by **T.L. Wiles** (UK) which highlighted several important issues linked to the development of agricultural mechanization in Latin America, confirms the considerable yet diverse need for mechanization of food and industrial crops on farms of widely varying sizes and management systems.

Levels of mechanization vary considerably throught the region and it is not uncommon to find well-organized, highly mechanized agriculture alongside systems based almost exclusively on hand-labour, as is the case with all the coffee grown outside Brazil.

Case study examples were provided on agrochemical spraying and soil tillage to illustrate the need for appropriate mechanization to protect workers and the environment, to conserve soil and water and to assist timely planting. These are issues which are currently much more critical in this part of the world than in most developed agricultural countries.

Moreover, the appraisal confirms that simply transferring technologies from more developed countries into Latin America, is often inappropriate. Requirements are location-specific and must take into account the prevailing climatic, pedological, agronomic, structural and socio-economic conditions.

The members **recommend** the following principles for improved mechanization in Latin America:

- to pay particular attention to the local conditions, which require the development of appropriate systems and strategies which often differ from those of more developed countries;
- to support links between agricultural engineering research institutions and equipment manufacturing companies as well as cooperation between Latin America and industrialized countries.

1.3 **ROLE OF ADVANCED TECHNOLOGIES IN MACHINE DESIGN AND OPERATION**

The key-note report by **F. Sevila, J.M. Roger and B. Bonicelli** (F) focussed mainly on mechatronics. This term is widely applied to machines operating with less direct human involvement.

These machines are being developed in response to new social, economic and technological trends:

- the development of highly-specialized types of farming;
- the reduced willingness of labour to perform some tasks;
- the improved performance and decreasing cost of electronic components and software;

The members recognize that mechatronics for agricultural applications (including on-line sensors, signal, data and information processing systems, and electronically controlled actuators) tend to be more complex than the ones developed for other industrial applications.

Mechatronics should not be developed in isolation, but rather in cooperation between farmers, engineers, information technology specialists, and scientists. There is, of course, a need for the industry to develop specific expertise in its design teams which will allow them to make experienced decisions.

Procedures to discipline the design process have been identified. They include hierarchical system modelling to represent the mechatronic device throughout its development, and systematic representation of the reasoning for each step of the design.

Having recognized the advantages that the application of mechatronics can give to the agricultural machinery sector, the members **recommend** a coordinated effort for further development of these technologies.

- Taking into account that a limitation of the application of mechatronics is that agronomic and biological models, and appropriate sensors, are less advanced than mechatronic devices, greater efforts should be devoted by agronomists, biologists and physicists, to remedy this deficiency.
- Taking into account that most agricultural machinery manufacturers are of a small to medium size improved R&D cooperation between research institutions and industry should be stimulated in order to support the application of this innovative approach.
- A high priority is also given to adequate education of engineers, which should not be by isolated training but by focussing on the real needs of machinery and farming systems.

CONCLUSIONI
E RACCOMANDAZIONI

CONCLUSIONI E RACCOMANDAZIONI della 6ª Sessione dei Membri Ordinari - Bologna, EIMA, 6-8 Novembre 1995

50 membri provenienti da **24 paesi**, hanno partecipato all'incontro, promosso sotto gli auspici della CIGR, per discutere il tema generale dal titolo "*Per una meccanizzazione agricola appropriata nelle varie aree geografiche*". Tale argomento e' stato suddiviso nelle seguenti tre tematiche specifiche:

1.1 - Metodologie per la identificazione di livelli di meccanizzazione ottimali

1.2 - Livelli tecnologici richiesti nelle varie aree agricole del mondo

1.3 - Contributo delle tecnologie avanzate alla progettazione e all'operativita' delle macchine.

Dopo approfondita discussione i partecipanti hanno unanimamente raggiunto le seguenti

Conclusioni e Raccomandazioni

1.1 **METODOLOGIE PER LA IDENTIFICAZIONE DEI LIVELLI DI MECCANIZZAZIONE OTTIMALI**

Sull'argomento sono state presentate tre relazioni introduttive da **E. Audsley** (UK), **P. Jannot** (F) e **G. Castelli-F. Mazzetto** (I), ciascuna delle quali riflette l'evoluzione della modellistica di settore nei rispettivi Paesi. Sulla base della successiva discussione, i partecipanti sottolineano le principali **conclusioni** raggiunte.

L'uso dello strumento informatico puo' contribuire in misura determinante alle scelte ottimali di meccanizzazione. I piu' recenti risultati della ricerca inducono a ritenere che il settore si sia fortemente sviluppato, a livello sia di impostazione metodologica (acquisizione e trasferimento dati, identificazione delle diverse tecniche modellistiche, individuazione degli obiettivi), sia di sviluppo e disponibilita' di software appropriati.

L'applicazione di sistemi basati sui modelli puo' consentire una migliore organizzazione aziendale in termini di rese produttive e di un piu' razionale uso dei mezzi di produzione, con conseguente miglioramento delle diverse situazioni economiche.

Per una reale diffusione a livello agricolo dei modelli proponibili, occorre, tuttavia, superare alcune barriere, quali:

- la difficolta' di disporre di dati aziendali analitici e attendibili;
- la scarsa propensione degli agricoltori ad avvicinarsi alle tecnologie informatiche;
- la mancanza, in diversi Paesi, di una efficace rete di assistenza tecnica;
- l'oggettiva difficolta' a dimostrare/validare l'efficacia dei risultati ottenibili attraverso i modelli.

Sulla base di quanto sopra, le seguenti priorita' di ricerca sono state identificate:

- metodologie di analisi migliorate che incorporino fattori di rischio, di impatto ambientale e altri;
- metodi di raccolta automatici di dati relativi alle specifiche operazioni aziendali;
- modelli interattivi per la gestione delle macchine.

Nello sviluppare sistemi basati su modelli aziendali le seguenti priorita' devono essere rispettate:

- raccolta e analisi di dati tecnico-economici sui trattori e le macchine operatrici regione per regione;
- accettabilita' da parte dei beneficiari quali agricoltori, contoterzisti e cooperative;
- flessibilita' d'uso;
- capacita' di identificare i fattori di rischio;
- compatibilita' con le esigenze ambientali;
- armonizzazione di standards relativi alle macchine e alle varie operazioni.

1.2 **LIVELLI TECNOLOGICI RICHIESTI NELLE VARIE AREE GEOGRAFICHE**

In argomento sono stati presentati quattro rapporti introduttivi relativi, rispettivamente, ai gruppi di paesi: industrializzati (Europa occidentale, USA e Canada), asiatici, est europei, latino americani.

Sulla base dei contenuti del rapporto presentato da **D.K. Schueller** e **B.A. Stout** (USA) i partecipanti, dopo approfondita discussione, **raccomandano**, per l'agricoltura dei paesi ad alta industrializzazione, lo sviluppo di una meccanizzazione che miri a: ridurre i costi di produzione; migliorare la qualita' dei prodotti; proteggere la salute e la sicurezza degli addetti e salvaguardare l’ambiente (suolo, acqua, aria). A tal fine, tenuto conto del ruolo crescente dei contoterzisti, richiamano l’esigenza di definire due tipologie base di meccanizzazione: una destinata alle imprese in conto terzi e una a servizio delle piccole aziende da impiegare limitatamente alle operazioni routinarie e ripetitive.

Questi obiettivi devono essere raggiunti:

- per quanto concerne i **trattori,** a mezzo di: l’ottimizzazione della combinazione trattore/operatrice; la riduzione del compattamento del terreno e il miglioramento dell’efficienza degli organi di propulsione; la riduzione delle perdite di energia; l’adozione di trasmissioni continue, di accoppiamenti portanti anteriori, di sensori e elementi di controllo per il miglioramento delle prestazioni;

- per quanto concerne le **macchine agricole** a mezzo di: tecnologie per il controllo puntuale delle produzioni collegate con sistemi di posizionamento spaziali; tecnologie per la riduzione e l’ottimizzazione della lavorazione del terreno; tecnologie per l’utilizzazione delle biomasse non alimentari; sensori e relativi modelli per il controllo delle prestazioni; sistemi innovativi per la riduzione dell’esposizione all’applicazione dei prodotti chimici e di altri fattori di rischio da parte degli agricoltori.

Tali tecnologie sono spesso troppo costose per il singolo costruttore. Pertanto i partecipanti sottolineano l’esigenza di favorire ogni forma di collaborazione fra mondo industriale e istituti di ricerca al fine di pervenire ad un rapido raggiungimento degli obiettivi anche in termini divulgativi.

La relazione presentata da **G. Singh** (India) sottolinea il grado di sviluppo raggiunto dell’agricoltura indiana negli ultimi 65 anni. Attualmente, l’India e’ autosufficiente per le produzioni alimentari di base avendo aumentato l’uso di varieta’ ad alta produttivita’ e le aree irrigue. Al contempo, si e’ assistito allo sviluppo dell’elettrificazione rurale e della meccanizzazione basata su trattori e operatrici di produzione locale.

Nel 2000, comunque, la popolazione indiana raggiungera’ 1 miliardo di unita’ mentre l’area agricola sara’ suddivisa in piu’ di 105 milioni di aziende di dimensione mediainferiore a 2 ha. L’uso dei principali fattori produttivi sara’, tuttavia, ancora basso e l’area coltivata non irrigabile superera’ il 70% di quella totale.

Sulla base di quanto sopra, i partecipanti **raccomandano** lo sviluppo locale di un’appropriata meccanizzazione con particolare riferimento alle seguenti tecnologie:

- per la conservazione ambientale;
- per il confezionamento e la manipolazione dei prodotti;
- per lo sviluppo dell’industria a valle dell’agricoltura nonche’ dell’acquacoltura e della gestione dei sottoprodotti;
- per lo sviluppo di moderni sistemi di irrigazione azionati da risorse energetiche rinnovabili.

Lo sviluppo dell’assistenza tecnica e delle imprese agromeccaniche, svolgera’, infine, un ruolo cruciale per il raggiungimento di detti obiettivi.

Circa i paesi dell’Europa centrale e orientale, i convenuti - dopo ampia discussione della relazione introduttiva presentata da **P. Kic** (CZ) - riconoscono lo stato di difficolta’ generale dei paesi stessi nel passaggio da un’economia di stato ad un’economia di mercato, difficolta’ che ha portato a una recessione economica in termini sia industriali, sia agricoli. Cio’ ha riscontro anche nell’industria delle macchine agricole che, causa le difficolta’ di mercato interno all’area, ha ridotto drasticamente la propria produzione.

Peraltro, la situazione nei diversi paesi e’ abbastanza differenziata anche se, in termini generali, sussistono alcune condizioni comuni fra cui l’elevato numero di occupati in agricoltura e la ridotta dimensione aziendale.

La forte riduzione della produzione industriale negli ultimi 4 anni e il decremento del mercato dovuto a mancanza di capacita’ di acquisto da parte degli agricoltori hanno limitato fortemente la possibilita’ di diffusione di una meccanizzazione appropriata e di una moderna gestione aziendale.

Mentre si assiste, in ogni caso, al progressivo - ancorche’ marginale - sviluppo di imprese agromeccaniche di servizio, si nota anche il sorgere di: piccoli costruttori e dealers che provvedono ai fabbisogni meccanico-agricoli piu’ urgenti; joint-ventures fra costruttori locali e industrie di paesi industrializzati.

Sulla base di queste analisi, i partecipanti **raccomandano** che sia compiuto ogni sforzo da parte dei paesi industrializzati per favorire il trasferimento di tecnologie meccaniche appropriate e mirate soprattutto a: diminuire le perdite (anche post-raccolta) di prodotti, aumentare le rese e migliorare le condizioni di protezione dell’ambiente. Senza la risoluzione di queste problematiche e delle proprieta’ delle aziende, lo sviluppo della cooperazione fra i costruttori occidentali e orientali verra’ fortemente penalizzato.

Il rapporto presentato da **T.L. Wiles** (UK) riferisce sui principali problemi legati allo sviluppo della meccanizzazione agricola in America Latina. Ivi, in termini generali, sussiste un’ampia esigenza di meccanizzazione sia per le colture alimentari di base, sia per le produzioni da reddito. Tale meccanizzazione deve essere tecnicamente ed economicamente appropriata, si' da rispondere alle crescenti esigenze di buona conduzione aziendale e di sviluppo delle produzioni alimentari, oltre che all'aumento progressivo del costo del lavoro e alla crescente necessita' di disporre di territori da coltivare. Non e', tuttavia, infrequente trovare - accanto ad aziende basate sul lavoro manuale - aziende ben organizzate e fortemente meccanizzate.

La discussione sullo stato delle irroratrici e delle macchine per la lavorazione del terreno mediamente impiegate - assunte come esempio - dimostra l'esigenza di sviluppare una meccanizzazione appropriata che protegga gli operatori e l'ambiente, migliorando le rese produttive.

Peraltro, l'analisi svolta conferma la dannosita' di un semplice trasferimento in quella regione di tecnologie prodotte e utilizzate in paesi a clima temperato, in quanto le esigenze locali risultano molto specifiche e diversificate derivando dalle particolari condizioni climatiche, agronomiche, patologiche, strutturali e sociali di ciascun paese.

Dopo ampia discussione, i partecipanti, nell'individuare i criteri di sviluppo della meccanizzazione da seguire per l'America Latina, **raccomandano**:

· di prendere in attenta considerazione le condizioni locali, peraltro ampiamente diversificate da paese a paese, che richiedono la produzione di soluzioni differenti da quelle proprie delle aree industrializzate;

· di instaurare un approccio di tipo pratico basato sulle reali esigenze specifiche senza pensare a un semplice trasferimento di tecnologie tal quali, supportando i collegamenti fra Istituti di ricerca e costruttori di macchine, cosi' come la cooperazione fra i paesi latino-americani e quelli industrializzati.

1.3 **RUOLO DELLE TECNOLOGIE AVANZATE PER CONTRIBUIRE ALLA PROGETTAZIONE E OPERATIVITA' DELLE MACCHINE**

Sull'argomento e' stato presentato un rapporto introduttivo da parte di **F. Sevila**, **J.M. Roger** e **B. Bonicelli** (F) focalizzato sulla "meccatronica", termine largamente applicato alle macchine che operano con basso coinvolgimento umano. Tali macchine si stanno sviluppando in conseguenza alle nuove tendenze sociali, economiche e tecnologiche relative a:

- lo sviluppo di aziende altamente specializzate;
- la rarefazione della manodopera per lo svolgimento di alcuni tipi di lavoro;
- l'aumento delle prestazioni e la riduzione dei costi, dei componenti elettronici e del software.

I partecipanti riconoscono che lo sviluppo in corso di sistemi meccatronici (includenti l'applicazione di: sensori on-line; sistemi di segnalazione, raccolta e informazione dello svolgimento dei processi; attuatori controllati elettronicamente) per la meccanizzazione agricola tende a divenire sempre piu' complesso. Di conseguenza, l'industria di macchine agricole non e' tuttora in grado di utilizzare appieno tali tecnologie, cosi' come avviene in altri settori industriali. Vi e', quindi, l'esigenza di sviluppare know-how specifici in fase di progettazione attraverso gruppi di specialisti di alta qualificazione (agricoltori, ingegneri, informatici ecc.).

Vi e', inoltre, l'esigenza di conoscere meglio il funzionamento di queste complesse tecniche progettuali includenti una modellizzazione gerarchica di sistema atta a rappresentare l'utilita' dei vari dispositivi meccatronici nel loro sviluppo, nonche' di qualificare i successivi passaggi nella progettazione.

Queste diverse rappresentazioni hanno portato a una serie di proposte per la definizione di un modello coerente del processo di progettazione.

Avendo riconosciuto i vantaggi che la diffusa applicazione della meccatronica e' in grado di apportare al comparto delle macchine agricole, i convenuti **raccomandano** unanimi che venga compiuto ogni sforzo coordinato per ulteriormente sviluppare le tecnologie, i processi e i loro sistemi di comprensione come indispensabile strumento per una meccanizzazione piu' rispondente alle crescenti esigenze economiche, qualitative e di protezione ambientale dell'agricoltura dei vari paesi.

In considerazione, inoltre, del fatto che una delle limitazioni all'applicazione diffusa della meccatronica consiste nel minor sviluppo dei modelli agronomici e biologici rispetto alle tecnologie della meccatronica stessa, un grande sforzo deve essere compiuto dagli esperti di questi settori per recuperare questo divario.

Considerando, poi, che la maggioranza delle industrie costruttrici di macchine agricole e' costituita da unita' medio-piccole, si raccomanda la creazione di uffici tecnici a servizio consorziale mirati alla ricerca e allo sviluppo del settore.

Infine, un'alta priorita' deve essere assegnata alla formazione di ingegneri specialisti, si' da meglio rispondere alle reali esigenze dei sistemi meccatronici e della loro gestione aziendale.

SESSION 1

METHODOLOGIES FOR IDENTIFYING OPTIMUM MECHANIZATION LEVELS

Chairman: Prof. Jaime ORTIZ-CAÑAVATE, SPAIN

Methodologies for the identification of the optimum mechanization level (Report n.1)

by *Eric Audsley*

UK

1. The farmer

One farmer method of mechanisation planning is to divide the number of hours he expects to be available for the task (e.g. 19 days for potato harvesting), by the area he has planted to determine the required rate of work. Then seek to buy machinery input (in addition to any he currently has) to achieve the rate of work. The ‘hours’ are determined by experience. The workrate of different machinery alternatives is determined by experience and observation. He has chosen to grow that area of crop.

This type of calculation is used by farmers for most tasks - they wish to complete harvest in a certain number of days, they wish to plant all the crop by a specified date, they wish to spray the whole area in a given number of days. Thus either the current machinery system is satisfactory - in that it can achieve these targets or needs improving. Thus if additional land had been taken on that required more combine power, the alternatives are purchasing an additional combine (possibly second-hand) or exchanging the current combine for a larger one. The analysis is a simple partial budget comparing the cost of the two alternatives, including the cost of an extra combine driver for harvest (**Fig. 1**).

Alternatives to improve existing satisfactory systems are considered the same way. This leads naturally to increasing the size of trailers at harvest to reduce the amount of travel time and the current trend to combined harrow/drill systems. One sugar beet farmer I recently met operated his farm with all 90 kW tractors (five of them). He had purchased a combined harrow/drill to improve his system which consisted of ploughing immediately followed by harrowing and drilling. Unfortunately the plough was now slower and held up the drill, so he had now made the (revolutionary) decision to purchase one 120 kW tractor for the ploughing. I predict next year he will discover it is now optimal to purchase a 120 kW tractor to speed up the drill!

Therefore one concludes that farmers are making piecemeal decisions without considering the whole system and aiming for progressively higher levels of efficiency (whatever that means) which means larger machinery but not necessarily optimum for his size of farm enterprise. In order to utilise larger machinery on farms which cannot justify them, we are seeing the growth of contractors, machinery rings, and so on. In truth of course, the decisions are not totally piecemeal since the farmer knows the whole system and is taking into account other cropping, other operations, soil type, abilities and preferences of the workers and many other unspoken factors in arriving at a machinery decision. However, even if they can be, they are not quantified in arriving at a decision.

2. The adviser

In the UK the extension service is now a chargeable consultancy. As such, farmers may commission a report advising on appropriate mechanisation. In general the same partial budgeting methods are used, although the calculations are likely to be more formalised. Comparison with the ‘top 10%’ may also be used. They are all, however, merely comparisons between a small number of alternatives rather than optimising. A number of linear programmes have been developed by the extension service but none have ever been used for anything other than developing general principles.

3. Research

In the research community, a large number of computer based models have been developed to assist with mechanisation planning. How do these match with the farmer's requirements?

3.1 *A method of comparing the capital cost of a machine with an annual cost such as labour*

Traditionally this is called depreciation and accountants' methods of calculating it ignore the real value of equipment and inflation. More accurate methods use discounted cash flow techniques to compare the rate of return of different cash flow streams and from this, an equivalent annual cost can be derived (**Fig. 2**). This accurate calculation is an important input to all methods for determining optimum mechanisation levels.

3.2 *A method of determining the workrate of systems of machinery*

There are three very distinct types of situation - power limited, logistics limited, optimal. In the power limited category are jobs such as ploughing and forage harvesting for which formulae have been developed. One concept for cultivation involves solving equations balancing power and pull based on empirical descriptions of soil characteristics (our TRAC program encapsulates this method). Alternatives are a simple formula such as for forage harvesting balancing power versus yield, slope, etc. This category suffers from the problem of determining the proportion of the maximum power that is used and "field efficiency" which is very variable particularly if turning, headlands, repairs, blockages and sundry other delays are included. If one allows 70% for operating power, 70% for turning and headlands and 70% for repairs and blockages, this is 34% of the nominal maximum workrate. Raising efficiency to 80% makes this 51%. Thus a nominal 1 h/ha could easily be 2 h/ha or 3 h/ha in reality. This makes a big difference when comparing alternative systems, and while it important to use the same procedure to derive comparable workrates, makes one question whether efforts are being directed at the right part of the procedure.

Spraying and harvest transport are examples of logistics limited workrates. Thus having calculated forage harvester workrate, the overall system workrate depends on the number of trailers, their travel speed and distance to the unloading point (SPRAY, TRANS). The actual workrate is again very situation dependent and it is again important to use a repeatable procedure to calculate the workrate of alternative systems. Doubling sprayer capacity does not double the workrate.

Combine harvesting is an example of an optimal workrate. The faster the workrate, the greater the threshing losses but the slower the workrate. The greater the shedding losses and operating costs. One can thus derive an optimum workrate which minimises total costs and thus compare alternative combine sizes on a fair basis (HARV).

In most of these methods, attempts are made to calculate a cost per hectare of the operation by including a cost per hour of labour or tractors. These are then compared with the cost of using a contractor. This is very wrong since the cost of the labour or tractor has not necessarily been reduced by the use of a contractor. In general, a safer assumption in a partial budget is zero cost labour and tractors.

3.3 *A method of optimising an operation*

In these the operation is simulated in detail and each aspect costed - thus losses, fuel, repairs, labour and capital costs, insurance and so on. In all cases it is necessary to define a system boundary beyond which costs are not considered. Thus, for example with combine harvesting, the effect on subsequent operations are ignored but the drier may or may not be included. Labour and tractor costs are still a problem. Nevertheless, where the operation represents a peak workload and can be disaggregated from other operations, these models can be fairly accurate. Thus forage harvesting, ploughing and drilling, and combine harvesting are reasonable subjects (McGechan, Oskoui/Witney, HARDRY).

Typically the procedure is to simulate the operation over a number of years to include the variability due to the weather. This produces a single estimate of the operation cost for which several optimisation methods exist such as the simplex method (not to be confused with the linear programming method of the same name) and genetic algorithms. A problem is the need to make allowance for the risk of not completing the task. A low penalty cost leads to mechanisation levels much lower than those in reality. However, a high penalty cost has the opposite effect and leads to the optimum system being that which just completes the task within the time available in the worst year.

3.4 *A method of estimating workability*

The procedure also introduces a major sub-problem of determining the workable hours available for the operation each year. For soil trafficability the technique is to use soil moisture simulation models and specify a moisture level boundary between work and no-work. For harvesting, complex grain/straw/forage moisture simulations have been constructed. Simpler rainfall based predictions have also been used. In general, the methods give reasonable estimates of the number of workable hours for analysis purposes but not necessarily the same hours as were actually workable. I often think it ironic that farmers spend large sums of money on enormous sprayers because of the need to apply chemicals at exactly the right time in few workable hours, yet I know of very few attempts to calculate the optimum system by simulating the number of workable hours for spraying and the cost of untimely spraying.

