Future trends in agricultural engineering

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Abstract

Agricultural engineering is a multidisciplinary field of science. Beside the traditional mechanical engineering other engineering branches, electronics, control engineering and physics play their specific role within the agricultural engineering area. Agricultural engineering has affected and stimulated major changes in agriculture. In the last decades agricultural engineering also focusses on environmental aspects. Nowadays knowledge and expertise generated in several agricultural and environmental engineering fields must be integrated with expertise of biological and socio-economical sciences. In the evolution towards sustainable agricultural systems it is clear that important contributions can be made. The redesign of production systems and its technology can help to achieve an ecologically sound and economically viable agriculture and its acceptance in community.

Keywords: engineering, machinery, automation, labour, management, animal housing, emission, greenhouse technology, energy saving, water use

Introduction

The principal developments in agricultural engineering started when replacing horses by tractors, integration of units for seeding, cultivating and harvesting with the tractor and the use of electric power after WW II (Hall, 1992). In several agricultural sectors labour productivity increased rapidly and the farming system has been adapted to facilitate further mechanization (Rijk, 1989). To benefit from the economy of scale, in the late 1960's, in Europe farmers specialized in dairy, poultry, pig or crop production. Investment in highly specialized machinery and buildings became an important cost of production and contract work was introduced. On the long term this specialization in farming structure may cause problems in terms of lack of flexibility and sustainability. In addition to that mechanization and rationalization were of growing interest for the farmer because of easying of work and improvement of the quality of the work. Several inventions had a large impact like precision drills, fertilizer broadcasters, pick-up wagons and the cubicle in loose housing. Development in other agricultural sciences a.o. animal breeding, -health and -nutrition, plant breeding, the use of chemicals for pest control and irrigation were essential for improvement of efficiency and productivity.

During the fifties and sixties agricultural engineering became a multi-disciplinary field of science. Other disciplines, a.o. electrical engineering, chemical engineering, systems- and control engineering, information-technology, robotics have got more impact (Hall, 1992; Matthews, 1991). Besides that there is a strong tendency to integrate agricultural and enivironmental engineering aspects.

So far, agricultural engineering and related technologies like information technology and micro-electronics have brought many opportunities for farm enterprises and related industries.

However, in society problems of overproduction, emission of bad odours and global warming gases as CO_2, N_2O and CH_4 and the leaching of plant nutrients are often related to the developments in agricultural engineering. The question whether labour was pulled or pushed from the agricultural sector by mechanization and automation is still debated.

In the following the actual and future trends in agricultural engineering are mentioned. The approach of the given trends is subdivided in general remarks and a number of specific fields.

General remarks

A rapid application of newly developed farm machinery and animal housing systems has sometimes caused negative effects on human comfort and health, soil structure, noise nuisance and animal welfare (Anonymous, 1990). We can underline that until the 1980's the professional workers in agricultural engineering have not always been aware of the effects of new developments. Major developments in agricultural engineering need a careful technology assessment procedure. In the Netherlands such an assessment study has been carried out on the subject of automatic milking systems (De Boer *et al.*, 1994). The results deliver the boundaries for application and the questions for further research and improvement e.g. a combination of automatic milking systems and pasturing. In agricultural engineering problems can be studied on the basis of systems, sub-systems, processes and products (Pellizzi, 1993). Not only the yield or the economic efficiency of the system requires to be optimal, but also the needs of the community must be met with respect to natural resource use, environmental protection, human health and safety, and animal welfare.

Design of farm machinery, equipment and management tools is largely depending on technical (system- and process quality control) and socio-economic parameters (investment costs, price/quality ratio, employment). The interaction with disciplines like ecology, ergonomics, sociology (Sevila, 1993) and biological sciences needs more attention (Hall, 1992). On the basis of these global trends a number of agricultural engineering departments of universities and research institutes for agricultural engineering changed their names in e.g. agricultural and biosystems engineering, bio-resource engineering, natural resource engineering, agricultural and environmental engineering and agricultural engineering and physics.

Matthews (1991) states that advanced engineering must bring certain benefits for production enterprises in agriculture. These benefits are cost reduction of equipment, buildings or labour, reduction of input (seed, fertilizers, chemicals, fuels), efficiency improvement in animal and plant production, improved quality of products and an improved social acceptability.