In practice, farmers modify their systems or their definition of workability in different years. As an example consider ploughing, cultivating and drilling. In dry conditions more work is needed to prepare a seedbed giving higher repair costs but workability is no problem. In wet conditions, farmers make do with a poor seedbed and work in conditions they would otherwise choose not to. This can by modelled by a dynamic programming approach which, at each stage, considers the costs of working or not, taking account of how much work remains to be done (CULTDP) (**Figs**.**3**, **4** and **5**) In this way a work schedule is produced which is optimum for all years: {IF today is day (300) AND there are (100) ha remaining to drill AND the soil is drier than (X) THEN work ELSE do not work}. The result is an expected operation cost and the mechanisation level can then be optimised as before. The penalty cost of not completing the task has less influence but is nevertheless an important factor.

3.5 *A method of optimising the whole farm system*

It is possible to simulate a whole farm system as just a collection of operations. The difficulty is to determine which operation to do at each point in time. One approach (van Elderen) is to derive a simple heuristic (a rule that gives a good but not optimal solution) to determine which operation is most important and should be done first. This also, of course, has to allow for operations to be delayed to better times even if they are most important now. The competing approach is to use the linear programming methodology which naturally optimises and schedules operations simultaneously (ARABLE, HORTIC, DAIRY). Both methods need the costs and workrates derived by the earlier methods (**Figs**.**6** and **7**).

While the simulation approach can appear more natural and allows several years to be simulated and the profits averaged, it is difficult to optimise and as it is still a simplification of reality, does not necessarily provide an answer which is more accurate than from a similarly constructed linear programme model; which, despite its name, can include non-linear components.

A major factor confounding the determination of optimum mechanisation systems, is the variability from year to year and farm to farm in crop yields, responses to crop inputs, workability and the farmer's view of workability. Since decisions are made before the event, the performance of an analytically determined optimum system can be guaranteed not to be optimum in the current year, even though it should be better than average. Advisers cannot therefore determine a best system to which all farmers should be persuaded to conform. This is, I think, well illustrated by an analysis of the optimum farm system calculated for a range of labour intensities expressed as {number of men per 1000 ha} (**Fig.8**). At low intensities the cropping is wheat, beans and oilseed rape, at high intensities it includes large area of sugar beet and potatoes. However, the farm gross margin varies from only 490 £/ha at 5 men to 454 £/ha at 10 men, less than 0.5 t/ha of wheat. Thus taking into account the uncertainty in crop yields and gross margins, any of these could reasonably be considered good solutions. (This was suggested to me as being a solution to rural unemployment - pity about the potato mountain!) There is a mountain of economics literature on different multiple criteria methods for selecting the best solutions when the profit is subject to variability, but they do not consider workability variability.

3.6 *Environmental concerns*

Although the above methods are generally all that is required, there is a modern need to also consider environmental factors explicitly, which is the subject of the current (UK+FR+IT) EC project. These factors can be conveniently divided into mandatory and optional restrictions. Mandatory restrictions are gradually being introduced such as restrictions on the amount of active ingredient. These can generally be easily incorporated as constraints within the models. Optional restrictions occur where a farmer can choose between different equipment or operations based on their environmental impact. The system therefore presents options with decreasing profitability but also with decreasing environmental impact and the farmer has the choice of foregoing some profit for reduced impact.

In order to determine optimum mechanisation in these circumstances, it is necessary to predict the impact from different alternatives. While many models have been and are being developed, they often give different answers. Leaching models will rarely include ploughing versus minimum cultivations as an option for the very reasonable justification that the error in the estimates is very much larger than the difference due to the equipment. Many are only useful for leaching research as they require lots of difficult to obtain or estimate parameters which is one reason why a few such as EPIC become very popular.

3.7 *Comparability*

One of the biggest problems in comparing alternative systems is to compare like with like. This is one of the reasons for using optimisation methods. Given an existing farm it is usually easy to devise a system with a new machine which is apparently better than the existing machine. By using the same procedures to calculate workrate and determine the optimum system with each machine, one obtains a fair comparison. While this procedure sounds fine, there is often a major problem with determining comparability. For example how many passes with a spring tine produce the same seedbed as one pass of a power harrow? The answer 1.5 is not very helpful, nor is the answer that they never do! Again using the example of ploughing versus minimum cultivations, the former controls weeds better and therefore requires less herbicides and consequently reduces the environmental impact due to herbicides although it uses more energy. There are many different conflicting and interacting effects which are confounded by different years' weather, soil types and crop rotation. A system model is needed to produce comparability to determine the best actions for each situation, and hence equivalent levels of weed control, soil structure, etc. This is likely to include probabilistic elements to allow for factors we do not understand, resulting in state transition matrices, which can be used in optimisation methods.

3.8 *Advisory systems*

Advisory systems (or Decision Support Systems) calculate the profitability of the present cropping and future options combining the LP or simulation which calculates the profitability of an option, with the methods to calculate workrates, environmental outputs, etc. (**Fig.9**).

In advising an optimum farm system one needs to consider the existence of capital equipment, farmer preferences and socio-economic reasons. Thus a farm with a potato store or dairy parlour has a zero cost to providing these facilities since the capital has already been spent, whereas a farm considering the purchase or replacement of such capital items has to include the cost. A farmer may prefer not to consider a crop because of lack of knowledge, desire to reduce management load or historical reasons, or may not consider it an option due to reasons such as lack of local labour for casual potato picking or distance to the market. It is well known that it takes time to learn how to grow a new crop and obtain the best yields. This can be included explicitly in the analysis as an initial reduction in profit. Thus one requires an interface to elicit the preferences and features specific to the farm under consideration.

The system can be applied at levels ranging from specific farms to policy level effects on farms. Having carried out an analysis which determines a new more profitable cropping plan, a farmer will not necessarily change to the new plan. In a policy level analysis, one needs to estimate the likelihood of change. One reason is the variability which means that “more profitable” should be more correctly expressed as a “60:40” chance of more profit. Clearly the bigger the potential change in profit, the better the chance. Desire for change is very much a socio-economic dimension depending on circumstances, age, income, need for income, etc.

4. Conclusion

The primary need is for a system to determine optimum farm systems and hence mechanisation levels. This is best done at the whole farm level but some operations can be optimised individually with little error. The methods used can be linear programming, dynamic programming or simulation with optimisation. All methods need input from other methods which calculate workrate, environmental effects and interactions between operations.

The major elements of this system that are missing are (1) a systems models to calculate equivalent operation sequences for alternative procedures, (2) methods to determine optima taking into account the variability and uncertainty in agriculture, (3) optimisations which include environmental factors and (4) a system to bring together all the methods, elicit the local factors and provide the advice from which the farmer can choose the optimum.

Elements of the system which exist and need improvement or improved foundations are (1) methods for calculating workability, (2) methods for calculating workrates and (3) methods for handling non-linearities.

Fig. 1 - A simple partial budget showing conflict between hourly costs and annual costs through not considering whole system

Partial Budget

Basis			**£**	**£/h**
	Tractor	f: £40000, 5yr, 750h	8519	11.4
		c: £40000, 3yr, 1500h	12169	8.1
	Harvester	f: £35000, 7yr, 150h	6234	41.6
		c: £35000, 4yr, 250h	8849	35.4
	Labour		14000	7.0
Hourly costs			**£/h**	
	Farm cost	L + T + H	60.0	
	Contractor	L + T + C	50.5	***
Annual costs			**£ p.a.**	
	Farm cost	L + T + H	28753	***
	Contractor	L + T + C	30094	

Other

Sell 5-yr-old harvester for £11401!

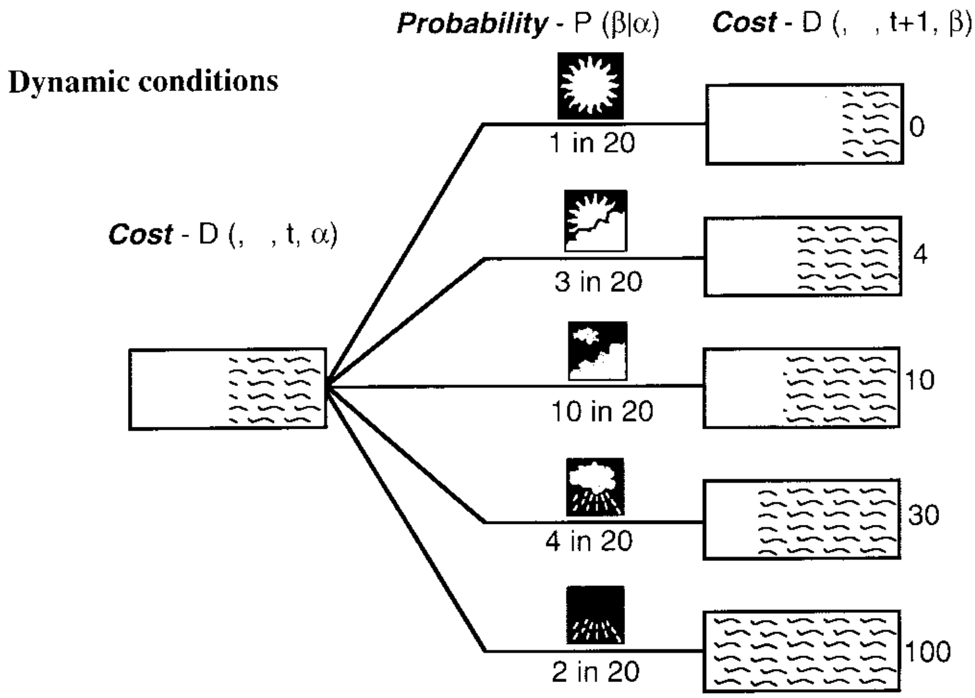
Harvester exists so annual cost is only £1500!

Fig. 2 - An example of calculating the equivalent annual cost by discounted cash flow

Discounted cash flow method

Year	Purchase /sale	Repairs	Cashflow	Discounted cashflow	Equivalent cashflow
0	30000		30000	30000	[6589]
1		331	331	298	6852
2		652	652	529	7126
3		1039	1039	760	7411
4		1459	1459	961	7708
5	-10908	1914	-8994	-5343	8016
				27205	

Fig. 3 - Typical probabilistic change of soil conditions on a day in autumn



Expected cost = (1/20 x 0) + (3/20 x 4) + (10/20 x 10) + (4/20 x 30) + (2/20 x 100) = 21.6

Fig. 4 - Dynamic sequential decisions to plough, drill or not work

Dynamic conditions

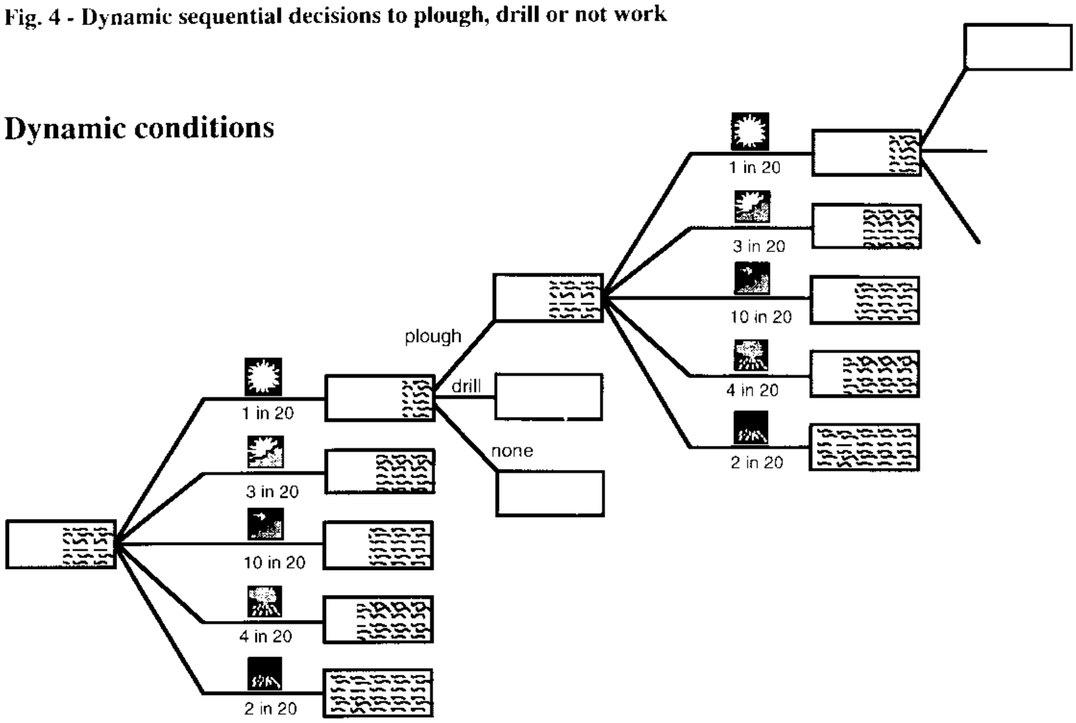


Fig. 5 - Example decision chart showing change in definition of workability depending on amount of work remaining

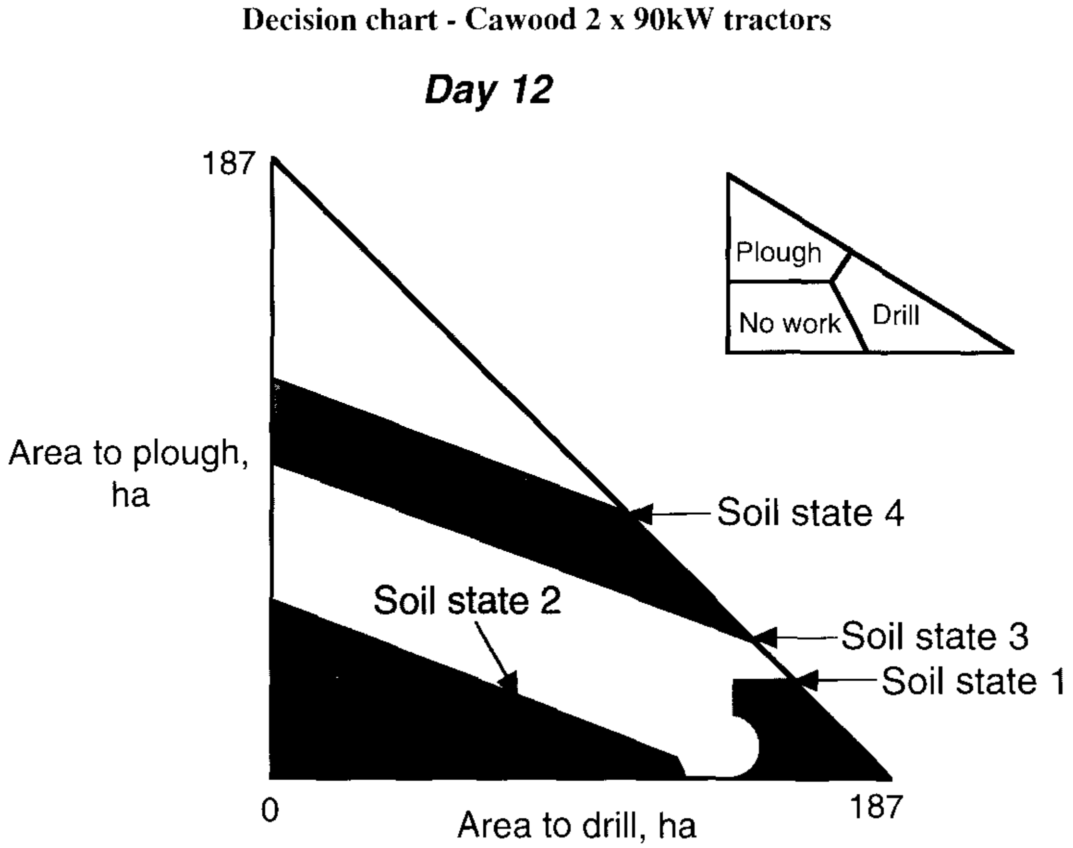
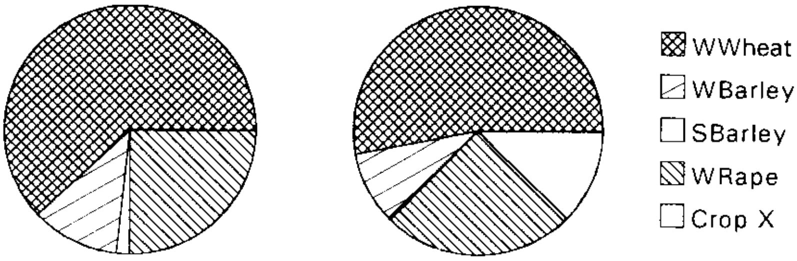


Fig. 6 - Whole farm analysis shows that a lower gross margin can be more profitable

Low gross margin crop

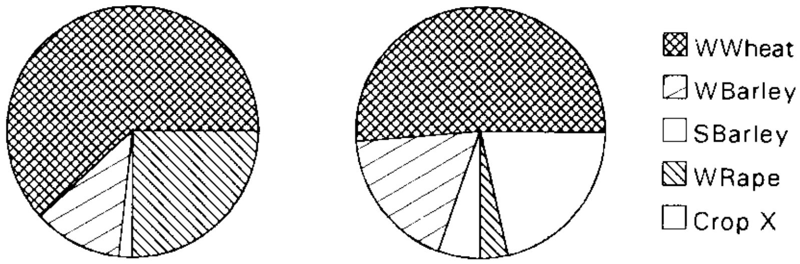
£370/ha versus £600-750/ha



(Sown spring, harvested September)

Fig. 7 - Whole farm analysis shows that optimal changes are not confined to the crop being considered

Spring Oilseed Rape



Causes area of winter barley to increase

Fig. 8 - Optimal cropping plan and farm gross margin as labour available increases

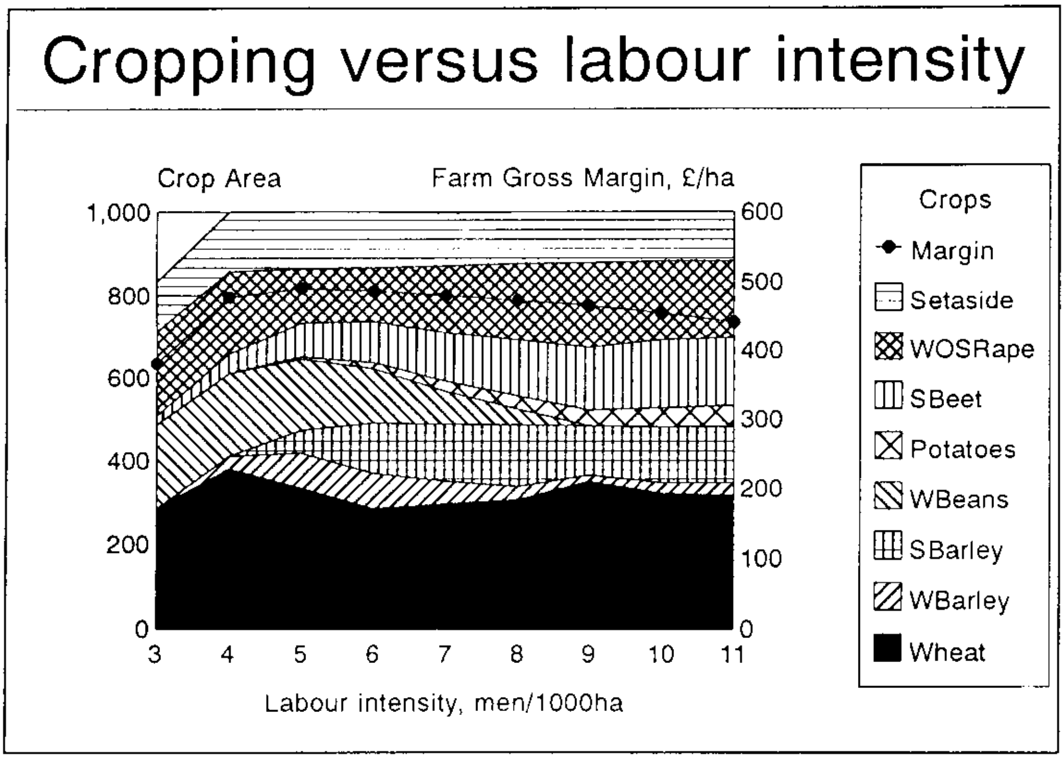
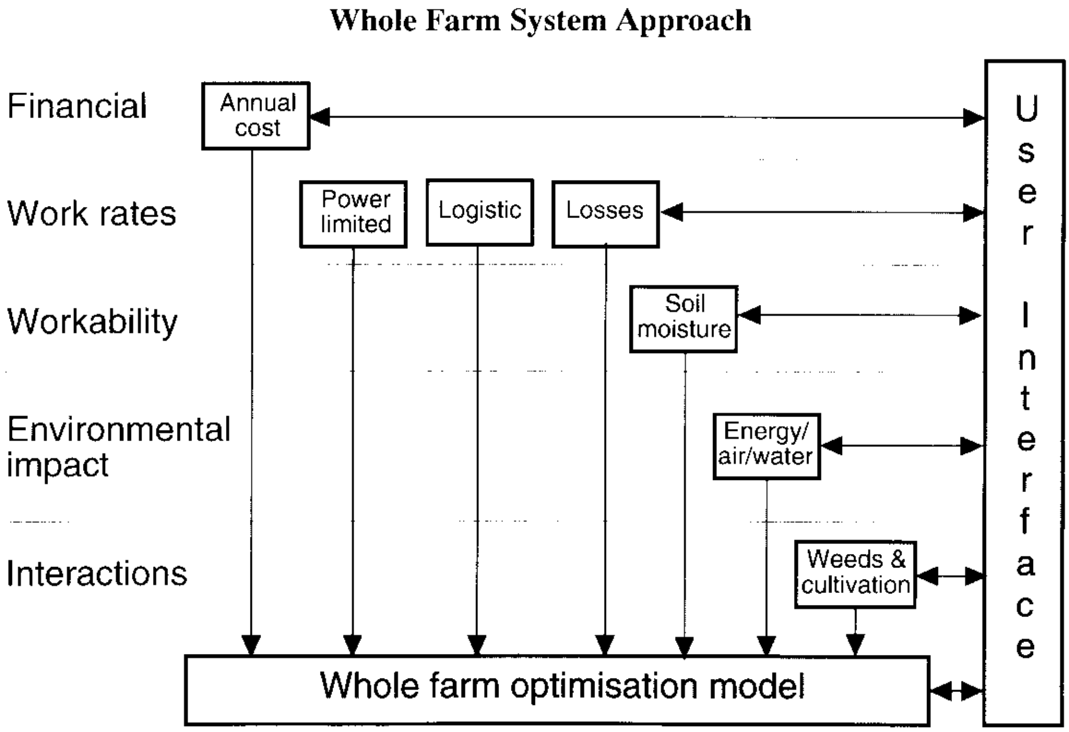


Fig. 9 - A schematic of a whole farm methodology to determine optimum mechanisation levels



Methodologies for the identification of the optimum mechanization level (Report n.2)

by *Giorgio Castelli, Fabrizio Mazzetto*

Italy

1. Information technology for farming systems

The general situation of the world agricultural system will make farm management more complex. Actions related to operative, management and strategic decisions will have an ever-increasing need of update information and of proper decision-making tools in order to optimize productive processes. An expected consequence is that Information Technology (IT) is going to achieve an ever-growing key role in helping the farmer inside his enterprise. The main applications so far are in accounting, record-keeping and word-processing. Anyway, the potential for IT to aid decision-making by providing scientific and other information to the farmer or his adviser is largely unexploited.