Agricultural production will move into sustainable systems and processes. Important is the accurate definition of indicators for sustainability. These indicators should be quantifiable and scientifically sound. In general one can distinguish between economical (income, production per unit input), ecological (maintenance of the resource base quality and productivity), biological (diversity) and social sustainability (healthy working environment, safety) (Østergaard, 1995).

Mechanization and automation

In mechanization, technological innovations and adaptations on existing types of machinery are made for enhancement of reduction of cost and improvement of efficiency and environmental protection. Improvements of work quality have to be based on an integral or 'chain' approach.

In potato growing the use of chemicals for haulm-killing must be reduced. For this reason the technique for 'Green-crop lifting and covering' has been developed. Especially for seed potatoes interest of practical farmers is growing in this technique. Another example of innovation is the growing and harvesting of flower bulbs in nets instead of the traditional harvesting or mechanical lifting and picking by hand (Bijl, 1990; De Maeyer *et al.*, 1995). Research on quality characteristics of the potato has led to the conclusion that especially the harvesting machines are a source for blackspot through impacts of the tubers with machine parts. The average travel distance of a potato from the harvesting machine, via storage, loading, unloading, grading, to washing and packing is 345 m. The number of impacts in the whole line amounts 340 (Molema *et al.*, 1996). In the Dutch sugar factories every year about 1 million tonnes arrives as dirt tare. Development of a single-beet lifting technology to harvest cleaner roots is subject of extensive research (Vermeulen, 1995).

The partners for improving machinery and tools on a relatively short term basis are the manufacturers and the users. In Europe it is a problem to tackle the cost for these innovation activities because of economic fragility of the relatively small manufacturers for farm machinery and equipment (Sevila, 1993).

With the help of special devices for automation and robotics new opportunities arise for agricultural machinery. Robots in the agricultural environment have specific constraints in comparison with factory utilization. Sevila & Baylou (1991) mention e.g. the biological variability, complex environments, specific actuators and end-effectors which must handle biological objects with special regard to speed, maintenance and price.

Automation is rapidly expanding. Examples are found in climate control systems in animal houses and greenhouses. Important developments are the site specific application of chemicals and fertilizers. In future farm machinery which can utilize information from sensors and external sources and related software can help the farmers with decision-making. Integral research and practical experience with automatic milking systems has learned that reliability of technology, capacity (Jongebreur, 1994a) and the fitting in the dairy cow management on production, animal health and feeding are crucial factors (Jongebreur, 1994b).

Remains the relationship between automation and employment or in other words the attractiveness for future young professionals in agriculture (Sevila, 1993). Mechanization and automation must fit into the goals of the farmers. Cooperation with scientists in rural sociology and psychology is necessary. Attention is needed for the man-machine interface. Technology assessment studies can deliver the pros and cons of progressive automation systems.

Structures and environment

In dairy production crucial inventions for the improvement of labour productivity were the milking parlour and the cubicle for loose housing (Soutar, 1977). Increased production was mainly stimulated by investments in modern cublicle houses with facilities for milking, dairy health care and young stock. The type of housing for pigs and poultry changed in the 1960's and 1970's strongly through the application of slatted floors and the battery cages. Besides, the introduction of mechanized feeding stations, automatic drinking systems and the liquid manure system had large effect. For dairy housing the conclusion can be drawn that the number of m^2 house per dairy cow increased. This was in contradiction with poultry and pig houses. Until the 1980's the design of livestock houses was mainly done on the basis of production efficiency, animal health and farm management.

Discussions on animal welfare related to housing circumstances and the ammonia and odour emissions from livestock houses has been the main background for adaptations and redesign since 1980. Development of livestock buildings which meet both the conditions for an improved animal welfare and low emissions of odours and volatile gases also requires a multidisciplinary and systematic approach.