Present and future farming systems should be regarded as a set of interconnected engineering processes, and IT can provide means for controlling the inputs to the processes. All the farmer's actions derive from *control* ⇔ *decision interactions*. No control is possible without information. Inside whatever enterprise (farming system included) there are three types of control activities which are different depending on the decision-making level the decider/farmer is going to act on (**Fig. 1**):

- operative control activities, using information to control farm processes as they take place; information derives from data collected directly by process monitoring through mechanical or electronic devices (sensors, automation control etc.);
- management control activities, using information for short-term coordination, documentation and administration tasks;
- strategic control activities, using information for long-term decision activities such as new investments, selection of alternative processes and planning of new farming systems.

Process, raw data, evaluations/calculations, information are all elements sequentially interconnected by the communication flows of the Farm Information System (**Fig. 2**). The key point of this system is the information user, who is enabled to decide and act on the process. Thus, new data are generated and the information circuit is closed. Up to few years ago all the elements of the information system were virtually confined into the user's mind: the farmer was the information system. IT changed and is going to change the situation. The aim of information systems using IT is to provide useful information to the responsibles of the decision-making processes, at whatever decision level they are working on. Data have to be treated in a selective way referring to particular problems and to the decision level in which they will be used. The value of the achieved information depends on the importance of the problem the information is going to influence. In other words: the importance of the consequences that may derive from the solution of these problems.

IT being applied in agriculture today adds an additional process to the ones already carried out on farm: to turn data into decisions. This dato-to-decisions process involves four factors:

- acquisition of data (primary or raw data);
- analysis of information (derived and interpreted data);

- addition of knowledge (interpreted and applied data/information);
- application of wisdom (desiderable end-use of data), implying farmer’s experience and ethics, as well.

The following tool-systems are provided by IT to handle these data-to-decisions factors (**Fig. 3**):

- automation and control systems;
- model-based decision support systems;
- data transfer and communication systems.

A full on-farm application of these systems is still far to be expected. There are certain features of farming which make the application of IT, particularly decision support techniques, more difficult. The biological and ecological systems that exist in agriculture are complex and frequently the scientific understanding of them is incomplete. There is a high degree of uncertainty, for example, due to weather variations and the difficulty of predicting the efficacy of chemicals for pest and disease control applied in a wide range of conditions. However, there are techniques for approaching these problems. It is necessary to establish research networks to secure consultation and an efficient exchange of information among:

- fundamental research in IT (mainly software engineering) and physics;
- agricultural research (including biology, agronomy and agricultural engineering);
- extension services;
- farmers.

The aim is to put up-to-date IT in the hands of decision-makers at farm level, providing the information which the farmer or his adviser needs to make a decision, including scientific knowledge and economic and weather data.

2. Decision support systems for mechanisation

The afore said control-decision levels require different types of model-based decision support systems. Two main decision-making activities can be identified:

- occasional decisions: typically dealing with strategic tasks, when there is usually time to take a careful decision. The results will usually be effective over a period of several years. These decisions may be made by the farmer, or by his adviser, both on a farm-by-farm and a regional basis. Systems for aiding strategic decisions also have a role in helping public policy decision-makers;
- frequent decisions: they consider tactical and even day-to-day tasks, which are often time-critical and usually taken in the light of earlier strategic decisions. Frequent decisions are those which are generally made by the farmer himself, often without time or opportunity to consult an adviser. However, he still needs to take account of constraints arising outside his own farm (say, environmental regulations, market prices, weather etc.).

Farm machinery-related problems involve both occasional and frequent decisions. Many efforts were spent in the past by researchers to solve the strategic problems of farm machinery optimum selection. This can be done facing the task at different increasing complexity levels:

- tractor-implement combinations;

- sequence of field operations referring to particular activities (say soil tillage and drilling, forage or cereal harvesting-handling operations etc.); these sometimes include interactions with stationary activities performed by specific plants (loading/unloading systems, driers etc.);
- whole farm activity system, in which the machinery set (all the power and non-power units on the farm) is used to perform multicropping farming systems; in such a case the boundary of the system to be analyzed is defined in order to include all the annual farm incomes and outcomes.

At A-level the "best" solution is usually identified by minimum or least cost criteria. At B and - particularly - C levels the optimum calls for solutions able to maximize partial/overall annual farm profit throughout conventional cost-benefit analyses. Further non-conventional approaches also use alternative techniques derived from Artificial Intelligence (neural networks and knowledge-based expert systems) or multidimensional methods. This in order to include into the decision-making process subjective, non-numeric information.

The following priorities can be enhanced for occasional decisions of machinery-related problems:

- machinery investment and management decisions: these decisions must be based on many factors such as the economics of purchase, or contracting or cooperation (machinery rings), availability and timeliness penalties, crop rotation and cultivation requirements, and organisation of work and labour. Environmental effects on soil may also be included;
- strategies for field operations: longer term work scheduling taking account of factors such as machinery availability, operations required, soil conditions, and environmental factors such as contamination of neighbouring crops, soil and water;
- adoption of new or alternative farm processes: the aim is to improve the operational efficiency of the farm, also considering the products' quality and environmental impacts.

Anyway, the machinery optimum selection is always a part of the problem and an interdisciplinary approach must be performed when the interaction of machinery with other farm subsystems is considered. From this standpoint, priority research should even concern topics such as:

- crop choice and rotation pattern: related to economics, markets, storage, soil factors, etc.;
- environmental policy decisions: there is potential for decision support at regional as well as farm level;
- decisions related to animal welfare: for example, alternative housing systems and the relationship between husbandry systems and product quality.

Machinery-related frequent decisions, on the other hands, generally require more detailed data and information. Decisions regard an already existing farm machinery set and the farmer's purpose is to optimize its use on crops and/or livestock from work organization (charge of work, tractor/implement combinations), profitability and enviromental standpoints. In such decisions hardware tools (sensors etc.) tend to prevail on softawre ones. Two research priorities can be underlined:

- the development of automatic devices to facilitate site-specific (or spatially variable) field operations, and animal-specific husbandry: the quantity of agrochemicals applied to crops could be significantly reduced if it is made possible to determine the spatial variability of factors such as weed occurrence and soil nutrients within the field, and only apply the chemicals to those sites which require treatment. In the same way animals could be treated individually with benefits in efficiency and animal health and welfare. These concepts need suitable systems for collecting and storing site-specific data about soil, crop yields, animal conditions, machinery identification and positioning. Two very important requirements are a range of new sensors for biological and machinery parameters, and decision models incorporating regional environmental constraints;

- interactive models: some of these models regarding crop and livestock management are already available; the range of applications and their user-friendliness should be extended, and it should be possible to include external data such as prices and weather forecasts. More effective interconnections with external database networks should be available, in order to achieve information for management in real time. Interactive models specifically developed for machinery management can be expected once the problem of monitoring and storing data from field operations through automatic systems will be solved.

3. Relevant features of model-based systems

3.1 *Representative and decisional models*

Models are one of the basic building blocks of an information technology system. Any successful system will require updating continuously with new or adapted models that reflect advances in knowledge. Two kinds of models must be distinguished:

- representative Models (Input Models): developed during research by biologists, agronomists, engineers and physical scientists in order to understand systems and processes and the biological constraints to crop and animal production;
- decisional Models: developed specifically for decision support in order to identify preferable solutions by alternatively running the following selection procedures (Ausiello et al.,1988): a) search algorithms: collecting a pool of feasible solutions among the ones able to satisfy all the technical and/or economic constraints considered by the user; b) optimisation algorithms: selecting an optimal (or sub-optimal) solution able to satisfy the requirements of a given objective function; this is identified by mathematical programming procedures (LP, dynamic programming, heuristic techniques, multidimensional methods etc.). Models must be user-friendly enabling the runner to easily change input parameters, perform sensitivity analysis and consult/update available database.

3.2 *Modelling a system*

A decision support system is always a combination of representative and decisional models. Indipendently on the purpose a representative model is used for, it is constructed to represent (in a simplified way) a system and is used to examine changes in that system. All the variables considered can be of uncontrollable or controllable type (Dent and Blackie, 1979), according to the potential role of the decision-maker (**Fig. 4**). Typical uncontrollable variables are wheather, soil type, prices, market available machinery, enviromental regulation constraints etc. They cannot be changed by user’s strategies and always represent an input to the model. Controllable variable (CV) are all the other inputs to the system through its boundary, fully under the potential control of the decision-maker. CV may represent:

- policies the outcome of which the model may be used to assess (CV to be assessed);
- policies that the model will not be used to assess, because a priori known (constants).

Based upon past modelling experiences on “whole farm systems”, three main CV-types can be listed:

- Farm Resources: factors used to perform farm processes. They regard:

- FR_{Ar}: farm area;
- FR_{Cr}: crop list;
- FR_{Mac}: plants and machinery;
- FR_{Lab}: labour;

  (in case of animal farms, livestock resources - FR_{Liv} - must be added too);

- Farm Actions: ways by which some farm resources are expected to be used to perform processes. Two main actions may be enhanced:
  - X_{Cr}: cropping pattern and rotation;
  - X_{Op}: list of expected annual operations per crop.
- where some primary logic functions can be identified as follows:
  - $X_{Cr} = f(FR_{Ar} , FR_{Cr})$ and $X_{Op} = f(X_{Cr} , FR_{Mac})$.
- Farm Performances: the results of the efficiency by which farm resources are used. They include parameters regarding:
  - S: work organization and scheduling;
  - P: economic assessment (costs/benefit analysis);
  - E: enviromental assessment.

Then performances can be evaluated in relation to specific farm resources/actions combinations (Y). For example:

P(Y) = annual profit with $Y = \{ FR_{Ar} , FR_{Cr} , FR_{Mac} , FR_{Lab} , X_{Cr} , X_{Op} \}$

Farm resources and actions are generally assessed through iterative procedures, independently on the type of algorithm used (search or optimisation). Farm performances can be assessed only once farm resources have been defined. In this sense, farm resources (FR_i) and actions (X_j) can be seen as inputs/outputs of the model, whilst farm performances are always output results. If we use the symbol "#" to indicate a controllable variable to be assessed, we could have a model performing such combination:

$$Y = \{ \#FR_{Mac} / FR_{Ar} , FR_{Cr} , FR_{Lab} , X_{Cr} , X_{Op} \}$$

Its purpose is to carry out a machinery selection on a farm where all the other resources and actions are defined as input information. If the objective is to select the best solution able to maximize annual profit, the optimal combination (Y*) is defined by the decisional model as:

$$Y^* = \max[P(Y)] , Y^* = \{ FR_{Mac}^* / FR_{Ar} , FR_{Cr} , FR_{Lab} , X_{Cr} , X_{Op} \}$$

If only a λ-part of a farm resource/action has to be selected, the following notation can be used:

$$Y = \{ \#FR_{Mac, (\lambda)} / FR_{Mac, (1-\lambda)} , FR_{Ar} , FR_{Cr} , FR_{Lab} , X_{Cr} , X_{Op} \}$$

3.3 *Flexibility needs in using the model*

Resources and actions already-existing for the user (model constants) are constraints to be respected for the assessment of the other resources. For strategic decisions a model flexibility is given by the possibility of an easy selection of farm resources/actions the user wants to assess. For example, one could wish to turn the above Y-combination into the following:

$$Y = \{ \#FR_{Cr} , \#X_{Cr} , \#X_{Op} / FR_{Ar} , FR_{Mac} , FR_{Lab} \}$$

(say, which alternative crops? How cultivate them with existing machinery?)

or

$$Y = \{ \#X_{op, (\lambda)} , \#FR_{Mac, (\lambda)} / FR_{Mac, (1-\lambda)} , FR_{Ar} , FR_{Cr} , FR_{Lab} , X_{Cr} , X_{op, (1-\lambda)} \}$$

(say, which alternative minimum tillages? Which additional machines are required?)

It must be stressed that decision-making processes require to perform multipurpose tasks. Decision support systems should always permit an high level of flexibility in their use even if it would be unrealistic the availability of an every-purpose model. Decisions to be undertaken are always of different nature and it's impossible to design a package able to satisfy every type of problem. Also the solution of a farm-tailor-made model is impractical for development costs and for the fact that a farm is a dynamic system where year-by-year problems change: so decision tools must be continuously updated and adapted to new needs. Advisors could play an essential role in relation to this point.

Researchers involved in model development can contribute providing aiding-decision tools - as multipurpose as possible - dealing with specific, homogeneous problems (say machinery management and selection, crop or animal management, financial analysis etc.). This considering the possibility of an efficient exchange of data/information among different models, even enabling the user to interface his models with external databases. The relevant problem of data/information standardisation must firstly be solved.

Interactive models - enabling the user to carry out sensitivity analysis with respect to the model's purpose - can contribute to an acceptable flexibility use. Anyway, it must be considered that flexibility has to be put in relation to the possibility of changing selection strategies too. For example, an enviromental criterium could be considered instead of an economic one:

$$Y^* = \max[P(Y)] \text{ changed into } Y^* = \min[E(Y)].$$

In addition, there may be the necessity of overcoming the limits of single-criterion approaches considering simoultaneously more selection strategies, also including subjective, non-numeric standpoints not directly evaluated by the model:

An interactive use of the model is still essential to performs such types of analysis.

4. Models in practice

Some experiences on models' development and application are now in progress at the Institute of Agricultural Engineering of the University of Milan. They deal with problems related to the selection of multicropping farm machinery systems and forage harvesting and conservation techniques.

4.1 *Multicropping farm machinery selection*

A model (ComFARMS*:* Computed Farm Machinery System) was developed to analyse arable farm mechanisation problems from strategic and/or management standpoints (Lazzari and Mazzetto, 1994). Arable farms represent the most common situation in Northern Italy: generally they are smaller than 250 ha and adopt crop rotations (dairy farms included, where no grazing is carried out and where winter and summer cereals are always in rotation with alfalfa and/or ryegrass). In such farms all the machinery-related decision problems must identify solutions able to ensure that target dates for successful crops are met (Pellizzi, 1970; Rotz et al., 1983).

Basically, the model considers the following:

A. overall sizing of the farm machinery set:

$Y = \{ \#FR_{Mac} / FR_{Ar} , FR_{Cr} , FR_{Lab} , X_{Cr} , X_{op} \}$

B. sizing of a part of farm machinery set (replacement of machines and/or equipment, adoption of alternative tillage systems etc.):

$Y = \{ \#FR_{Mac, (\lambda)} / FR_{Mac, (1-\lambda)} , FR_{Ar} , FR_{Cr} , FR_{Lab} , X_{Cr} , X_{op} \}$

$Y = \{ \#X_{op, (\lambda)} , \#FR_{Mac, (\lambda)} / FR_{Mac, (1-\lambda)} , FR_{Ar} , FR_{Cr} , FR_{Lab} , X_{Cr} , X_{op, (1-\lambda)} \}$

C. work scheduling using a given farm machinery set.

$Y = \{ FR_{Mac} , FR_{Ar} , FR_{Cr} , FR_{Lab} , X_{Cr} , X_{op} \}$

Off-farm and on-farm data are required. The former regards standard crop data, standard and cultivation techniques, operational and commercial machinery-related parameters. These are provided by the model referring to the Northern Italy situation. When A-type problems must be solved, the use of such data is essential. On-farm data must be directly entered by the user taking into account the use of machinery in relation to crop rotation and cultivation techniques actually carried out. These data prevail when B and C problems are considered.

Once a given farm crop rotation pattern and a list of possible operations per crop are entered as input information, the selection puts forth a machinery set (tractors + implements) where each machine is defined in terms of type, number and size. The outputs produced provide technical and economic information that can be used to compare a set of possible solutions from different standpoints. To do this, ComFARMS is being interfaced with other computer programs forming a more general decision support system. The purpose is to enable the user to carry out sensitivity analysis by modifying input off-farm and on-farm data and to perform multicriteria methods that include subjective and non-numeric information. ComFARMS could be useful to researchers, policy makers, advisors and farmers, these latter being more interested in solving the above B (strategic) and C (management) type problems at farm level.

ComFARMS simulates a mechanisation system through three main representative models that define:

- the list and size of equipment to be used (definition of the machinery set);
- the working performance of the machinery, in terms of quantity and quality of work carried out, considering labour time required;
- the economic performance of the system, in terms of direct costs and any potential change in the gross agricultural output (GAO) as a consequence of the quality of work performed.

Implement sizes are calculated by two distinct approaches that separately evaluate operational and economic performances. These produce a technical sizing (D=Dt) and a profitable sizing (D=Dp), respectively. Selection strategies can be described as follow:

- Technical sizing: $Y^* = \max[S(Y)]$

S(Y) = (hrs actually used for field works)/(workability hrs);

- Profitable sizing: $Y^* = \min[P(Y)]$

P(Y) = total annual machinery costs.

In the case of mechanisation chains with operations simultaneously performed, technical sizing must consider the competition for the available labour, tractors and implements within common feasible periods. In this case, the allocation of resources must be resolved, as well. To do this, the model splits up the entire calendar year into subperiods (according to operations' feasible periods) and performs iterative computations on a matrix (Operations) X (Subperiods*).* The size D of each implement is increased during successive iterative runs until the farm machinery complement is able to complete successfully all the work to be done within the expected feasible periods. The nominal rated powers (Pt, kW) of all the tractors used on the farm are calculated once all the implement Dt-sizes have been determined. This algorithm thus provides the afore said selection Y*=max[S(Y)].

Total machinery costs (TMC) are computed on yearly basis adding ownership (TFC) and operational (TVC) costs: P(Y) = TMC = TFC + TVC. The TFC-method of costing calculates the annual cost for purchasing a machine which is directly comparable to other farm annual returns and costs (Audsley and Wheeler, 1979). As far as labour costs are concerned, the model allows consideration of the following possibilities, to enable the evaluation of opportunity costs:

- cost on hourly basis (temporary labour, which is added to TVC costs);
- cost on yearly basis (permanent labour, considered as a fixed cost);
- no cost for labour (e.g., when farms are run only by the owner).

The profitable Dp-size selection is carried out by an optimisation algorithm running two procedures that can increase or decrease the implement sizes (then adjusting power requirements). Each change is retained only if: 1) it falls into the afore said search area; 2) it is more profitable than the previous size-solution; this exploiting the heuristic technique of the "closest element" (Rich, 1983) to seek a minimum cost solution, including or excluding labour costs.

Besides the above automatic Dt and Dp-selections, the model enables the user to run search algorithms based on interactive analysis. Within the search area - the lower extreme of which are the implement Dt-size values previously calculated - the user may select specific situations modified with respect to the structure and the sizes of machinery set or to the crop pattern area.

To give an applied example, the model was run to perform an overall farm machinery selection (A-type problem) for a 85-ha farm with loamy soil in Northern Italy. The following 5-yr rotation is carried out: 1. sugar beet; 2. wheat; 3. maize; 4. wheat; 5. barley. For each crop, harvesting operations are charged to contractors. Three alternative machinery scenarios were assessed:

SC1. Dt-technical sizes;

SC2. Dp-optimum sizes, with 3 tractors;

SC3. Dp-optimum sizes, with 2 tractors.

The results are shown by **Table 1** together with the composition of the machinery set actually used on the farm.The following remarks can be pointed out:

- for solutions SC1 and SC2 the necessity of performing simultaneously 3 field operations in busy periods is respected. SC1 maximizes the hours of machine use meeting the need of completing all the field-works within the expected feasible periods. Thus, the lowest machinery sizes are selected, matching the highest charge of work (13.2 hr/yr.ha);
- in case of operations with very long feasible periods (e.g. 30 days for maize and sugarbeet late summer, early-autumn harrowings) there is the possibility of increasing the machine size without the necessity of increasing tractors' rated power. SC2 identifies these situations, assessing a more profitable solution with the same SC1 tractor set, but with some machines increased in sizes. In this way, more suitable tractor/implement combinations are matched, producing a slight cut in

machinery costs (-3.4%), thanks to lower fuel/oil consumptions and in spite of increased implement fixed costs. An appreciable reduction in timework needs (-14 %) is also gained;

- a more profitable solution is identified by SC3. Implement sizes are further increased with respect to SC2, thus enabling the use of only 2 tractors. This results in a reduction in total costs (220 and 335 US$/ha, excluding and including labour costs, respectively) and charge of labour per ha (10.2 hr/yr), associated with more suitable timeliness conditions. Slight differences exist between SC2 and SC3 machinery costs because cost savings due to a decrease in tractor number tends to be compensated by greater fixed costs due to the increase of implement sizes. Only 2 field operations can be simultaneously performed, thus forcing the farmer in paying more attention in working organization. This makes SC3 less attractive than SC2, due to the necessity of a prompt assessment of sequential operations in busy periods;
- the machinery set actually used on the farm was notably oversized (above all in terms of available machine number and sizes) when compared to the solutions suggested by the model. This because the purchase of new machinery is not always associated to the sale of the old ones. There are 5 tractors (2 of which are more than 10-yr old) and the highest rated power (124 kW) is twice as much the one suggested by the model. This is linked to the choice of using 2-furrow and 4-furrow ploughs, for maize and winter cereals soil tillage, respectively. The great part of the other implements is oversized, as well (harrows, seeders etc.) and there are also some old machines not listed in Table 1 because very rarely used. The charge of work per ha falls to 8.1 hr/yr with a total cost (machinery + labour) representing the 23.2 % of the GAO;
- generally speaking, an existing farm machinery set is always the result of a series of past decisions undertaken by the farmer to solve specific strategic problems of the above B-type (machinery replacement etc.). In each decisional step, besides technical and economic aspects, farmers often took into account further subjective and non-numeric criteria. In the case here considered, the farmer tended to make operational-related criteria to prevail on economic-related criteria. Timeliness is his main target, paying few attention to the problem of machinery costs. These are considered only when the necessity of the purchase of a new machine occurs, and the financial availability of the moment is the main constraint conditioning his decision-making process.

ComFARMS was tested on 10 arable farms of Northern Italy (35-90 ha). The obtained results were substantially similar to the ones discussed about the above 85-ha farm. When the model was specifically run to provide suggestions for B and C-type objectives, many problems arose mainly for the general lack of on site information. In such cases on-farm input data must prevail and generally farmers were not able to provide them without introducing unacceptable, imprecise estimations. This is because they are not accustomed to collect data on field activities as they take place.

All considered, in the present Italian situation the model can be useful for researchers and policy makers when it is used to examine general scenarios of farm mechanisation. It can be run also by farmers and advisors to provide helpful information for decision-making processes at farm level. We were able to determine that farmers strongly felt the need:

- to be supplied with an efficient recording system in order to build a past scheduled activity data-base to carry out cost analysis for management and future investments;
- to be enabled to introduce into a decision support system their own declarative knowledge, thus matching the procedural knowledge of a model with their experience and subjective standpoint.

In order to overcome these barriers which still hamper the introduction of model-based systems at farm level, we are now considering the above points as research priorities.

4.2 *Selection of forage harvesting and conservation systems*

Several mathematical models have been developed to simulate the performances of forage harvesting and conservation systems (FCS). Most of them are detailed studies applied to the analysis of specific aspects of the production process. Nonetheless, there have also been some more global approaches to the problem with a significant attempt at interdisciplinary synthesis, involving agronomical, zootechnic, engineering and economic aspects. Italy has also come to feel the need for adequate decisional support systems able to analyze the numerous, complex aspects that the choice of an FCS may require. This with the goal of reducing production costs in order to cope with the consequences of recent CAP legislation.

A specific model was developed to evaluate the efficiency of alternative FCSs, paying attention on their quantity-quality yields and on the employment of the required technological and human resources (Mazzetto, 1994). This efficiency is evaluated on the basis of classical economic cost/benefit analysis and through multi-criteria methods. Thus the final choice, rather to represent a solution that optimizes one particular aspect, constitutes a reasonable compromise satisfying various kinds of needs.

The model is based on an abstraction process that divides the dairy farm into three main subsystems: forage, feeding and livestock. Attention is focussed on the relationships among machinery use, farm production of hay and silage crops and purchasing of out-farm integrative feedstuffs. The nutrient composition and palatability of forages are known to be causally related to the losses due to harvesting and conservation activities. For this reason the benefits of FCS's machinery are those associated with the quantity and quality of forage produced and can be phisically measured in terms of forage dry matter and nutrient produced. This greatly influences the performances of forage and feeding subsystems.

To run the model, the type of FCS to be analyzed must be firstly selected. A series of files then provides all the relevant parameters necessary to simulate its operative and economic performances, on the basis of the algorithms already developed for the ComFARMS model. In particular, the procedures simulating the harvesting and conservation activities break down the entire FCS processes into four phases:

- field operations, from mowing to baling (when used);
- handling operations, from the field to the farm center;
- loading and possibly unloading of stationary plants, in the case of FCSs with post-harvest processing;
- post-harvest treatment (when used).

Dry matter losses (quantitative) directly affect the area required to cultivate each forage species. At the same time, this area is also influenced by qualitative losses. These, in fact, directly affect the quantity of each nutrient composing the ration, with consequent changes in the annual requirements of the herd. Cropped areas and forage yields, in turn, strongly condition the FCS mechanization costs. In practice, when alternative FCS solutions are analyzed, the possibility of considering situations modified with respect to machinery set composition, forage cropping pattern and operations to be scheduled must be offered to the user. Thus the model performs the following Y-combinations of farm resources-actions:

$$Y = \{\ \#X_{Cr,(\lambda)}\ ,\ \#X_{op,(\lambda)}\ ,\ \#FR_{Mac,(\lambda)}\ /$$
$$/\ FR_{Mac,(1-\lambda)}\ ,\ FR_{Ar}\ ,\ FR_{Liv}\ ,\ FR_{Cr}\ ,\ FR_{Lab}\ ,\ X_{cr,(1-\lambda)}\ ,\ X_{op,(1-\lambda)}\ \}$$

When the results are evaluated on the basis of conventional cost/benefit analysis, the following selection strategies are generally considered:

Profitable selection: Y* = min[P(Y)]

P(Y) = annual machinery costs;

or P(Y) = final ration costs.

This is the typical problem in which several subjective and non-numeric criteria are often simultaneously taken into account to decide on the final selection. To do this, the model also permits a more general approach via multicriteria analysis. The method used is based on Concordance Analysis with respective sensitivity analyses. It processes a series of input information manageable through a matrix (criteria)X(alternatives), also known as effect matrix. This is associated to an input-weight vector for estimating the subjective importance the decision-maker attributes to each criterion of analysis with respect to the others. Criteria may also be clustered in groups of homogeneous factors (e.g. economic-related, operational-related) according to the aspects considered.

In order to test the model, several runs were performed on 12 dairy farms of Northern Italy, in close collaboration with farmers. They wished to evaluate feasible alternatives to their forage conservation methods, all currently based on traditional haymaking, with forage (mainly alfalfa) harvested in round bales. A typical results is shown by **Fig. 5**, where a 100-lactation-cow herd (ave. fat corrected milk production: FCM = 30 kg/day.cow) is considered. In order to improve hay quality, round-bale-drying and barn-drying were considered as possible alternatives to the used solutions. The feeding subsystem provides a ration composed of alfalfa hay + maize silage + concentrates. Maize silage harvesting operations are self carried out on the farm. Some machinery are thus shared by the hay and silage harvesting systems: in this case, the breakdown of fixed costs is computed according to the hours the machine is used in each system.

Thanks to the better quality achieved through drying the forage/concentrate ratio increases from 61:39 in the case of traditional hay production, to 70:30 in the case of hay from barn drying. Consequently, due to various needs for alfalfa area, the ration cost is reduced by 0.24 US$/cow.day, while its incidence on a ton of FCM declines from 90 to 82 US$/t with traditional and artificial hay production, respectively (this incidence only reflects the costs for harvesting and conservation).

This conclusion could be generalized even if it appears in contrast with the very limited spreading of hay drying in Italy. This apparent incongruence can be explained performing a multicriteria approach to the FCS selection problem (Castelli and Mazzetto, 1994; Nijkamp, 1977). The possible criteria to be included in this analysis are listed in **Table 2** which describes the effect-matrix of the multicriteria problem. Two weight-vectors are here proposed, each reflecting the different standpoint of two groups (Gr.1 and Gr.2) of homogeneous farmers. The weight-values were estimated through interviews averaging the figures declared by farmers with similar points of views. Criteria can be grouped into the following homogeneuous factors:

- economic-related: yearly concentrate saving; additional investments; yearly energy costs;
- operational-related: labour requirement; ave. forage field-stay per each cut (mowing-harvesting period); process management flexibility from farmer's standpoint (subjective qualitative index: 5 = very high, ... , 1 = very low).

The selected criteria reflect the aspects actually taken into account simoultaneously in such a type of decision-making process. Contrary to cost/benefit analysis which quantifies an alternative's efficiency by calculating a single economic parameter (incidence of FCS costs on ration), this method matches farmer's need of considering one by one - though simoultaneously - specific aspects affecting the decisional process. These are aspects presenting the most appreciable effects of changing and strictly linked to the daily experience/perception of farmer, who often is both entrepreneur and worker. So he preferes to distinguish among investement required, annual savings and extra-costs, operative advantages ecc. The criteria's effects were directly calculated by previous model running, a part from the last one (criterium n.6) that was directly entered by the farmers as input data. The 12 farmers involved in this exercise were divided as follows:

- Gr.1 : 10 farmers giving more importance to economic-related criteria;
- Gr.2 : only 2 farmers giving more importance to operative-related criteria.

Based on figures in **Table 2**, Concordance Analysis produced the following preferability rankings:

- Gr.1: 1.Traditional haymaking; 2.Barn drying; 3.Round bale drying;
- Gr.2: 1. Barn drying; 2. Traditional haymaking; 3.Round bale drying.

The following remarks can be enhanced:

- the need of improving hay quality is always strongly felt, though most of farmers tend to consider hay drying as an impractical solution due to its high investment and energy costs. It must be underlined that the great importance given to economic-related criteria is a priori conditioned by the high investments required by barn drying. Performing a sensitivity analysis on the effect of such a criterium, it was possible to see that some farmers were available to increase the importance of operative aspects only halfing the investments originally proposed by the model. But in the present situation this is quite unrealistic, so most of them wished to explore further alternative solutions such as the substitution of hay with wilted forage silages or the adoption of round bale wrapping systems;
- round bale drying gained low interest from both the groups of farmers. This because hay quality advantages cannot repay the greater costs and the operative complications this solution requires;
- the two farmers that gave more importance to operative criteria can't consider silage solutions, becouse the produced milk is used for the production of Parmigiano Reggiano cheese. So they have high-quality targets while maintaining good operative conditions. Barn drying is the best solution from their standpoint. Only one farmer actually adopted this system, being the other not allowed by financial availability.

The above analysis could be better presented listing a greater number of criteria and discussing the intermediate results from interactive, sensitivity analysis on effect and weight values. However, it should be clear how the use of a multicriteria approach can contribute to a better comprehension of whatever decision-making process. This kind of strategic exercise makes a decision support system very difficult to be run directly by the farmer. A more preminent role of advisors should be expected.

5. Final remarks and conclusion

The use of whatever farm model-based system cannot be successfully considered without framing the overall problem of how organizing an efficient information system at farm level. Attention must be paid to the use of information and to its utility in solving decision-making process at strategic, management or operative levels. Information derives from data, and data must be supplied by specific systems that must not require high costs and skillness.

These needs were clearly stated by the farmers involved in testing the models we are developping and improving. Most of them are not accustomed to collect data on farm processes (mainly field activities) as they take place, thus losing what one can call their “farm hystorical memory”.

In order to check the extension of this situation, we recently carried out a survey on 52 farmers considered as possible targets for the work we are developing. The following results have been obtained:

- almost the totality of the farmers declared their interest in using information technologies to better manage their machinery;
- 37% of them have already got a computer. The use of farm computers is not so common in Italy mainly because the farmers do not need detailed administrative data to pay taxes. The annual amount of these is calculated based upon the available cropped area and not on the farm actual revenues;
- only 8% collect data on the machines use, but nobody utilises a computer to analyse them. Among the others farmers, few tried to collect data. Some of them asked us to prepare pre-typed sheets to be hand-filled directly by the operators before starting each field operation. In these cases the data were regularly lost after only 2 or 3 weeks of work, being their collection generally considered too time-expensive.

All considered, the surveyed farmers showed a great interest in solving the problem of how building a past-scheduled operation data-base in order to carry out cost analysis for management purposes and future investments (this independently on the use of the proposed models). In other terms, they seem interested in solving problems of work organization and operation scheduling and of investment analysis about machinery replacement and use of alternative processes (possibly without advisors). But before using computer tools they feel that their primary need is to be provided with an efficient data collecting system.

This is why we patented an automatic system to collect mechanisation data at farm level. The system is being developed in close collaboration with an Italian electronic Company that provides low cost sensors for identifying tractors, implements, workers and fields interested in each farm activity. A preliminary analysis on the overall expected system’s cost carried out by the Company encourages us in developing of such a system. Tests on the first prototype are in progress. We are confident that in the near future with this solution it could be possible to build up a complete farm information system able to provide information for driving strategic and management farm control activities.

Generally speaking, the identification of an optimum mechanization level is always a subjective problem requiring different model-based systems depending on the final user. In case of farmers, models must be seen as a part of a more general information system and their use must fit farmer’s needs and past experience. In case of advisors and policy-makers, models should be more strategic-oriented, and work on data/information that can have a lower degree of detail if compared with the needs of particular farmers. In addition they should be as multipurpose as possible.

In conclusions, the following priorities should be respected in developping model-based systems:

A. Acceptability:

A.1. Farmers must really accept the help offered by decision support systems, researchers must work with them. Systems must be based on a careful study of farmers' needs. The decisions which they must take have to be identified, and the information they need to take decisions has to be analysed. The present sources for information and the farmers' own expertise must be included into the system;

A.2. Farmers must have interactive models presenting significant alternatives to examine the results of different possible choices and the effects of different criteria, and make their own decision. They must be enabled to consider different selection strategies;

A.3. Farmers must be able to understand the logical basis of the models used. Research on suitable man/machine interfaces for systems intended for advisers and farmers is a priority goal;

A.4. Having farmers no time for lengthy manual keyboard entry, data collection (e.g. details on operations carried out) must be automated;

A.5. Good support and maintenance for software must be available;

B. Incorporation of risk and uncertainty:

Techniques for taking into account the risk and uncertainty in biological processes must be included in the models; farmers are accustomed to assessing risk in their day-to-day decision-making so it will be important to explain them how the model can reflect the degree of uncertainty that exists, and identify a confidence level for the information it provides;

C. Flexibility:

C.1. Models must be adaptable to local and regional conditions and allow farmers to choose parameters for optimisation. It must be possible to adapt existing models for a range of conditions, validate and incorporate them into the system;

C.2. Systems must also be able to incorporate new scientific knowledge or new legislation, however, without having to be completely redesigned;

D. Standards for specification:

A standardised specification system for farm decision support systems should be agreed to improve their flexibility and transferability between farms, regions and states.

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Table 1 - Alternative scenarios assessed by ComFARMS model on a 85-ha arable farm in Northern Italy performing a 5-yr rotation (see the text). The machinery set actually used on the farm (ACTUAL) is listed, as well.

SCENARIOS ⇒	SC1		SC2		SC3		ACTUAL (#)	
TRACTORS	(kW)	(hr/yr)	(kW)	(hr/yr)	(kW)	(hr/yr)	(kW)	(hr/yr)
Tract.1 (4WD)	62	406	62	438	62	496	124	272
Tract.2 (4WD)	52	372	52	321	52	370	66	192
Tract.3 (2WD)	30	345	30	200	-	-	59	126
Tract.4 (2WD)	-	-	-	-	-	-	45 (##)	60
Tract.5 (2WD)	-	-	-	-	-	-	35 (##)	40
IMPLEMENTS	(m)	(hr/yr)	(m)	(hr/yr)	(m)	(hr/yr)	(m)	(hr/yr)
Turnwrest plough (250 mm) (@)	0.65	228	0.65	228	0.65	228	1.15	130
Turnwrest plough (400 mm) (@)	0.45	203	0.45	203	0.45	203	0.88	122
Cultiv.harrow	1.80	83	3.00	49	3.60	42	4.20	36
Spike-tooth harrow	1.80	79	2.10	69	2.10	69	3.60	40
Spike-tooth roller	2.00	63	2.00	63	3.60	35	3.20	39
Precision seed drill	3.00	28	3.00	28	3.00	28	6.00	14
Winter cereal seeder	2.00	51	2.50	41	2.50	41	4.20	24
Spinn. fert. distrib.	6.00	78	8.00	55	16.00	29	10.00	49
Hoeing machine	1.50	128	4.50	44	4.50	44	4.50	44
Crop sprayer	6.00	62	6.00	62	12.00	30	6.00	62
Haulm cutter	1.80	20	2.10	17	2.10	17	2.40	15
Ditch cleaner	0.80	20	0.80	20	0.80	20	0.80	25
2W trailer (**)	10	35	10	35	10	35	10	42
4W trailer (**)	15	45	15	45	15	45	15	48
Combine (***)	C	-	C	-	C	-	C	-
TOTAL WORK HOURS (hr/yr)	1123		959		866		690	
(hr/yr.ha)	13.2		11.3		10.2		8.1	
MACHINERY COSTS								
(US$/ha)	234		226		220		316	
Tract.costs:Impl.costs (% : %)	75 : 25		71 : 29		66 : 34		71 : 29	
Incid.on GAO (% GAO)	13.4		12.9		12.6		18.0	
TOTAL COSTS (MACHINERY + LABOUR)								
(US$/ha)	382		353		335		407	
Incid.on GAO (% GAO)	21.9		20.2		19.1		23.2	

(#) hours of work are estimated based upon recorded data available on the farm
(##) more than 10-yr old (annual fixed costs are not computed)
(@) depth of plowing
(**) used for both internal and external transports (harvesting operations included)
(***) charged to contractors

Table 2 - Effect-matrix and weight-vector referring to the dairy farm discussed in the text. The standpoints of two different groups of homogeneous farmers (Gr.1 and Gr.2) are presented. (B = benefit-criterion ; C = cost-criterion).

CRITERIA ⇓ / ALTERNATIVES ⇒		Traditional Haymaking	Round Bale Drying	Barn Drying	WEIGHTS Gr.1	WEIGHTS Gr.2
1. Yearly concentrate saving (US$/yr)	B	0	12200	29700	15	10
2. Additional investment (US$)	C	0	19000	75000	30	20
3. Yearly energy cost (US$/yr)	C	800	5800	8900	15	10
4. Charge of work (hr/ha.yr)	C	21.4	19.2	16.2	20	30
5. Forage field-stay per cut (hr)	C	330	230	170	10	15
6. Process flexibility (1 = very low; ...; 5 = very high)	B	5	2	4	10	15
Total economic-related weights:					60	40
Total operative-related weights:					40	60
Total weights:					100	100

Fig. 1 - Control activities and farm decision-making levels

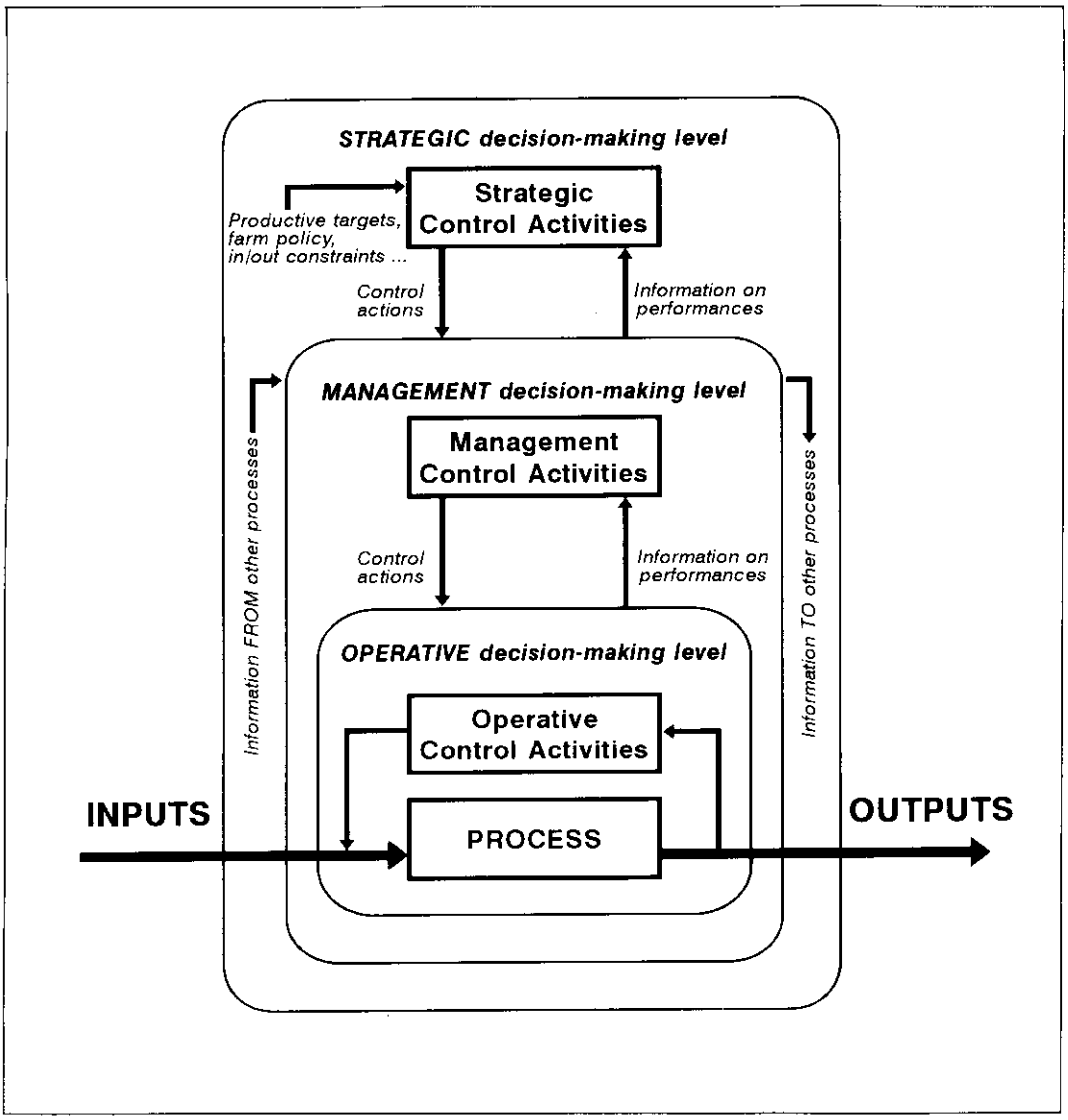


Fig. 2 - Structure and functions of a Farm Information System

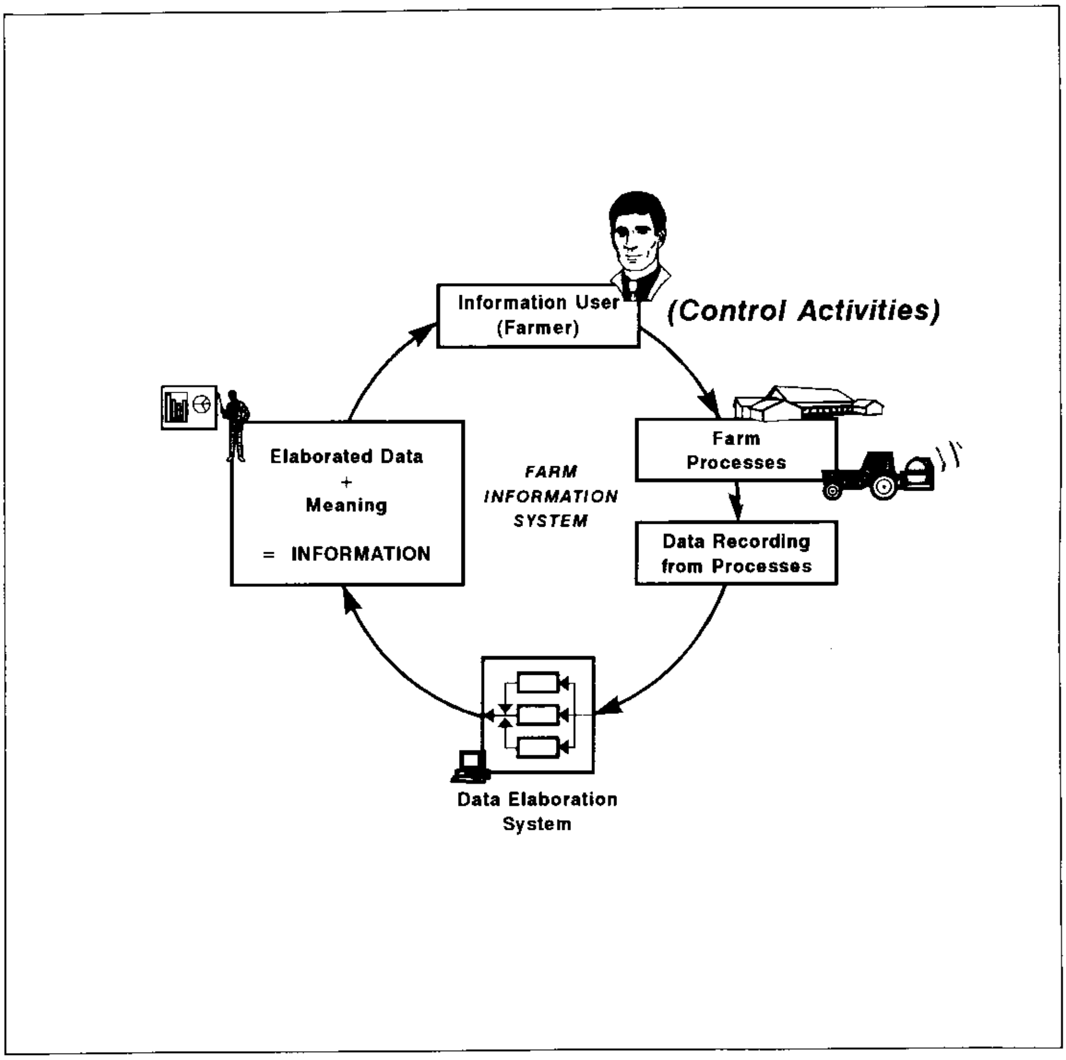


Fig. 3 - Components and functions of a Farm Information System

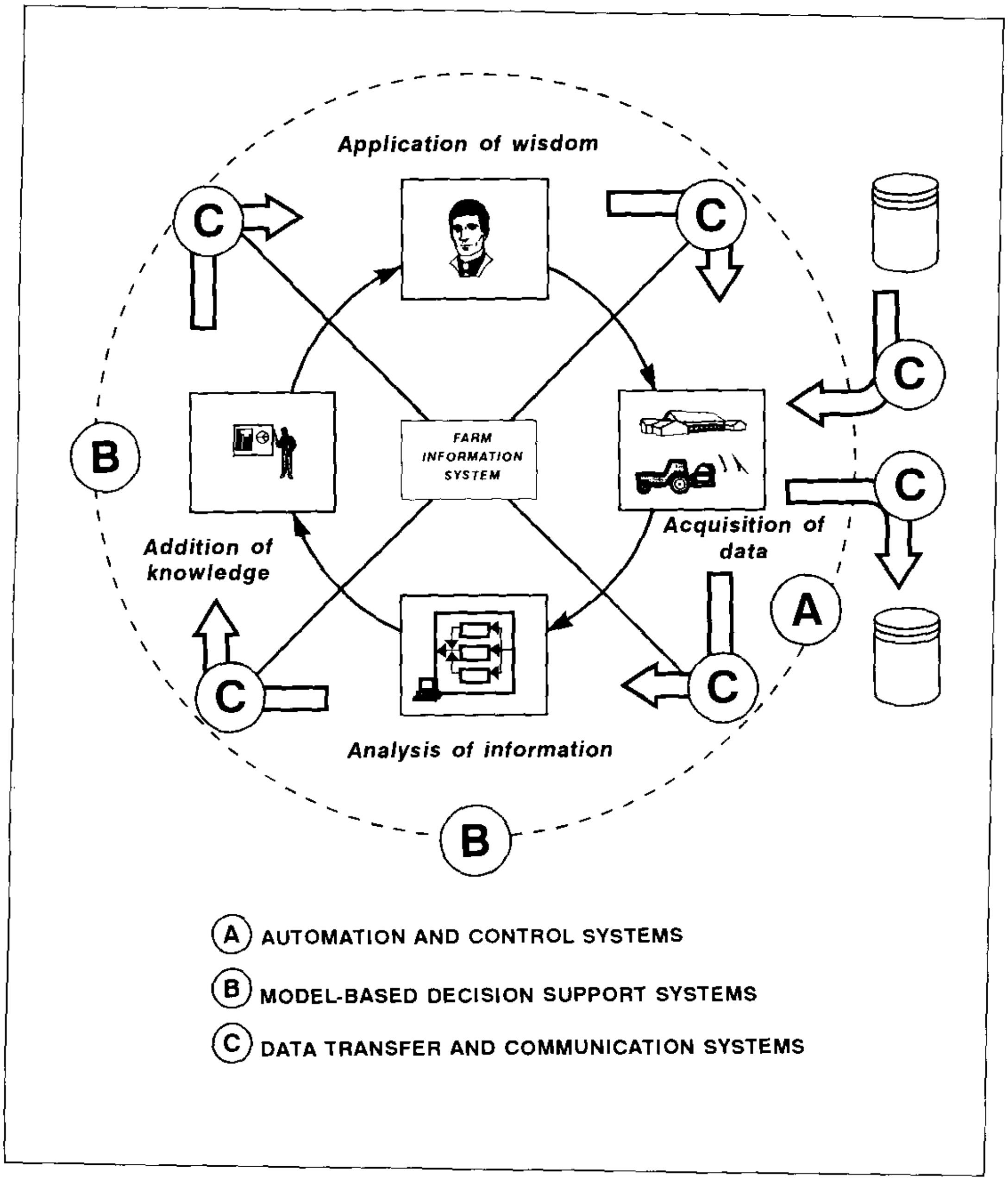


Fig. 4 - The concept of a farm system. Different types of variables are listed.