In several European countries research efforts are paid to the development of alternative housing systems for laying hens (Blokhuis & Metz, 1995). Aviary housing offers the laying hens free movement. This type of houses have tiers at different levels and so the number of hens per m^{-2} ground surface is comparable to cages. The original concepts of the Tiered Wire Floor (TWF) aviary systems showed bottlenecks on the aspects of ammonia emission, labour conditions, labour needs and the economics (Blokhuis & Metz, 1995; Lokhorst, 1996). Management support and climate control are also aspects to be considered in redesign of animal houses (Groot Koerkamp *et al.*, 1995). Latest research indicates that with the TWF system the animal welfare is improved (Metz & Blokhuis, 1995) and the reduction of ammonia emission is possible (Groot Koerkamp *et al.*, 1995). Improvement of labour conditions has been achieved partially while the egg cost price in the TWF system is slightly higher due to the higher feed consumption and labour requirement compared to the battery cage system (Metz & Blokhuis. 1995).

Emissions from livestock houses form, beside the emissions after landspreading of manure, one of the most important sources of ammonia emission (Hey *et al.*, 1991). Improvement of animal welfare and reduction of emission of odours and ammonia are aspects of public concern in pig production. In the redesign of housing and equipment for sows and fattening pigs many factors play a role e.g. farm management, climate control, animal health and investment costs. For this reason a multi-goal knowledge-based design method is worthwile to be developed. A first approach is carried out by Lippus *et al.* (1996). Maybe this approach can also be applicated for designing multi-functional buildings for a more flexible use. Aarnink *et al.* (1995) investigated factors which affect emissions of ammonia on partially slatted floors for fattening pigs. From this research it is concluded that ammonia emission varies significantly during the growing period, during the day and between seasons. In sow husbandry research work is carried out in different systems of group housing. From the point of view of animal welfare, group housing is better than the tethering systems. However, the surface of the floor fouled by faeces and urine in tethering systems is more restricted than in group housing systems.

Emission of ammonia from cattle houses is influenced by the slurry pit, flushing the floor with water or formalin, acidification of the slurry stored under the slats, floor type (slatted or closed) and type of housing system (Metz *et al.*, 1994).

Research is carried out on the influence of the floor surface on both emissions of ammonia and on ease of walking by the dairy cows. Floor properties do influence the ammonia emission, however, until now a positive influence is not found (Braam, 1996). Animal house design can affect directly (e.g. floor design) or indirectly air quality and movement and so animal health (Wathes, 1993). Quantification of relationships between the incidence of animal diseases and the physical factors like air temperature, air flow pattern and air humidity is necessary for the future.

It can be concluded that sustainability of agricultural production systems also strongly depends on the quality of structures (Jongebreur, 1993).

New technological developments like the automatic milking system affect the layout of a building considerably.

New developments in material technology must lead to structure designs of greenhouses with high insulating and highly light transmitting covering materials. Use of solar energy through high light transmittance mostly competes with application of high insulations covering materials in greenhouse structures (Waaijenberg, 1995; De Zwart, 1996).

Labour and management

During the period 1950–1980 labour research was mainly concentrated on labour productivity and ergonomic aspects. Mechanization decreased the physical load of the worker. However, safety and human health aspects are still important. One can observe this in the design of the modern tractors and self-propelled equipment.

Labour organization and labour conditions are nowadays studied in the framework of sustainability of production systems.

Van Dieën (1993) developed a model for measuring the physical load of the low back. With this model different work situations in agriculture and horticulture e.g. lifting of loads and harvesting can be analysed and improved. For the maintenance of labour productivity job variation seems to be important. The labour-rest ratio is an important indicator in the prevention of complaints in the musculo-skeletal system. In existing work situations the exposure to dust and agrochemicals can result in health risks for the worker. Personal protection measures can help, however, it should be more in line with sustainability policy to adapt working methods and climate in livestock houses to each other.

In these decades of expanding use of information technology man-machine interrelationship has to be optimized with respect to labour demand, human health and safety aspects and mental load.

Application of advanced technology requires a contribution from labour science. This may play a role in the cultivation of flower bulbs in nets, development of the aviary system (Metz & Blokhuis, 1995) and the application of robotic milking (Sonck, 1996). From this last research it may be concluded that advanced machinery systems need a clear management strategy on feeding, pasturing, cow traffic and milking frequency.