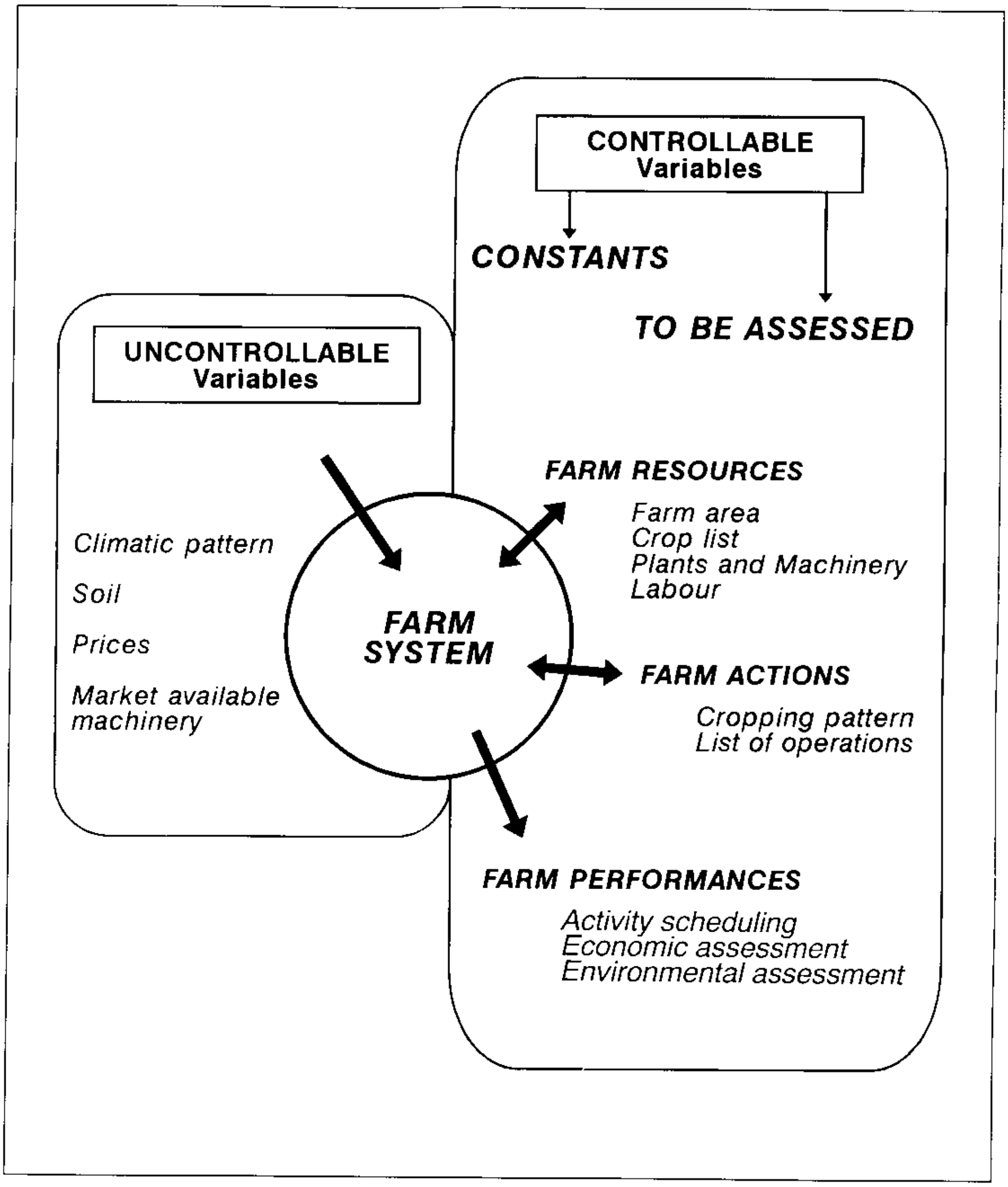
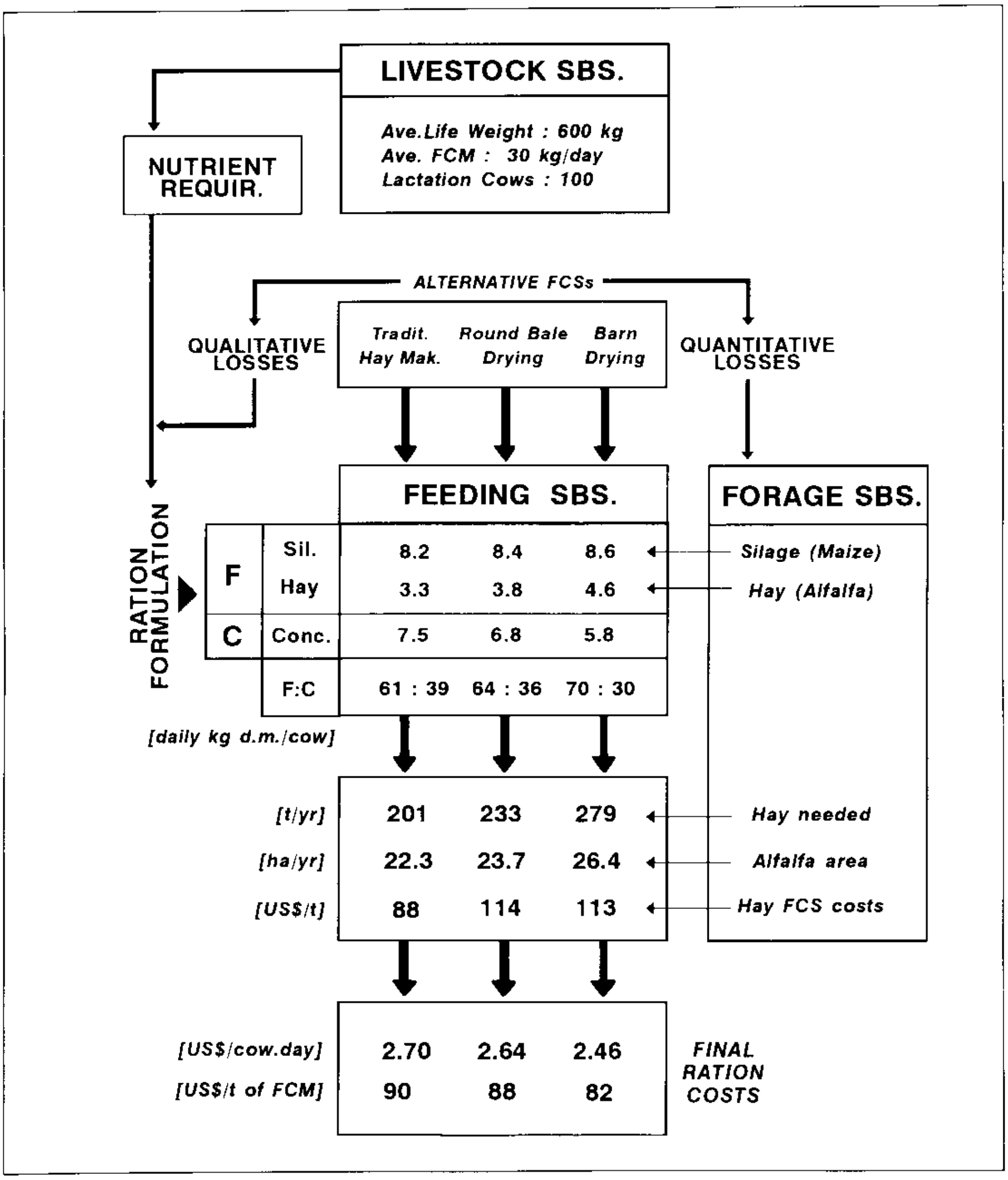


Fig. 5 - Example of the effects of qualitative and quantitative hay losses of different FCSs on the economic efficiency of a dairy farm (see the text)



Methodologies for the identification of the optimum mechanization level (Report n.3)

by *Philippe Jannot*

France

1. Introduction

Arable and mixed farms are faced with two major challenges: the reform to the Common Agricultural Policy and the environmental pressure. These challenges induce farmers to seek alternative farming methods in order to minimize their sensitivity.

This paper describes firstly the specific french situation; the three following parts develop methodologies which are classified from the easier to the most complex. At last, some future trends to improve these methodologies are indicated.

2. Agricultural problems and consequencies for the farms

- Two major constraints (the CAP and the future environmental constraints) which imply a strong uncertainty on the future;
- economic challenges for the farms are various: to reduce production costs, specially machinery costs; to improve the productivity of labour; to adapt to present and future markets; to diversify the farming methods (such as less intensive farming methods);
- a growing environmental pressure concerning the water quality: a better management of mineral fertilizers especially nitrogen is become a prime objective in sensitive areas, a better storage and management of organic fertilizers is necessary in intensive animal production area, the problem of pesticids in water become sometimes sharp;
- some solutions adopted by the farms:
  - an increase in farm size with an unchanged labour force, sometimes combined with a decrease in labour force. The agricultural population decreases each year that implies an increase in farm cultivated area per worker;
  - more and more solutions of collective ownership and use of farm equipment The farm machinery investments have considerably decreased for several years but they have increased in collective ways (the number of new tractor has decreased of 40% between 1987 and 1992 - from 40,000 to 26,000 per year - but in the farm machinery co-operatives, it has increased up to 26%);
  - a new demand of advices from the farmers. If in the past, the farmers need only informations concerning the technical characteristics of machines, nowadays they ask about the economic consequencies of a machine purchase, on the different alternatives to machinery ownership and use (machinery sharing arrangements, contractor use, machinery hire or machinery rings), about the work organisation with a new machine or a shared machine. The advisers have to renew their practices;
- scientific choices:

- all the french methodologies are designed for use primarily by advisors to guide choice in farm equipment for actual farms. If most of them have been developed by Research institutes, their applicability is always checked with advisers and farmers;
- the farm is seen as a farm family system: the farmer in relation with his family carries out land use, crops and livestock production in order to reach his own objectives (such as profit, standard of living, improvement of working conditions, farm future, ...), he tries to reach his own objectives taking account of socio-economic farm environment and of farm evolution;
- the farm equipment selection and management have to be analysed through the decision system in relation to the operating system (Allain & Sebillotte, 1991) (**Fig. 1**).

3. From the diagnosis of machinery costs

3.1 *Accounting machinery costs and their limits (Cairol & Jannot, 1990)*

The machinery costs can account for 25 % of total production costs within the arable farms. But these costs are very differents from a farm to another one (**Fig. 2**): for example they vary from one to three or more whatever the types of farm and it is difficult to explain these differences (a low machinery cost does not mean an optimum mechanization level and conversely).

These costs include fixed and variable cost elements: fixed costs are depreciation and interest, variable costs are fuel, repairs, maintenance and contractors. The most important part is the fixed cost such as depreciation (50 to 75% of the total machinery cost).

All these data are issued from farm accountancies: they are calculated to a financial and fiscal use. They are not directly useful to analyse and compare different mechanization levels. It is the reason why a method to calculate machinery costs has been developed.

3.2 *Mecagest 1: a software to calculate and compare machinery costs (Vaquié & Al, 1994)*

Mecagest 1 has been developed by the Federation of Farm Machinery Cooperatives (FNCUMA). It is used by advisors in order to calculate the annual machinery costs of a farm. Input data are the list of all used machines including hired machines and contractors and the amount of fuel, repairs and third works. Each machine is described by its characteristics (horse power, size, number of ploughs) and its date of purchase: its price of purchase is evaluated from a reference database. Output data are an annual machinery costs and a breakdown of the cost components: six parts are identified such as tractors cost, harvest cost, spraying and sowing cost, soil preparation cost, transports cost and fuel. They are presented on a star which shows easily the most important parts (**Fig.3**).

3.3 *A comparison of individual results to a reference database*

The obtained results in various farms are gathered and constitute a reference database. Farms are classified according the productions and the major types of soil: each type of farms is characterized by a total machinery costand its breakdown in six parts.

A comparison of an individual result to the reference allow to identify the deviations for example concerning the tractors cost and then to propose solutions to reduce it.

3.4 *A new implemented part on work time*

As the farm machinery depends on the labour force, a new implemented part on work time is developing by the FNCUMA. The required time to the different farm operation is calculated according several periods: it is distinguihed the part of the farm labour force in its own farm, the part which is provided to other farms and also the part which is received on the farm.

The result is indicated in a chart which compare the available and the required time.

4. To methods combining machinery, labour force and farm area

The methods which combine machinery, labour force and farm area are the most numerous. They aim to calculate the best combination of these three means of production. The farmer with his family is simultaneously the actor who takes decisions and the labour force (a part or the totality) who works in the farm (**Fig. 4**). They allow to compare several machinery options for a single farm.

Three main methods have been developed by different research or technical organisations. These methods are based on various calculation process: they can be subdivided between simulation models and optimisation models. They are always used on actual farms: they include essentially input data provided by the farmer.

Each method is briefly described in three part: its objective, a short description of the calculation process and the main expected results.

4.1 *Simulation model*

4.1.1 A spreadsheet: SIMEQ (Jannot & Nicolletti, 1992)

SIMEQ has been developed by theTechnical Institute for Cereals and Forage (ITCF). SIMEQ is a SIMulator for the choice of Equipment. It matches machinery and labour resources to the needs of crops that is to say the cropping plan and the field operations. The process uses a climatic data base which computes available working days according to different climatic scenarios. It enables to compare a range of machinery options or work management to a current farming situation.

SIMEQ calculates the beginning and the ending dates for each field operation under several climatic years. It determines a working timetatble (with periods of five or ten days) for each climatic year and on an average (ten to thirthy years). It includes crop yield penalties for late completion of some major field operation (sowing, harvesting). At last, it calculates the farm's profit and the machinery costs. Comparisons between several machinery options are carried out on a range of indicators.

4.1.2 A knowledge based system to analyse daily work organisation: OTELO (Attonaty & Al, 1993)

OTELO has been designed by the French Institute of Agronomic Reseaerch (INRA). It is a simulator of daily work organisation, using expert system. It has four components: a frame representing work planning rules; an information system referring to indicators used by the farmer (climate, soil conditions) and to the farm characateristics (farm area, labour, equipment); an engine for the day to day running of the model specified; a module for processing and analysis of the data recorded.

The frame consists of three management levels:

- level 1: tasks, performing one or several operations simultaneously, and consuming labour and equipment; their performances are determined by some rules according to organizationnal or environmental conditions;
- level 2: sequences, managing succession rules and selection of tasks to be performed on several homogeneously managed fields;
- level 3: periods managing priority between tasks and sequences at a given time.

Decision making rules are expressed as « If Conditions, Then Decisions. These rules are deduced from a discussion between the adviser and the farmer who compare the simulated results to his own calendar requirements.

Then, it is possible to calculate the work calendar over 20 climaatic scenarios and to compare the simulated end dates of some tasks with the objectives of the farmer: it provides an analysis of a technical risk.

4.2 *Optimisation model*

4.2.1 GEDE and GELEV (Jannot & Cairol, 1994: Goth & Al, 1993)

GEDE and GELEV have been developed by CEMAGREF Institute for agricultural and environmental engineering research. It is based on Linear Programming. It calculates the optimal crop layout which maximizes the farm profit under constraints. It determines also the resources consumption of all the constraints and it indicates the active constraints with their shadow prices.

It is used to decided what changes are to be evaluated from the active constraints. For example in the case of a labour limitation, different solutions are possible such as extra overtime, employing casual labour or contractors, late completion of tasks with consequent losses in crop yield, upgrading equipment to reduce workrates. Among all these possibilities, a limited number is selected to simulate the effects of changes and to compare them with the original farm. At the opposite, in the case of no labour limitation, it is possible to release the farm area constraint and to examine which are the new limiting factors.

GEDE has been designed primarily for arable farms; GELEV has been specifically designed for use on mixed farms that is to say farms where grow together livestocks forage and cash crops which are in competition for land, labour force and farm machinery resources.

5. Towards methodologies including social and human factors

These recent researches are in progress: the first obtained results have to be completed but they show new prospects.

5.1 *An example showing the importance of social relations between farmers: the collective purchase and use of a tractor (Jannot & Cairol, 1994)*

Sharing of tractor between several farmers is a practical solution in difficult economic conditions. A study has been recently conducted in regions with different socioeconomic contexts (types of farm, mutual help practices). The technical options of the farmers, in this case the collective purchase and use of a tractor were linked not only to the technical and economic aspects of individual farms, but also the social relations between farmers (**Fig. 5**).

So a farmer will adopt a collective solution if its individual situation is favorable (he has a need to replace a farm machinery such as a tractor and he cannot invest individually); but he must know other farmers who have also this need at the same time and with which he has already work together. In the group of farmers favorable to a collective solution, it is necessary that a farmer is able to federate the other farmer round a technical project (such as a purchase of a tractor with a plough, a work organisation between all the farmers).

So individual decisions are taken not only in the family farm context but also in relation to the interests of the local social system. It implies the methodology have to take into account this level of interaction between farmers. The results show also the importance of the time: a farmer decision depends on the time.

5.2 *The design of a multiagent negotiation model (Petit-Singeot, 1995)*

The model of negotiation concern the share of a farm equipment between several farmers; each farmer is being able to get individually this farm equipment.

The multiagent negotiation model include several agents: each one is modelled according to an utility function that quantifies a given situation, but the agent can modify this utility function through constraints issued from the environment.

The share of a resource is obtained by an iterative and dynamic process of negociation: each agent makes a proposal of sharing and gives a judgement on the previous proposal.

Using the framework of the Game Theory, the multiagent model take into account the limited rationality of the cognitive system with an evolutionist dynamic. It includes the computational possibilities of artificial intelligence such as neural networks and genetic algorithms.

6. Conclusion

These different methodologies have been primarily designed by researchers: they include a growing number of parameters in order to be more relevant to the complex reality of the farming world. The farmers and the farm equipment advisors need operational methods to solve more and more difficult situation. It is necessary to think about the methods to associate researchers, advisors and farmers in the design of methodology to identify the best mechanization level at the scale of a farm enterprises including individual and shared machinery.

These existing methodologies were developed to maximise the use of resources in order to improve the economic results. They do not include the implications of environmental aspects which will become more and more important. It is why a research has recently begun gathering three european teams: its objective is to propose methods of farm systems analysis for advisors which take account of environmental requirements when reasoning the choice of systems of farm equipment. The first results of this research funded by the European Community will be available in 1996.

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Fig. 1 - The mechanisation in the farm-family system

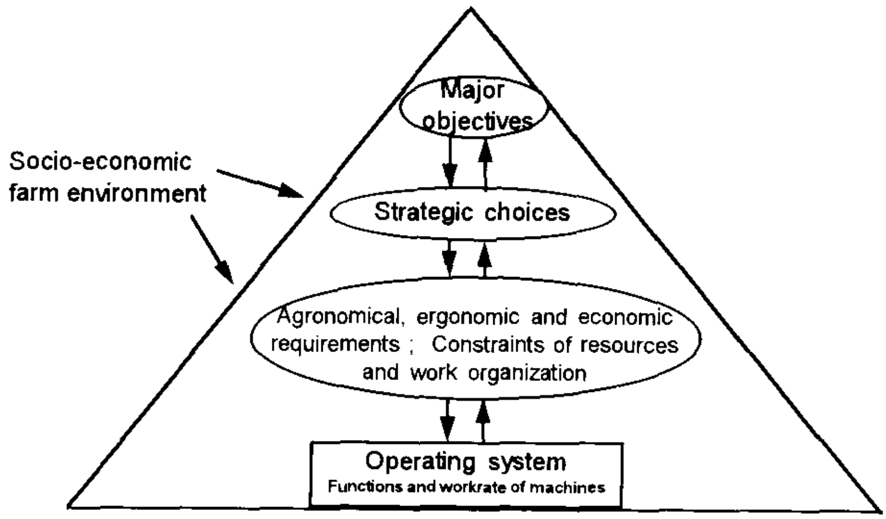


Fig. 2 - Machinery costs and their variabilità

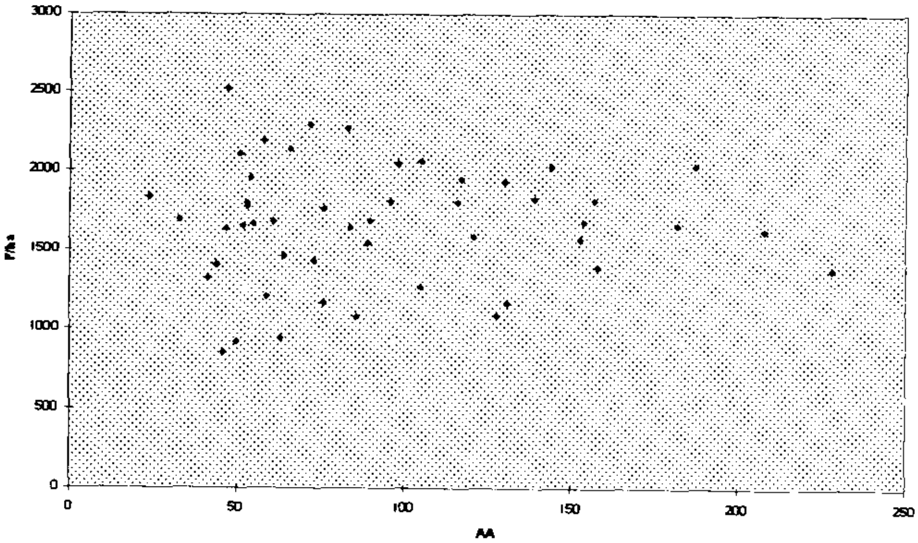


Fig. 3 - An example of machinery costs star

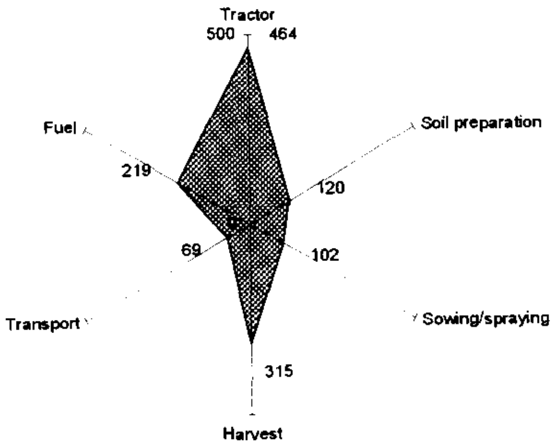


Fig. 4 - Machinery, labour force and farm area combined

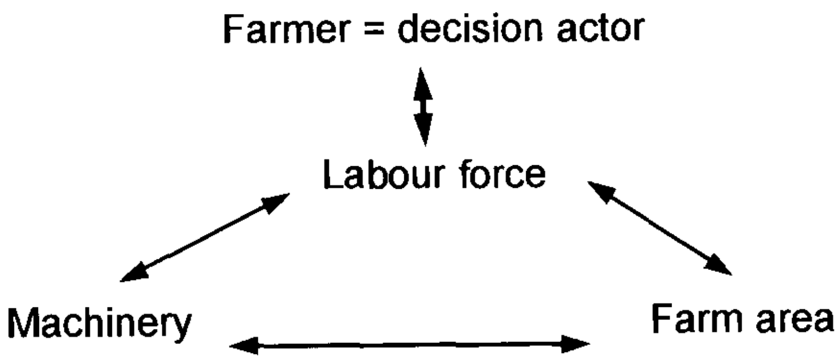
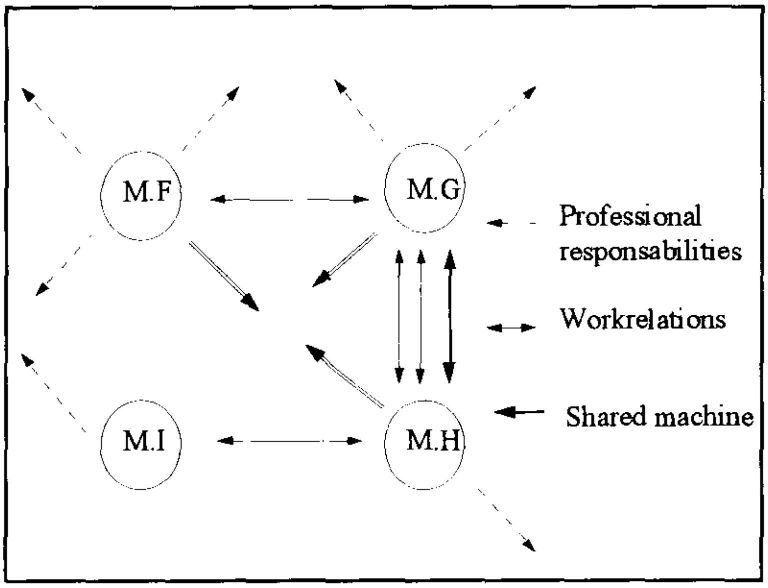


Fig. 5 - An example of social relations between four farmers



Prof. Arturo LARA

Mexico

I thought the presentations were excellent, very well prepared, and covered most of the aspects of interest to us. However, I would like suggest that, for the conclusions, we extend the analysis from the farm level to the regional level, thus issuing recommendations for local mechanization in each country or region of a country. This will provide advisers with some elements for formulating appropriate mechanization policies.

Prof. Brian D. WITNEY

UK

I would like to discuss a detail that links into more general issues, with reference to Dr. Mazzetto's paper. In Table 1 he compared three alternative farm machinery systems with the real system, and suggested that the farmers were in fact overmechanizing in order to achieve a higher level of timeliness. In actual fact, studies of farm systems don't bear this out. Very high levels of mechanization don't necessarily result in a high level of timeliness, because often these levels of mechanization are incorrectly managed. I would put a different interpretation on his results: the actual farm system is composed of a farmer and son who work 690 hours, whereas the optimum system was identified as requiring 800 to 1,000 hours. Obviously, a farmer-and-son operation will identify with the system that gives them the least amount of work. So I would raise the question of how to include, within the objective function, some parameter to account for the value the farmer places on "quality time" or "leisure time".

Dr. Eric AUDSLEY

UK

This doesn't pose a problem in terms of modelling. It's mainly a question of defining that constraint within the system. Most models include a parameter for the number of workable hours available per person. It's simply a case of obtaining, from the user of that particular model, the correct value for workable hours per person. I have conducted studies on many farms that had employed workers, and not just farmers with their sons. After inputting reasonable values for hours per hectare for all the tasks, and assuming reasonable - not excessive - workable hours available for jobs like combining and so on, the calculation results say that that farmer should have seven men - when in fact that farmer has ten. So obviously it doesn't apply only to the farmer and sons, but to the workers as well. A lot of time is going missing, so that each worker actually spends only 70% of his time on what we identify as prime farm tasks, and the remaining time is devoted to secondary farm tasks. Which brings us back to the problem identified earlier, that when we speak of spot work rates and overall work rates we are not really identifying where the time goes. We need systems that identify exactly how workers spend all their time, because in many cases it doesn't go where we think it does. We run these models and assume that a man is working six or eight hours a day, but from our everyday experience we all know that's not strictly true, for us and I'm sure also for farm workers.

Prof. Horst GÖHLICH

Germany

I've learnt from people in the industrial production sector that they are increasingly using psychology in their work. Looking at this morning's presentations, and at the problems involved in advising farmers, I feel there might be some scope for including a psychological component in identifying optimum mechanization. At the very least, some aspects of psychology could be used for more effective persuasion of farmers.

Prof. Ali M. EL HOSSARY

Egypt

Dr. Audsley discussed optimum mechanization levels, and touched on the question of depreciation. Depreciation rates really do affect cash-flow too much, but he took it from the side of the real value of equipment and inflation. However, in developing countries, where we always have monetary and official accounting systems, we put emphasis on the depreciation rate of the machine itself. When we buy a machine or put out a tender for equipment, we assess each machine's feasibility in terms of the depreciation rate, which we classify into three categories (good, normal or bad) depending on the conditions in which the machine is operating, and on the condition of the machine itself. For instance, we calculate the depreciation rate as 12,000 hours in good conditions; 10,000 hours in normal conditions and 8,000 hours in bad conditions. By good conditions we mean that the machine is reliable and of a good make, environmental and soil conditions are good, the operator is highly skilled and so forth. If even just one of these parameters falls below the norm, conditions are considered normal even if the machine is reliable. I wonder whether your exercise takes these sorts of conditions into account? Because they affect the workability of the machine itself. In developing countries we are faced with so many problems - in terms of handling, maintaining and working with machines. Did you touch on this aspect in your exercise?

E. AUDSLEY

There has probably been a misunderstanding of what I meant by depreciation earlier. In England, depreciation is a term used by accountants in preparing tax returns for the government, and there you are allowed various levels of depreciation for machinery. A better term is machine "resale value", meaning that after various lives of the machine it has an actual resale value. So within the system I would use whatever resale value you feel the machine will have at the end of any given life-cycle. If a machine operates for only 8,000 hours in what I would call poor conditions, then the machine will be sold sooner than if it had a life of 12,000 hours. You would also probably expect significantly higher repair costs in those conditions. You can still perform the same calculation that I presented, but using appropriate values. We have a formula for the resale value of various machines, many of which were in fact taken from ASAE, although we have our own UK figures. Similarly, for repair costs we tend to use either the Claude Culpin repair cost formulae or the ASAE - their cost formulae related to hours of use, but you would obviously have to adjust the expected repair costs depending on whether you have good, bad or average conditions. Costs vary from country to country and the repair cost values given for American conditions include a labour component and a parts component, that will obviously have different values in different countries. In some places repair spares might cost more and labour less, so you really have to look in your own country, which is very difficult because there are cost variables. The other side of the coin, of course, is that in the models you have to use the work rate you expect to achieve under real working conditions. That's why models are far-based or regional-based. They have to be adjusted for that situation. This problem doesn't apply only to Egypt, but also to farming in Scotland or East Anglia. In Scotland they have flinty soils, so their machines for ploughing the soil are more likely to require repairs because the flint has broken something, and you have to adjust the work rate for those farmers accordingly.

Dr. Bernard CHEZE

France

A question for Mr. Audsley: at the beginning you said that the cost per farmer per year was lower than the contractor cost. I don't question the accuracy of your calculations, but consider this. Presupposing, of course, that the farmer is not overmechanized, so that you initially pre-optimize his level of equipment, bringing it to an optimum level. Would it change your conclusions if the cost of the contractor's operator were calculated just over the duration of the operation, and not over the whole year of salary? But I suppose that a good contractor would also use an operator to do other jobs, thus paying him for the rest of the year, instead of charging everything during the 150 days of operation.

E. AUDSLEY

Perhaps there was a slight misunderstanding of my first slide. What I tried to show was that if you costed the contract on one basis you found the contractor, on an hourly cost, appeared to be cheaper, whereas if you costed the contractor versus the farm system on an annual basis, then the farm cost appeared cheaper. What I was hoping to show was that hourly costs are not a good way of doing costings, because you have to look at the whole farm system on an annual basis to determine optimum systems. That probably answers your point about the contractor finding other work for the person during the year. What tends to happen, I think, is that the contractor assumes more hours than a farmer does. This is similar to the point Brian made about quality time. The farmer is only prepared to work, as in my example, 150 hours on harvesting in the days are available for harvesting, whereas the contractor is prepared to work 250 hours in the days available for harvesting. His hourly costs are therefore cheaper than the farmer's hourly costs - but unjustly so, in many ways.

B. CHEZE

My second question is for Dr. Mazzetto. You defined farm areas, crop lists, machinery and labour as controllable variables. However, I would like to point out that these variables are not always so variable, and can in fact be very difficult to change, particularly the farm area.

Dr. Fabrizio MAZZETTO

Italy

In fact, in this case they would be defined as constants. From the point of view of the runner - not of the farmer - these parameters fall into the category of controllable variables, which is subdivided into "constants" and "variables to be assessed". For example, if I am testing a certain type of new machinery set with new tractors, new soil tillage systems and so on, I can run the model to see the result from a specific farmer's viewpoint, in which case farm area and crop list are constants. But if I run the model from the researcher's or policy maker's point of view, the farm area could be viewed as a "variable to be assessed". If I ask: "what is the minimum area to make this solution convenient for a farmer?", the area becomes an output of the model. That is the meaning of "constant" or "variable to be assessed". I evaluate the result of my running by analysing farm performance. I said before that resources and actions may be seen as input/output of the model. Farm performance, not always but in 99% of cases, can be seen as an output of the model. From the modelling point of view, you can take risks and uncertainties into account. You can model only physical, biological, climatic patterns and so on. To do this, you need what I call "representative models", or input models. You can also test the results of your model by running hypothetical situations, as in sensitivity analysis. What would be the result of my models if, for example, the price of wheat halved? Or what should the composition of my machinery set be if I expect the price of tractors to increase by 50% in the next three years? If I am not able to simulate something with specific procedures, I can perform sensitivity analysis to see the results of the situation. Another example, that partially answers Prof. Witney's point: in my talk I said that the actual solution seems to be oversized with respect to the one suggested by the model. This is true, but the solution suggested by the model is based on fixed, objective functions - I refer to maximum hours worked on the farm or minimum costs. However, the farmer is not accustomed to considering isolated parameters. Instead he evaluates several aspects as a whole, and also takes into account things like the quality of life. It would be interesting to consider the example I presented in light of multicriteria analysis. In fact we performed multicriteria analysis on this example, and got the following results: as I said, the farmer was originally more operations-oriented than economy-oriented in his selection criteria, but if we hypothesized a major drop in the price of wheat, barley or maize - as is expected to result from the Uruguay round - multicriteria analysis gave a totally different result. The farmer was willing to become - it's his declaration - more economy-oriented than operations-oriented. What I've tried to present is really a classification of how we can work, not an absolute solution.

Dr. Lothar FISCHER

Germany

I think we have to add the political aspect, which was not mentioned before. As long as political decisions can alter conditions much more than any other factor, and as long as some farmers can make more money by filing the right documents at the right time, all these simulations will remain theoretical. We should also make a strong distinction between farmers and contractors, small-scale farmers and large-scale farmers, because small-scale farmers are very dependent on their historical experience, whereas the educated managers of large farms may have a completely different attitude to simulations. Experience shows that it is hard to persuade farmers to believe in simulations - in what we consider to be measurable facts - and you yourself mentioned several times that you have trouble obtaining reliable data from the farmers. I think we have to start with less sophisticated simulations, that these people can understand, and which they feel can come true. Then when they see the next year's harvest - six months or so down the road - their belief in simulations will be enforced and you can progress to more in-depth simulations.

Prof. Jaime ORTIZ-CAÑAVATE

Spain

Perhaps the three speakers wish to comment on these suggestions. In my opinion, a very important point is that models are only as good as their data, which must be collected appropriately - in a manner specific to each agricultural region - because there is a lot of diversity. I think that Mr. Fischer's point was very important, and I would comment that it's vital to estimate repair costs and establish to what extent timeliness - which varies greatly from one country to another - may be calculated. We've also mentioned environmental impact. Which is the cost deriving from the effects of herbicide and sprayer applications?

E. AUDSLEY

I agree with all that has been said. Our models are created so that the farmer can input his own data - that is the whole point of the model. They enable the farmer to play with the system and see what happens if he tries something different, using all his own information. Where our models try to help is where the farmer is not sure of particular data, guiding him along the way to approximate values. Repair cost was the classic example. In some studies conducted in England, they looked at repair costs and came to the conclusion that the ASAE repair costs for the machine they had used were in fact quite reasonable for UK conditions - a very adequate representation. For some things like combines we have actually developed our own resale value formulae which are different to the ones you find the USA, which is exactly what you said about using local values. I am quite sure that the values would be different again in Spain or France and so on. I also strongly believe that the system must grow gradually, with the farmers. Farmers can gain confidence by using a simple system without applying it, just to try out their own ideas and see what the system would have said. Their reasoning is: “the model is correct”, rather than “the model is telling me what to do”. But gradually they will start to trust the model - also through people who are already users of the model and who confirm its validity - and start to grow with the model. They can start off with simpler models and eventually ask for more. This is certainly what happened in the industrial sector, where people started using models for monthly forecasting and gradually gained confidence in those and asked for more, until before they knew it they were doing hourly scheduling on computers. But it takes time for people to gain confidence, not only in the model but also in the use of computer technology, because most farmers have never used computers.

F. MAZZETTO

I, too, completely agree with Mr. Fischer about the need for addressing the problem of farm-level data acquisition, but not only at the farm level. A model is always a combination of algorithms, procedures and input data. The problem at the farm level can be examined through analysis of the farm information system I discussed earlier. That is why I spoke of farm information systems, because without a farm information system, it is impossible to have reliable data available at the farm level. If I run a model and tell the farmer he can save 50 hours on soil tillage with a given solution, the farmer is unable to assess the impact of those 50 hours. He doesn’t know exactly how many hours he’s spending on tillage each year, because of variability due to the weather, interconnection with other operations and so on. If the farmer stops to think about the problem, he will realize that if he works about 200 hours then 50 hours means 25% less, which is quite interesting. But there are no records of farm field operations. Data is available only for those operations carried out in the farm centres - typically livestock operations like milking parlour, because these daily operations require control of human-specific variabilities, animal by animal. We don’t currently have the instruments to control the site variability of operations carried out in the fields. That’s why one year ago we began to explore the feasibility of providing farmers with a low-cost automatic system for collecting farm field operations data. Some of our priority research now is on model-based systems at the farm level, which in the future could also be useful to farmers and advisors, allowing them to work with past data from their own farm. A farm historical database. Without such a database, the use and application of models at the farm level will be always very difficult. The situation is different, in my opinion, for models run by researchers policy makers, because there the level of detail can be considerably lower.

Dr. Adrianus G. RIJK

FAO

Italy

If would add, to what the last few speakers have said, that we must be very careful not to let the models make the decisions. In my view, models are useful tools for understanding complex mechanisms, but certainly not for making decisions. I also have a question for Mr. Audsley: your cash flow methods include an adjustment for inflation, which I found somewhat unusual, having worked in financial institutions for a long time. How do you predict what inflation will be five years from now in the UK or in the developing countries? My understanding has always been that you don't put inflation into the cash flow because all your factors inflate and, moreover, you can't really predict what the inflation is going to be.

E. AUDSLEY

In fact what you should actually use is the difference between the interest rate and the inflation rate. That is a value that stays relatively constant, but in the days when I created our method we had quite high inflation and interest rates in the UK, and if you do your discounting cash flow with interest rates of 15% you are getting completely the wrong answer, because inflation is probably 12% and you really have to take inflation into account or use a real interest rate which is 1.15 over or 1.12 in the calculation. It goes even further wrong if you get into situations where inflation is over 25% a month. You are getting totally the wrong annual cost of your machine.

A.G. RIJK

First of all you compare A with B, and both are inflating. Labour costs are inflating, your crop prices are increasing, and so on. In the short or medium run - five or ten years - an economy inflates at the same rate. In longer run, of course, capital goods tend to inflate less than labour. The point I wanted to make is that it is very difficult to predict inflation. We've seen what happens when people put inflation into their calculations - in the real estates markets of countries like the UK, the Netherlands, France, and what is happening now in Japan.

E. AUDSLEY

But if you don't include inflation you get equally erroneous answers. You have to include a real interest rate. You can't disregard inflation because if inflation is high, then the real cost of a machine is actually very low and, comparing it with the cost of an animal, people will buy machines. That's why in situations where inflation is 30% and the interest rate is only 15%, everyone buys machines and fires workers: because the real cost of owning a machine is pathetically cheap compared to the real cost of employing labour. That what happens in practice, and that's what the analyses tell you.

ORTIZ-CAÑAVATE

To recapitulate, in cases where inflation is not high, less than 5%, it is not important to consider inflation. This is what I am doing with my students. When inflation is not high everything - labour, machinery, etc. - inflates at almost the same rate.

E. AUDSLEY

No, you get the wrong answer if you look at the actual mathematics of it whilst what we should be using is the difference between the interest rate and the inflation rate - then you get the right answer.

Prof. Karl TH. RENIUS

Germany

One more comment on the principles of developing models. I think the primary output of the model is an understanding of the process, and a second benefit is the development of strategic consequences. The models shown in figures 1 and 2 of Mr. Mazzetto’s presentation are very similar to the closed-cycle control principles applied to machinery. A tractor's draught control, for example, operates on the same principle. It might therefore be interesting to apply the mathematical models typical of these types of closed control cycles. One very important parameter is, for example, the natural frequency of such a cycle, which might be ten hours for a draught control and perhaps a year in agriculture. This means one cycle per year or at least one cycle every so many months. My thinking is: what would be the consequences of increasing this frequency to speed up the process by, for example, applying better sensing systems, to know earlier what is happening. This may be a strategic point of some importance that we could perhaps include in the conclusions.

E. AUDSLEY

I disagree slightly with the statement that the aim of the model is to understand the process. As I mentioned in my talk, you can create different models for different purposes. If you are an engineer trying to understand draught control or even why you get certain work rate responses from transport processes, then you need a very complex model to understand the process, which includes the transport distance to the particular field you were studying at the time, and such like. From the point of view of management models, you need a much coarser model that gives you a prediction of the overall work rate of the process. So there are very different levels of model.

Dr. Oleg S. MARCHENKO

Russia

I would like to comment on the applications of these decision-support systems. I think that in the future this methodology will be widely used, by farmers and advisors, to make considered decisions, which is of course the primary aim of these models. But there is also another aspect. If, at the strategic level, we want to improve agricultural production and farmer profitability, decision models should allow for a totally new set of crops or machinery. This is because, over a period of several years, a complete change in crop production might be necessary, because new crops become more profitable or competitive. This greater flexibility would improve the strategic impact of these models. Furthermore, the models should also take contractors into account. We have already discussed the use of contractors, but these models don’t take into account the possibilities of contractors. I feel these aspects should also be included.

Prof. Gajendra SINGH

India

I would like to know if there is a simple procedure for calculating timeliness costs, or timeliness factors. We have been using data from the USA and other countries. The difficulty is that, in developing countries, labour costs are relatively low as compared to capital costs, which naturally results in smaller-size machines. On the other hand, timeliness penalties are not low, especially in rainfed areas when everything is under the rain and you must plant very quickly, in which case the penalty cost of timeliness can be extremely high. Previous systems suggested small-size machines for this situation, because there are plenty of labourers on a yearly basis, but in this area there is a serious shortage during the brief spells to get the crop out. Another major factor is that input levels vary greatly in developing countries, so the yields vary tremendously, while in developed countries input levels are fairly uniform over large areas and yields are very similar, so you can put some confidence in the calculations of timeliness penalties. I would appreciate it if somebody could suggest a reasonable procedure for determining timeliness costs.

F. MAZZETTO

We do not have any good procedure to this end but we are working on it.

SESSION 2

TECHNOLOGICAL LEVELS NEEDED IN THE VARIOUS AGRICULTURAL AREAS. STUDY CASES: EUROPE AND USA; INDIA; SOUTH AMERICA; EASTERN EUROPE

Chairman: Dr. Oleg S. MARCHENKO, RUSSIA

Agricultural trends and their effects on technological needs for farm equipment in the 21st century

by *John K. Schueller, Bill A. Stout*

USA

1. Summary

Production agriculture has become a high technology industry with a high level of sophistication from biological, chemical, and mechanical points of view. Computers are a major tool in farm equipment research and manufacturing, as well as in farm and machinery management.

Agriculture seems to be losing its political clout as the farm population diminishes. Support for traditional farm equipment research in the universities is diminishing as more emphasis is placed on biological and environmental issues. As a means for survival, agricultural engineering departments are shifting their identity, their faculty, and their curricula to a greater biological and environmental orientation. The prevailing attitude seems to be to let industry develop the equipment.

As the shift away from traditional power and machinery research continues in universities, several technological trends are evident. Spatially-variable crop production may offer environmental, agronomic, and economic benefits. By recognizing variations within fields and employing “smart” machinery that can adjust seeding and chemical application rates, increased yields or reduced input costs may generate greater profits with reduced environmental risk.

Developments in tractor-implement communications offer the benefit of improved equipment performance and greater efficiency. Standards are needed for physical connections, data structures, and information content so that interchangeability is assured and maximum utility is achieved.

Farm power units will have to meet similar emission standards as automobile engines. Renewable fuels continue to have appeal, especially when derived from agricultural products which may lead to increased commodity markets and higher prices.

Gear and shaft power transmissions predominate on today’s farm tractors. Continuously-variable transmissions as well as hydraulic power replacement of the PTO are being researched and may find their place on future tractors.

Research and development will continue on pneumatic devices, improved mechanical front wheel drives, rubber tracks, unmanned robotic tractors, increased use of electronics, vision systems, and other innovative technologies. Widespread farmer acceptance and adoption will depend upon industry development, marketing, and proven economic benefits to end users.

This paper discusses the current farm equipment situation, primarily from the perspective of the United States, but many of the remarks are also applicable in Canada and to some extent in Western Europe. Technological needs for farms of the 21st century are discussed. Although broad generalizations are made, it should be remembered that there are significant differences between and within countries due to variations in climate, soils, politics, and social/economic conditions.

2. Background conditions

2.1 *Agriculture*

The agriculture practiced in these countries (United States, Canada, and Western Europe) has a high degree of technological sophistication from biological, chemical, and mechanical points of view. The seeds are specially bred for optimum performance, sometimes using genetic engineering. The fertilizers and pesticides are the latest formulations selected and applied to meet the specific needs of a particular situation. And the machines used for tillage, planting, cultivating, chemical application, and harvesting are the most advanced available.

The general level of managerial expertise is similarly high. Computers are being applied beyond their initial accounting applications to management information systems, machinery selection and management programs, simulations, and other analyses. Progressive farmers know their costs and manage to achieve maximum economic yield (MEY).

Despite these countries having long capitalistic histories, politics and government policies have very strong influences on agriculture. Farmers have been insulated from international market prices by various subsidies and import restrictions. The passage of the GATT and NAFTA treaties and the perceived needs of the governments to reduce subsidies in order to reduce governmental spending will impact farm income. The agrarian heritage of these societies and historical momentum have enabled agriculture to have a political impact disproportionate to the size of the agricultural voting population. The continuing decline of the voter base and the lack of understanding of the intricacies of agriculture among non-farm consumers may be problematic for agriculture in the future. Urban consumers seem primarily interested in cheap food. It will be especially interesting to see how the environmental and safety concerns of the public with respect to agriculture are resolved.

The consolidation of agricultural production and the specialization of individual farms appears to continue unabated. There are fewer and fewer farms. And those that remain tend to specialize more.

A recent random survey of 1225 young U.S. farmers under 35 years of age indicates that although their views vary widely (the public opinion firm which conducted the research grouped them into traditionalist, techie, discouraged, laid back, and community leader categories), young farmers tend to be politically and fiscally conservative (Taylor, 1995). Many shop tirelessly for bargains and try vigorously to avoid large debts.

2.2 *Field equipment industry*

As mentioned above, the agricultural machines in these countries are quite sophisticated. However, the health and vigor of the agricultural equipment industry through most of the 1980s and early 1990s was poor due to low equipment sales compared to the 1960s and 1970s. The combination of fewer farmers, low farm profitability, and the greater capacity and higher reliability of new models resulted in fewer units of new equipment being sold. And there was reduced technical obsolecense of older equipment corresponding to the great power increase during the earlier period. The agricultural equipment market in these countries is viewed by many as primarily a market in which worn machines are replaced. While that replacement market is not insignificant, it is less than the market available when existing equipment is made obsolete.

The low demand for machines coupled with improved manufacturing technologies have resulted in farm equipment manufacturing overcapacity.That overcapacity combined with the more important equipment industry fiscal problems led to significant consolidation in the industry. For example, Case and International Harvester merged. AGCO is another example, being formed from what was (at least in North America) White, Massey-Ferguson, Deutz-Allis, New Idea, and other firms. Still more examples are the Ford-New Holland/Fiat and Deutz/Same combinations.

Internationalization of equipment design, production, and marketing also continues. It has become important to produce vehicles which can be sold in many countries. This means meeting customer expectations as well as abiding by governmental regulations. Given the needed technological sophistication and financial investment, multinational companies cannot develop machines for just a single market.

Electronics and computers are being used increasingly on agricultural equipment (Auernhammer, 1989). Monitors and controllers are commonplace. As discussed below, communications standards and spatially-variable capabilities are receiving a great deal of attention.

Governmental regulations are having a greater and greater impact on the farm equipment industry, especially from an environmental and safety perspective. Air pollution from engines will have to be reduced. Oil leakages will become more problematic. Environmentally-conscious manufacturing is being emphasized. Pesticide and fertilizer application is being further regulated. And safety is receiving more and more attention.

One way that the North American farm equipment industry is trying to draw some attention and build some political support is by having the various industry segments join together. A special North American Agricultural Equipment Conference is being sponsored on 4-5 November 1995 in Chicago by the Equipment Manufacturers Institute (EMI), American Society of Agricultural Engineers (ASAE), Farm Equipment Manufacturers Association (FEMA), Agricultural & Industrial Manufacturers Representatives Association (AIMRA), and North American Equipment Dealers Association (NAEDA). Leading politicians and journalists are being involved, as well as the members of the sponsoring organizations (Anon., 1995a).

3. Technological trends

It is instructive to view some of the technological trends in agricultural equipment as they might affect the equipment design, the equipment industry, and agriculture itself. Manufacturers, agribusiness suppliers, and farmers will need to adapt to the new technologies. This evolution may be difficult given that the technologies which will develop, their form, and their importance cannot be predicted with certainty.

3.1 *Spatially-variable crop production*

Crops, soils, pests, and other factors are not uniform throughout an agricultural field. Detection of these nonuniformities and the response to them has become an area of great interest in agricultural equipment development. Research efforts are underway at many institutions and commercial adoption of the technologies is progressing rapidly.

The tracking of this technology has been made somewhat difficult by the variety of names assigned to it. Some titles include spatially-variable, precision, prescription, site-specific, soil-specific, computer-aided farming, pin-point, and GPS-based. Schueller (1992) reviews some of the early work, including Schueller and Bae (1987), Elliott (1987), and Searcy, et al., (1989).

More recent work is available in many places, including special issues of Computers and Electronics in Agriculture (Volume 11, Number 1, 1994 and another issue that will be published in late 1995 or early 1996).

Spatially-variable crop production has come to refer to a variety of technologies which are linked by their use of a geographic index to refer to some measurement or action. The most common operation is automatically mapping crop yield during harvest. This has become especially popular during grain combining and is achieving widespread commercial success. The GreenStar System recently introduced by John Deere is an example of such a system (Mangold, 1995). The Massey-Ferguson Datavision Yieldmapping system introduced in Europe in 1993 and the efforts of Auernhammer, et al., (1993) are more examples. Other crop (e.g., Vansichen and De Baerdemaeker, 1993) and soil mapping can occur. The second most common operation is applying fertilizers or pesticides at variable rates according to some predetermined map, such as by Rudolph and Searcy (1994).

Spatially-variable field operations generally rely on three different types of component technologies. The first is the determination of the equipment's position in the field. This may be done by dead reckoning, radio trilateralation, or satellite navigation techniques. For at least the near future, it appears that the differential global positioning system (DGPS) form of satellite navigation will dominate. The second technology is some sort of computerized database, such as a geographic information system (GIS), which handles all the map data. The third component technology is the sensing or control elements which measure or affect the agricultural operations. Since the first two component technologies are driven to a large extent by the many applications outside of agriculture, they are advancing rapidly irrespective of the agricultural community.

However, someone needs to take responsibility for adapting them to agricultural needs. The third area, developing adequate sensor and control performance on agricultural equipment, seems to be the key engineering need for spatially-variable field operations. The design, accuracy, and dynamic response of the equipment is very important. Much research and development is needed.

One example is the further development of practical farm equipment that automatically and economically extracts and tests soil samples from fields in intensive patterns.

A number of issues are of concern with spatially-variable crop production. One issue which has generated considerable discussion in the farm press is the question of information ownership.

Farmers and their supporters want the farmers to own the maps since the farmers have paid for them. However, the equipment and service providers who developed the maps want ownership so the maps and the embedded proprietary technologies can not be used by their competitors.

The timely information in the maps, such as yield trends or pest infestations, would also be valuable information in the volatile commodity markets.

The issue of technology ownership is exemplified by the concerns with patent rights. For example, Ag-Chem, the largest fertilizer and pesticide applicator manufacturer in the United States, has brought a suit against Tyler, another large manufacturer, alleging infringement of its Ortlip (1986) patent (Knowels, 1995). The patent claims the spreading of material according to digital maps.

Proper evaluation of equipment performance is another concern. Schueller (1995a) and others have called for unbiased testing of spatially-variable equipment similar to the Nebraska or OECD tractor tests. Adequate steady-state accuracy and rapid dynamic response are necessary to achieve the potential of spatially-variable field operations. There is much uncertainty among farmers about the actual performance of the available commercial equipment.

In a similar manner, there is a concern how the existing agronomic recommendations should be used in spatially-variable agriculture. For example, Cassman and Plant (1992) developed a model to quantify soil spatial variability and to assess the variability's impact on fertilizer use efficiency with uniform or spatially-variable fertilizer application.

The economic evaluation of these technologies is also problematic. Since the basic supposition of this technology is that fields are variable and diverse, making generalizations about the economics of spatially-variable production is difficult. Yet economic justification seems to be the key issue limiting farmer adoption.

There is also the social issue of the effects of the adoption of this technology on the competitiveness of different size farms. The availability of this technology may allow the small farmer who has other individuals perform field operations (such as custom grain combining) to better manage those operations through maps. It may similarly allow the very large farmer to better control his farm by automating information handling with his staff. Conversely, maybe it will help the medium-large farmers who often have better managerial control and are better able to take advantage of technologies. The true effects have not been determined yet. And, of course, the adoption and advantages are dependent upon the worker skill levels, including computer literacy.

Spatially-variable crop production is being adopted in some areas. Testimony before the U.S. Congress in 1994 claimed that five percent of the farms use the technology (Anon., 1994). It has received the biggest acceptance in the midwestern U.S. areas dominated by corn, soybeans, and wheat production. However, it is expanding to other regions and crops. It seems to enjoy a rare popularity with farmers, environmentalists, politician, the media, and scientists and engineers.

There also is great interest in other developed countries, particularly Germany and the United Kingdom. Leading researchers in Germany include Schnug (FAL-Braunschweig) and Auernhammer (TU-Munich). Activity in the U.K. includes a specialist group within the Institution of Agricultural Engineers, a conference for farmers, and research at Silsoe Research Institute and other places.

3.2 *Tractor-implement communications*

The technical advances in electronics have been reflected in continuing increases in the amount of electronics on agricultural equipment. The initial applications of electronics resulted in “islands of automation” in which individual tractor, implement, or harvester functions were controlled or monitored by self-contained systems which shared neither hardware nor data. The integration of these independent systems into a coherent whole has been proposed by Ruckman (1986), Schueller (1988), Stafford and Ambler (1988), and others.

A standards-making process has been initiated and has progressed far under the leadership of such individuals as Marvin Stone (Oklahoma State University), John Stafford (Silsoe Research Institute), and Hermann Auernhammer (Technical University--Munich). SAE Standard J1939 is close to being promulgated as a long, eleven-part document to specify the communications between various devices on agricultural equipment in North America, as is DIN 9684 in Germany. An ISO Standard (11783) is also in an advanced stage of development. The data link layer is now a draft international standard (DIS).

Standardization is necessary on the physical connections, the data structures, and the information content so that information can be shared between the various devices and they can work together. This will become particularly important as spatially-variable agriculture is increasing adopted.

The design of this standard is complicated by the need to insure compatibility while allowing for innovations and upgrade paths. Philosophical differences on what to specify and where to place the decisionmaking power need to be resolved.

3.3 *Engines and the environment*

Power units have always been an important element of mobile agricultural equipment. This can be seen by the naming of the ASAE division dealing with equipment as the “Power and Machinery Division.” Power unit development in the last few decades has focussed on achieving greater fuel efficiency with reduced emissions.

The reduction of emissions continues to be an area of great concern. In the United States, the emission requirements of the California (which also happens to be the most important agricultural state) will impose stringent demands upon tractor and self-propelled equipment manufacturers. The president of a British manufacturer states that “because it would be uneconomical for OEMs to install separately certified engines in California, the California emission standard, in effect, becomes the standard for the industry.” (Cantrill, 1995)

Since the late 1970s, there has been interest in the use of renewable fuel sources for agricultural equipment. Various oils and esters of natural origin have been studied as potential fuels, but none has achieved widespread usage. Ethanol is widely used, however, in some reformulated gasolines where its octane enhancement and pollution suppression characteristics are in demand. Biodiesel research is on-going in the areas of laboratory and real world engine durability tests, regulated and unregulated engine exhaust emissions, storage, handling, toxicity, lubricity, and biodegradability assessment. Biodiesel efforts are reported in sources such as the Biodiesel Report (Fairchild, 1995). In the European Community, consideration is being given to promoting the use of biofuels by means of direct aids or tax remissions (Ortiz-Cañavate, 1994).

3.4 *Power transmission*

Engine power in agricultural equipment used in North America and Western Europe is usually transmitted to the driving wheels through gear and shaft transmissions. The power transmission system usually supplies a large number of travel speeds for a given engine speed. Manual, powershift, and combination transmissions are all popular on tractors. Torque converter and continuously-variable transmissions have not achieved significant market penetration, except for the use of hydrostatic transmissions in harvesting and similar machines.

However, that may change. Professor Renius indicates that infinitely-variable transmissions are now more feasible because conventional transmissions have become very complicated and expensive, continuously-variable units have improved in efficiency and cost, automatic drive line management can best be realized with stepless shift, and continuously-variable transmissions enable the highest possible comfort levels (Renius, 1994). His Institute built a research tractor with a continuously-variable chain drive. Claas and Komatsu have introduced a multipurpose agricultural vehicle and a bulldozer respectively which use hydromechancial continuously-variable transmissions (Schueller and Khan, 1995).

Power to operate tractor-towed or tractor-attached implements has traditionally been supplied by the tractor power-take-offs (PTO) at 540 or 1000 rpm. However, more applications are now using hydraulic power to drive hydraulic motors. Engineers such as Shearer et al., (1992) and Lin and Buckmaster (1994) suggest replacing the PTO with hydraulic drives. The tractor hydraulics themselves are becoming more sophisticated with the increased use of load-sensing and electronics (e.g., Backé and Zãhe, 1991, and Endress et al., 1992).

A concern with the potential pollution from oil leaks on mobile equipment has led to the limited use of environmentally-friendly oils, especially for hydraulic systems. These oils have improved biodegradability and toxicity but temperature effects and frictional characteristics need to be monitored carefully. With the continuing development of special pumps and motors, there may soon be some systems with water-based hydraulics.

The issues in power transmission are primarily economic and technical, with cost and reliability being the predominate areas of concern. Continuously-variable transmissions, hydraulic drives, and alternative oils tend to be expensive in both first-cost and operating expenses. Their adoptions require cost-benefit analyses.

3.5 *Innovative commercial vehicle concepts*

Some innovative vehicle concepts have been released to the commercial agricultural equipment marketplace. Their practicality needs to be assessed. If they are suitable, the proper use and management of the equipment and the affected field operations needs to be elucidated.

Large dry fertilizer applicators are moving in the direction of pneumatic distribution. Pneumatic techniques are also being extended from row-crop planting to the broadcast seeding of grain crops in areas such as Canada's prairie provinces and the bordering U.S. states.

Mechanical front-wheel-drive (MFWD) is now achieving dominant market share of the larger conventional tractors in North America, following western Europe's example. The recent steering system designs of New Holland and Deere have allowed MFWD tractors to achieve a small turning radius. Renius (1994b) chronicles the recent trends in tractor design.

Rubber tracks are competing more and more with tires. Caterpillar has extended its line of rubber-tracked tractors down into the popular North American row-crop class where it competes with the flagship tractor lines such as the Deere 8000 series, Ford Genesis, and Case-IH Magnum. Studies in Europe and the U.S. have attempted to compare rubber tracks and tires (e.g., Okello, 1994).

Some recent introductions of interesting vehicle concepts have been made in Western Europe, where there is a long history of specialized agricultural vehicle designs, such as the Unimog, Fendt tool carrier, and the MB-Trac. The Modulaire unmanned robotic tractor from Finland removes the driver from the vehicle (Mononen, et al., 1995). The Xerion multipurpose agricultural vehicle from Claas is bidirectional with a moveable operator's cabin. And in the United States, Agro Technology's Birotor combine (recently licensed to Deere but not currently commercially marketed) is built around what is called a Versatile Power Unit. These new vehicles are intended to perform some of the tasks of the tractor, but differ radically from the conventional designs. Gantry and cable systems (e.g., Chamen et al., 1994, and Kline et al., 1986) have also been under development.

As in the other automotive industries, the electronics content will continue to expand in farm equipment. Vision (e.g., Zhang and Chaisattapagon, 1995, and Olsen, 1995) and other sensors are becoming less expensive and more reliable. Controller hardware is becoming vastly more powerful and inexpensive.

These innovative concepts demonstrate that despite the difficult financial problems of the agricultural equipment industry in the 1980s and early 1990s, creativity and risk-taking are still part of the industry. In addition, farmers and mechanical innovators continue to pursue new concepts. For example, one farmer has built a microwave hay drier to be operated before baling (Leidner, 1995). The viability and proper exploitation of these technologies remains to be determined.

4. Infrastructure changes and needs

The current status of agriculture and agricultural equipment industry was discussed briefly above, as were some of the current technological trends. The status and trends will affect the infrastructure which supports agriculture. The infrastructure will also be affected by external political and social trends, as well as by its own internal evolution.

4.1 *Technology transfer*

The transfer of technology from the research labs and commercial manufacturers is necessary to promote adoption on individual farms. The farmers are now fewer and more sophisticated. Some are even using computerized tools such as CD-ROMs, satellite systems, and the Internet (Walter and Meade, 1995). As the number of governmental transfer agents (such as the U.S. Extension Service County Agents) have been reduced due to budgetary constraints, the agricultural press has increased its technology transfer activities. For examples, advanced technology is featured in specialized media such as Grant Mangold's ag/Innovator newsletter.

The large volumes of data needed for technologies such as spatially-variable crop production and the vast amount of data generated using computer technology, make the need for synthesis, organization, and codification of knowledge a crucial, continuous need. Researchers and manufacturers continue to develop new insights and products, but the integration and systemization of the knowledge and transfer to the farmers in a practical, usable manner is lacking. Agriculture will benefit significantly as data processing methods are improved and the results are translated into practical information for end users.

4.2 *Universities*

The support of the universities in the U.S.A., Canada, and Western Europe for the agricultural equipment research has declined. In reaction to the declining employment market for graduates in the industry during the 1980s and early 1990s, Agricultural Engineering departments have shifted their emphasis towards biological, environmental, and food processing areas. This can be clearly seen by the faculty hirings (e.g., the replacement of Prof. Gunkel at Cornell by a non-equipment specialist), by the current course and specialization offerings, and by the new names of the departments (e.g., Biological and Agricultural Engineering, Biological Systems Engineering, and Bioresource Engineering).

U.S. Mechanical Engineering departments have similarly moved away from agriculture as they have been driven more by national searches for grant and contract funds and less by the perceived state needs. In general, the automotive-type industries (including agricultural power and equipment) have been de-emphasized with a higher priority placed on the military, aircraft, robotics, and manufacturing industries. The teaching of machine design has decreased at state universities with the pressures from state legislatures to reduce costs by reducing degree requirements and the concurrent expansion of knowledge in other areas (Schueller, 1995b).

Outside of some emerging efforts in spatially-variable crop production, the funding of equipment research by the U.S. government has seemed to decline. The perception is that the development of machinery should be undertaken by the private sector.

4.3 *Environment and safety*

Due to its entwinement with inherently-volatile politics, it is hard to discern the future trends of environmental and safety concerns. However, most observers believe that both environmental and safety issues will continue to increase in importance. For example, lawn and garden equipment manufacturers must now advertise in California to warn users not to breathe engine exhaust (Anon., 1995b).

With the reduction in industrial injuries and continued improvement in industrial occupational health (with the possible exception of cumulative trauma disorders and some other problems), the focus on United States agriculture has increased due to its high annual fatality rate of about 50 per 100,000 workers. The large numbers of children (about 300 annual child fatalities in the United States) and elderly killed and injured on family farms is particularly disconcerting. Efforts will continue to reduce entanglements in machines and moving vehicle accidents. Operator presence detection is one of the areas of technical development. Of course, those intending to market equipment in the European Economic Area must comply with the Machinery Directive (von Ekelenburg, et al., 1995).

A recent area of research emphasis is the accommodation of disabled individuals. This usually involves the modification of the machines so such individuals can operate them.

Exposure of farmers to chemicals is also a problem as some types of cancers and other diseases are showing elevated rates in the agricultural population. Efforts, such as in the U.K. (Parkin et al., 1992) and Italy (Spugnoli and Vieri, 1994), are attempting to begin to deal with the problem by classifying application equipment. The general public is also becoming less tolerant of chemical exposure, whether it is drift from application or chemical residues on food. Although organic foods have made little market penetration, there is increased consumer sensitivity towards chemicals. This may be reflected in changes in chemical application equipment to achieve higher use efficiency. Air-assisted sprayers are accordingly starting to have some of the popularity in North America which they have enjoyed in Western Europe (Dunn, 1995). Chemical use reduction is an often-stated element of the rationale for spatially-variable agriculture. Chemical use reduction is also a goal in the development of a vacuum machine that removes insects from plants and the resurgence in the use of postemergent mechanical cultivation to control weeds (e.g., Buhler, et al., 1995).

The use of mechanical cultivation, however, is under attack because it may increase erosion and lead to soil degradation. Limited tillage and no tillage are encouraged. The U.S. Department of Agriculture farm program requires that a certain amount of crop residue be left on the soil surface to mitigate erosion. Agricultural equipment will also have to apply fertilizers and pesticides to minimize the water pollution potential. Or perhaps new or resurrected technologies, such as weed control by flaming will be applied (Ascard, 1995).

Agricultural laborers are of emerging political concern for the fruit, vegetable, and specialty crops. Both CNN and CBS, major U.S. television networks, have recently run documentaries highlighting the problems faced by laborers. Working and living conditions are under examination, including exposure to pesticides. And the political and social climates in some regions are hostile to the foreigners who often perform this work. It is premature to predict the consequences for the agricultural equipment industry.

The environment and safety area is an emotional issue to many. The hazards involved and the technologies to reduce them need to be understood. As in many other areas, the agricultural equipment industry will undoubtably be forced to follow the automobile industry in devoting significant efforts and resources to these topics.

The agricultural equipment industry will also have to operate in an environment where the customer base has diversified. Farms in the U.S. and Canada might be generally classified from largest to smallest as: corporate farms, commercial family farms, moderate size family farms, subsistence farms, and hobby farms. The third and fourth categories (moderate size family and subsistence) have historically tended to dominate American agriculture, providing a coherent customer base for the industry. But the percentages of total farms in these two categories have declined in the later part of this century, causing a more diverse market. The situation in Europe appears analogous.

Similarly, individual farms are becoming more specialized. Rather than being diversified farms, they tend to specialize on a limited set of crops or livestock. In addition, immigrants from Latin America, Asia, and Africa and the willingness of substantial fractions of the base populations to try new foods has resulted in new crops being introduced to substantial production (e.g., jalepeño peppers and kiwi fruit). Customer demand for their favorite fruits and vegetables at all times of the year has also dispersed production due to local climate restrictions.

5. Challenges and opportunities

The challenge of the American and Western European farm equipment industry and the supporting infrastructure remains to support farms in a developed world of decreasing political and economic support where the complexities of agriculture are understood by a decreasing percentage of society. The industry needs to support farmers by developing and supplying equipment which increases farm profitability while protecting the environment.

To survive in a competitive market with worldwide manufacturing overcapacity, manufacturers must produce economically-priced equipment. Yet the customers demand equipment which is technologically sophisticated and extremely reliable. The continuing advances in electronics and the rising concern with safety and the environment provide opportunities for continued technical development of agricultural equipment and for increased market share to the manufacturers who are able to take advantage of those opportunities.

5.1 *Acknowledgements and comments*

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Due to the space limitations for this paper, the references cited are just examples of what can be found on these topics.

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Technological levels needed in the various agricultural areas. Study case: India

by *Gajendra Singh*

India

1. Status of agriculture

India has achieved significant growth in its agriculture after her independence in 1947. The increase in foodgrain production from 50.82 Mt in 1950 to 186.4 Mt in 1994 (**Fig.1 and 2**) is an indicator to this. The annual growth rate in foodgrain production in India between 1900 and 1947 was 0.1%.

After independence, two broad phases in agricultural evolution took place. The first phase between 1950 and 1967 was marked by considerable progress in the development of infrastructure, land tenurial reforms, provision of institutional credit, community development programmes and supply of inputs essential to offer farmers mutually supportive packages of technology, services and public policies. Agricultural production increased during this period from 50.8 to 72.4 Mt largely through expansion in cultivated area from 97.3 Mha in 1950 to 115.1 Mha in 1965 [1]. The country had to import up to 10 Mt of food grains annually to meet the domestic requirement. The second phase between 1968 and 1989 has been characterised by productivity improvement as well as a relatively greater stability in total agricultural output. The introduction of highyielding genetic strains of wheat, rice, poultry, dairy cattle, fish and other plants and animals, extension of irrigated area and increased consumption of chemical fertilizers and pesticides helped to maximise the benefits from better nutrition of crops and animals and from water. The chemical industry played a major role in initiating and maintaining the momentum. During the period of 1966 to 1985, while the increase in area under foodgrains from 121 to 127 Mha was small, the foodgrain production more than doubled from 74 to 150 Mt largely through increase in net irrigated area from 25 to 39 Mha (**Fig.3**), use of chemical nutrients from 0.65 to 12.7 Mt (**Fig.4**) and coverage of area under high-yielding varieties from around 1 to 55 Mha [1]. The most important contribution of the second phase was generation of confidence to build a stable national food security system on home-grown food.

Indian agriculture has been traditionally dependent on draft animal and human power as the major source of energy. The total bovine population increased from 226.8 million to 272.6 million during 1961 to 1987. The draft animal population, however, declined from 80.4 million to 73 million due to adoption of mechanical power for field operations. Increased cropping intensity and modern agriculture demanded a higher energy input in field operations and agro-processing which required supplementation of animate power by tractors, power tillers, diesel engines and electric motors. With introduction of a little over 8,000 tractors every year during the fifties, tractor population increased by 20,000 per year in the seventies, 75,000 per year during the eighties and 150,000 per year during the nineties (**Fig.5**), indicating a compound growth rate of 13.3% per annum. With an estimated total tractor population of 1.5 million, the country presently has potential to cover 16-17% of cultivated area under mechanisation. The tractor population is, however, mainly concentrated in only seven states in the country, thereby, implying the continuing dependence on draft power in large parts of the country. With increasing adoption of prime movers, improved equipment for tillage, sowing, plant protection and threshing have been widely accepted by the farmers. High productivity level and labour shortage during harvesting of major cereals as wheat and rice have brought in use tractor drawn and self-propelled combine harvester in the progressive states. With development of irrigation infrastructure and simultaneous encouragement of the Government, adoption of irrigation pumpset showed remarkable increase. The estimated compound growth rate of adoption of electric pumpset had been 17% per annum and diesel pumpset at 13% per annum. It is estimated that during the nineties more than 700,000 irrigation pumps are being introduced every year leading to an estimated total population of about 14 million in the country.

Apart from disparity in the production of various crops, regional disparity in crop productivity has been significant in the country. The increase in yield of foodgrains between 1960 and 1980 was 126% in the northern region, 36% in the central region, 23% in the eastern region, 58% in the southern region and 32% in the western region as against the all-India average increase of 41%. Corresponding values in food production increase were 185%, 53%, 46%, 40% and 49% as against the all-India average increase of 58% [1]. The northern region of India had contributed the maximum to the growth in foodgrain production through wheat and rice.

2. Agricultural R&D and extension

Subsequent to independence of India in 1947, the country had realized that for development of a viable and productive economy agriculture would require a place in the country's priority. Food security for future population was thus conceived as an important task and agricultural research and developmental activities were geared up to meet the challenge. The "Green Revolution" in the country was the result of this endeavour which brought self-sufficiency in foodgrains production in the country. Food security in terms of economic access yet remains to be ensured to a large section of the population. The Seventh Five Year (1985-1990) national plan policy defined “Food, Work and Productivity” as a key factor which implied development of agriculture as a core programme around which the whole process of expansion and multiplication of economic activities would operate so as to attain broad-based objective of increasing food production, creation of additional employment opportunities and bring improvement in productivity of land and labour.

In order to keep the pace of growth of agriculture adequately supported by technologies emerging from agricultural research, the Government of India restructured the Indian Council of Agricultural Research (ICAR) in 1965 as a supreme central agency for co-ordinating, directing and promoting agricultural research and education in the country. To provide adequate autonomy in functioning, the ICAR is a registered Society and has direct simultaneous linkage with the Government of India (GOI) through its Department of Agricultural Research and Education (DARE). The research set-up presently encompasses 49 Central Institutes, 30 National Research Centres, 10 Project Directorates and 78 All-India Co-ordinated Research Projects and Networks, and 16 other projects/programmes. Agricultural education is being imparted through 27 State Agricultural Universities, 1 Central Agricultural University and 4 ICAR Institutes as deemed-to-be universities [2]. The universities also carry out mission-oriented research on region-specific problems. Apart from the public sector establishment, the private sector has recently started investment in this direction. In the seed sector alone, about 500 small and big firms are presently functioning with research and development establishments [2].

During the sixties and seventies, research policies generated development and widespread adoption of seed-irrigation-fertilizer-plant protection technology ushering in the green revolution. Research programmes were simultaneously initiated in drought-prone and rainfed areas, dairy, poultry, piggery, fishery and horticulture including quality improvement programmes in different sectors and sub-sectors. During the eighties and nineties, research was strengthened in pulses, oilseeds, integrated pest management, conservation of natural resources and their effective utilization.

The public research system in India is supported by about 30,000 scientists. The research activities under the ICAR system are monitored and executed by seven Subject Matter Divisions, each headed by a Deputy Director-General. The present thrust areas of the Divisions are as following:

2.1 *Soils, agronomy and agro-forestry division*:

- land-use planning and resource monitoring;
- sustainability of rice-wheat cropping systems in the Indo-Gangetic plains;
- farming system research;
- enhancing productivity of rainfed areas through integrated approaches;
- agroforestry system research for rehabilitation of wastelands.

2.2 *Crops sciences division*:

- consolidation of yield grains achieved in irrigated rice and wheat through insulation of future varieties, maximisation of genetic yield level of rainfed rice in eastern India with special emphasis on semi-deep water and relatively favourable upland ecologies and development of hybrids in rice and wheat to break yield barriers;
- development of efficient hybrid technology for sorghum and winter maize, pearlmillet (short duration), cotton (north-west India), pigeonpea, castor, sunflower, rapeseed-mustard and safflower;
- genetic enhancement of major pulse crops with special emphasis on rainfed ecologies;
- development of high-yielding and pest-ressistant varieties of forages, cotton (short and medium staple for rainfed areas), groundnut and soybean and subtropical sugarcane;
- development of cost-effective crop production-protection technologies with special emphasis on integrated nutrient management and integrated pest management;
- basic research towards finding new yield threshholds for major pulse, sugarcane and oilseed crops;
- strengthening seed technology research and production of quality seed of hybrid crops;
- produce value-addition in terms of quality, processing suitability, by-product utility of jute and tobacco;
- exploring potential of underutilized crops, especially for medicinal and aromatic products.

2.3 *Horticulture division*:

- arid horticulture with emphasis on efficient soil-water conservation and management;
- development of appropriate horticulture-based cropping/farming systems for different agro-climatic areas;
- development of protected cultivation technology for export-oriented cultivation of vegetables and flowers;
- seeking solutions to national disease problems of fruits and vegetables;
- genetic manipulation for introduction of desirable traits;
- development of integrated pest management systems;
- improving contribution of oilpalm in tropics and olives in temperate areas to edible oil economy;
- hybrid technology for vegetables for higher variability.

2.4 *Animal science division*:

- identification, evaluation and creation of information base for non-conventional animal feed resources and development of complete rations;
- development of immuno-diagnostic kits for diagnosis of diseases in livestock and poultry;
- development of value-added indigenous milk products;
- development of housing and management practices for livestock and poultry;
- use of micronutrients in health and production of livestock and poultry;
- development of package of practices for production of wholesome milk, meat and their products;
- improvement for milk and draft in cattle, and milk and meat in buffaloes through selection and crossbreeding;
- genetic resources, biotechnological manipulation especially for vaccines, milk products and feed.

2.5 *Fisheries division*

2.5.1 Capture fisheries:

- improving productivity of capture fisheries;
- stock assessment of offshore and marine resources in the Economic Exclusive Zone (EEZ), survey of coastal ecology with special reference to island ecosystems, management of endangered coastal and marine ecosystem and fish;
- development of models for assessment of fish population in rivers/reservoirs;
- strategies for management of river basins;
- development of fuel-efficient craft and suitable resource-specific gear for optimum exploitation of pelagic and demersal fish stocks.

2.5.2 Culture fisheries:

- intensive and semi-intensive aquaculture technologies for fin- and shell-fish, mariculture and sea ranching;
- nutrition, reproduction, disease control, hatchery and nursery rearing systems, broodstock management, aquacultural engineering principle application for freshwater including coldwater bodies and hill streams, brackishwater and marine culture systems.

2.5.3 Common areas:

- value-addition to products from low value fish quality;
- improved harbour and plant hygiene for packaging processes;
- instrumentation for on-board operations and on-shore processing plants;
- cataloguing of germplasm resources, identification and maintenance of pure lines, population genetic structure and creation of gene bank.

2.6 *Agricultural engineering division*:

- appropriate mechanisation technology for all farm-holding categories;
- development of field plot machinery for agricultural research experimentation;
- value-addition through processing of agriculture produce (fruits and vegetables, oilseeds, fibres, spices, plantation crops) to cater to both national as well as international market;
- appropriate technology for packaging and handling of perishables and duarables;
- technology for better utilization of agricultural waste;
- entrepreneurship development for rural agro-processing;
- agricultural machinery production technology appropriate for rural entrepreneurs and small-scale manufacturers;
- energy demand-assessment and management in food production system and development of technology for use of renewable/alternate energy sources in agriculture;
- drainage technology for waterlogged and saline soils;
- irrigation hardware, including micro-irrigation, for enhanced water application and use efficiency;
- engineering applications to aquaculture and forestry;
- application of electronics in agriculture through instruments, cost-effective and rugged electronic devices and electronic-aided machinery to improve productivity and minimise storage loss, electronic equipment for controlled environment cultivation.

2.7 *Agricultural extension division*:

- Human resource development through:
  - continous training of village workers (VLWs) in broad-based extension, joint training of Mitra Kisan and VLWs;
  - continous updating of training faculty of Farmers' Training Centres (FTC), Extension Education Institutes, Advanced Training Centres and National Institute for Management of Agricultural Extension (MANAGE);
  - establishment of Farmers' Training Centres in each district of the country.
- developing effective linkages between research and extension through:
  - making national, state, zonal and district committees more effective;
  - inclusion of small and marginal farmers in monthly workshops and fortnightly training programmes for enhanced feedback;
  - organisation of Farmers' Fair at the FTCs and Krishi Vigyan Kendras (KVK), conceived as the grass root level vocational training institutions to be located at each district and designed to bridge the gap between the available technologies at one end and their application for increased production at the other) before each cropping season;
  - intensifying direct farmer-scientist interaction at block level during each cropping season;

- strengthening of research/extension support in disadvantage areas as hilly, tribal and rainfed through non- government organisations (NGO) and local volunteers.

- reaching large number of small/marginal farmers through organizing field demonstrations, arranging farmers' visits to demonstration/research stations and to other states, establishment of large-size demonstration/exhibition on private farms, distance learning and media support extension;
- enlarging crucial supportive areas by encouraging private sector initiatives, involving village panchayats, establishing soil-testing facilities at the KVKs/FTCs, strengthening extension services for specialized areas as floriculture/agro-processing/farm implement, encouraging agricultural graduates to establish input agro-service centre in rural/hilly/tribal areas and promoting farmers' organizations;
- strengthening frontline extension system (for assessment and refinement of technologies being developed) through orientation of KVKs on farming-system research and vocational training programme in post-harvest technologies and other vocations for farmers and farm-women and making the KVKs selfsustaining, developing some of the Institutes to provide training support to the Subject Matter Specialists and KVK trainers through involvement of social scientists in the lead research programmes.

3. Information management

One of the major challenges before Indian agricultural research in the 1990's and beyond is to mould the vast scientific infrastructure and human resource into a more coherent one. Improved information is considered as one of the most effective tools for accomplishing the same. India is rapidly becoming a world leader in this field also, known particularly for its expertise in computer software development.

In early 1991, the Government of India decided to undertake a major project to bring the power of new information technology to the Indian National Agricultural Research System (NARS). This project has been named as Agricultural Research Information System (ARIS). Most funds are coming from the Government itself and also from the World Bank. The goals of ARIS are:

- to make information easily available to scientists;
- to improve capacity of research organizations to organize, store, and retrieve information relevant to their mandate;
- to develop procedures and mechanisms for information sharing institute-wide, nation-wide and world-wide;
- to improve capacity of organizations to plan, monitor, and evaluate their research programmes.

The ARIS will include information relevant to the performance of three main functions:

- system and Institutional Management-Mainly data on financial, human and physical resources. Regular procedures would be developed for programme and project budgeting, monitoring of resource use, and administrative reporting;
- research Project Management-Information on the substance of completed projects in form of documents;
- resource Management-Data on natural resources, germplasm, agro-climatic conditions, and problems affecting agricultural production.

The ARIS Network would develop at four levels. The attention given to each will depend on whether the content is mainly management information, scientific information, or resource data. The four levels are:

- between the Institute/university and its constituent centres/stations (WAN);
- within the Institute/university campus (LAN);
- between the Institute/university and national organizations (ERNET, NICNET etc.);
- between the Institute/university and the international scientific community (Internet).

The ARIS will be decentralized as far as possible, in keeping with the objective of putting information close to the users. The ARIS system will consist of separate, loosely linked systems for management information, scientific information, and resource data. Each such "Sub-ARIS" will consist of its own procedures and databases, though many of the technologies will be shared so that each user can choose that part of the overall ARIS that best meets his/her needs. At the same time, some common standards (software, data, formats, procedures) will be used for information exchange.

The network services to be provided under ARIS will comprise:

- electronic mail;
- bulletin boards;
- bibliographic databases and CD-ROM;
- electronic circulars;
- gopher;
- World Wide Web (WWW).

Electronic mail will reduce paper work and transit time in message communication between people with the facility to forward copies to various people and maintenance of electronic mailing list. The bulletin boards will provide a group communication mechanism for discussion around common topics. Any user can post a message to that topic which will be seen by all subscribers to that topic. The readers can subsequently send their replies to a message. The bibliographic databases will be available on CD-ROM through the network and will provide an efficient tool for search and retrieval mechanism to the researchers. The gopher will be a tool for navigation in the network. The menu-driven distributed document retrieval system will provide efficient search mechanism to locate documents residing anywhere on the network and also provide interface to other information retrieval systems. The World Wide Web (WWW), a web of information servers, will provide access to graphic displays of information in attractive formats, hypertext for browsing information by simple button-use and use of text, sound, pictures and video clips.

4. Role of Department of Agriculture and Cooperation (DOA&C), Government of India

Under the Constitution of India, agriculture is a State Subject and thus the respective State Governments are primarily responsible for required developmental activities. The Department of Agriculture and Cooperation in the Government of India is responsible for the formulation and implementation of national policies and programmes aimed at achieving rapid agricultural growth through optimum utilisation of the country's land, water, soil, plant, and fisheries resources. The Department of Animal Husbandry under the same ministry looks after similar activities of animal husbandry. The DOA&C undertakes measures to ensure timely and adequate supply of inputs and services such as fertilizers, seeds, pesticides and agricultural implements; to provide agricultural credit, crop insurance; and to ensure remunerative returns to the farmer for his agricultural produce. The Department is entrusted with the responsibility for collection and maintenance of a wide range of statistical and economic data related to agriculture, assisting and advising the States in undertaking scarcity relief measures and in management of natural calamities. The Department is also responsible for the formulation of overall cooperative policy in the country.

The DOA&C plays a key role in agricultural development through extension in collaboration with the State Governments. The extension service in the country has been reorganised on the pattern of Training and Visit (T&V) system operating in 17 major states. The system provides for a regular and systematic training of extension functionaries and transfer of latest production recommendations through scheduled visits to the farmers. A World Bank assisted National Agricultural Extension Projects in three phases, the last phase having ended in March 1995, supplemented the activities. The Department operates a scheme entitled “Farmer-Scientist Interaction on Agro-Climatic Zone Basis” in order to introduce and build up an instituionalised system of providing direct two-way linkage between farmers and scientists for problem assimilation and technology dissemination. In order to increase the coverage and efficiency of extension services, the efforts made by the NGOs have been dovetailed through a pilot scheme involving 14 NGOs in eight States. The dissemination of technology beyond the contact farmers would be supplemented by the NGOs who will also highlight on the constraints and feed-back mechanism. Apart from the above, training materials are published, exhibitions/fairs/shows at national and regional levels are organised and national productivity awards are given by the Department.

5. Future issues

In the nineties agriculture is likely to face serious challenges on the ecological, l economic, energy, equity and employment fronts along with the demand to feed a population of more than one billion by the turn of the century. The Scientific Advisory Council to the Prime Minister in its Technical Report on perspectives in Science and Technology [3] has observed that research will face the problem arising from the loss of biological potential of the soil on one hand and biological impover-ishment of the country on the other. Economists and policy makers have to find answers to the problems arising from increasing diminution of land holdings and from the cost-risk-return structure of small farm agriculture. Social scientists will have to find means of ensuring that the benefits of new technologies reach the unreached. Technologists will have to find optimum energy mixes for agriculture in different parts of the country, enhanced post-harvest technologies and frontier technologies to increase productivity. National policies have to address to build of rural infrastructure on priority, consider agriculture as a source of income and employment, increase purchasing power of rural and urban poor to ensure economic access to food and stabilisation of population at a level which can be supported by the carrying capacity of the available land and water resources on an ecologically sustainable basis.

The traditional farming systems and practices have evolved over centuries through observation and experience to suit specific agro-ecological conditions. Such systems, however, are generally not intended for market-oriented agriculture which succeeds only with a high degree of efficiency at production, post-harvest and marketing stages. With open economic policy of the country, the goal of agriculture is required to be set to achieve highest possible yield per unit of basic resources, time and human resource. Input of improved technology becomes the key word in this context.

6. Challenges

Keeping in view that a population of over 1 billion is to be supported by the turn of the century, the foodgrain production target for 2000 AD is estimated at 225-245 Mt [3]. This means that an additional production of 43-63 Mt would be required to be achieved over the production level of 186 Mt during 1993-94. Balanced diet to the population being a national priority, self-sufficiency in other agricultural products would be equally important. It has been projected that by 2025 AD, about 50% of the country's population will live in urban areas, which would change the pattern of food demand. The major perceivable challenges before the country [3, 4] may be:

- the number of operational farm holdings in the country has increased from 71 to 105 million during the period 1970 and 1990, whereas, the total area under agriculture marginally increased from 162.14 to 165.64 Mha. 78.9% of the farm holdings, as in 1990, are below 2 ha (**Fig.6 and 7**). Further fragmentation of land holdings with increase of landless labourers are expected to continue with growth of population. Population migration to urban area would continue, consequently affecting rural population for agriculture;
- small farm families are more affected by the cost-risk-return structure of farming. Farm income has to grow ahead of production to provide security and better quality of life;
- the intercrop disparity in production and productivity, specially in oilseeds and pulses, has to be reduced. Similarly, regional imbalance in productivity needs to be narrowed down to improve productivity of the country;
- safeguard of ecological security through conservation and sustainable management of natural resources is a prequisite for a healthy growth of agriculture. Indian agriculture is faced with the problems of depleting soil fertility and building up of pesticide residues, land degradation process already affecting about 175 Mha, periodic flood and drought, fragile ecosystem affecting about 12% of total geographic area by aridity and groundwater depletion;
- about 70% of total cropped area is dryland where crop yield potential is low and variable;
- use efficiency of key agricultural inputs have been low;
- employment opportunity in agricultural sector has not been growing adequately to offer intellectually and economically satisfying job opportunities to the rural youth.

7. Future research strategy

Future research strategy is governed by the guiding principle that agriculture would continue to be among the predominant sector of Indian economy in decades to come. The equity, social and economic justice and sustainable growth would be expected only with well planned and executed research-development strategy. To capitalize on the strength of the existing well-developed research and development institutions in the public and private sectors along with vast human resource, cheap labour and requisite diversified agroclimatic resources, efforts would be directed towards further development of infrastructure and human resource as well as establishment of better linkages between various institutions. The first step in this endeavour would be to set up a demand-driven research agenda, institution-, region-, crop-, commodity- and discipline-wise on a perspective plan basis with required amendments in policies. In order to be competitive nationally, regionally and internationally, frontier areas of technology would require pin-pointed attention. In the fast changing enviornment, reorientation of agricultural research system with clear-cut delineation of mandate and responsibilities to ensure far more problem oriented, receptive, responsive and productive output is imperative to bring much needed commerce in agriculture. Efforts are underway for orientation towards production to consumption system research, knowledge demand orientation and higher management skill for effective technology generation, assessment, refinement and transfer system. A programme-oriented matrix-dnven approach would be essential to bring in harmony between different arms of the network, including the private sector, NGOs and farmers. A firm policy commensurate to perspective planning for the coming 2-3 decades based on rolling five-yearly plan concept to accomodate midcourse corrections is being actively developed by the ICAR [2]. The reform in approach would start with the ICAR Headquarters and percolate to the laboratories. Freedom, flexibility and accountability would be the keywords in this exercise. At the international scenario, India is presently considered as a developed country in agriculture by a number of developing countries. India can offer trained manpower, techniques and technologies to such countries through further strengthening of TCDC programmes. India will simultaneously look forward to more close collaborative programmes with the developed countries in the area of frontier technologies.

Technology transfer, in order to be effective, must be preceeded and succeeded by technology assessment. Technology assessment and transfer are thus required to function complimentary to each other. The ICAR would endeavour to establish proper scientist-farmer linkage. The role of ICAR and the developmental Departments of the Government machinery will be more clearly defined.