Management quality is a critical success factor in modern agricultural enterprises. More and more data connected to production (volume, composition, quality) and production processes (climate, utilization of greenhouse surface) become available for the farmer, because advanced information systems are available. The question is how to use these for improvement of the quality of the management decisions of the producer (Speelman, 1993).

Management information systems, decision support systems and expert systems are under achievement for farmers. Poultry farmers with an aviary system can use an expert system for the detection of alterations in production (Lokhorst, 1996).

Location planning in pot plant nurseries can be optimized with a decision support system (DSS).

In the coming years the development of models as part of a DSS must be continued in order to support the farmer in complex management questions of detection of diseases (De Mol *et al.*, 1996) and optimal implementation of robotic systems (Devir, 1995).

Energy and water

Energy use is an essential topic in agricultural engineering. It is often a driving force in the development of improved machinery and greenhouse constructions and equipment (Stout & Huff, 1992). The consumption of direct energy (fuel, electricity, natural gas) on agricultural farms and horticultural holdings, amounted in 1993 174 PJ[1],

[1] 1PJ = 10^{15}J

which was 7,8% of total energy use in the Netherlands (Anonymous, 1995).

About 80% of the energy consumption comes on the account of the greenhouse sector. Wise use of energy is an indicator for sustainability because of the increasing carbon dioxide concentrations in the atmosphere. Based on the agreement between the Dutch government and the representatives of the horticultural sector the energy efficiency should be improved. Energy saving options and the related cost-effectiveness have therefore the interest of the growers. The analysis of the prospects of energy-saving options can be carried out with the help of simulation models (De Zwart, 1996).

This author has evaluated the effects of simple improvements of the heating system, improvements of the greenhouse building and application of combined heat and power. The last option is able to provide substantial energy savings. Specific experiments on alternative cladding materials as coated glass planes (Out & Breuer, 1995) are worthwile. Application of a movable thermal screen is also a point of further research.

Climate control can be optimized by balancing the benefits associated with a higher yield of crop production and the operational costs of climate conditioning system (Van Henten, 1995).

The accuracy of crop growth models and models for the greenhouse climate affect the usefulness of optimal control systems (Bakker, 1995). Application of the Computational Fluid Dynamics may lead to a better description of the three-dimensional distribution of temperature and humidity. This knowledge can result in the improvement of greenhouse efficiency.

In dairy production the direct energy consumption is mainly related to the milking process and the application of farm machinery for fertilizing and harvesting. Optimal combination of tractor and machinery influences the use of fuel. The energy consumption in the pig and poultry production is considerable. For the future decreasing of the ventilation capacity and application and control of natural ventilation systems require more research (Van 't Klooster, 1994). Climate control in livestock houses is not only related to energy use, but also important for human and animal health.

Application of sustainable energy sources is part of research programmes of many institutions. Harvesting, collection, drying and transport of various biomass flows a.o. several types of waste and agricultural byproducts is studied nowadays. Growing of energy crops like willows, poplars and miscanthus can contribute to sustainable energy or the production of the so-called 'green electricity'. Application of solar energy systems a.o. photo-voltaïc solar cells in agricultural buildings is an important research field in the future.

Agriculture has to face increasing competition for scarce fresh water by other consumers. In agricultural production water is a basic resource and it is well-known that restricted availability will affect the production volume and effiency dramatically.

Also in Europe an economic use of water in agricultural production is an urgent topic, as it already is for a long time in other parts of the world. The consumption of water in livestock production is influenced by the cleaning methods of equipment and housing. Techniques for recycling and saving of cleaning water are important.

In greenhouse horticulture advanced technology like modern climate management can play a major role in an economic use of water. Better knowledge of the water requirement is therefore a necessity. Water savings up to 30% can be achieved by the application of closed systems (Van Os & Stanghellini, 1996). Control of pathogens spread in recirculation systems by the use of sand filters is in development. The prevention of leaching of nutrients to the groundwater may be achieved by better measurement and control systems (Gieling & Van Den Vlekkert, 1996).

Measurement technology

In agricultural engineering measurement has always been a crucial element in research and development. The early years of this century started with testing of tractors and farm machinery. Nowadays the possibilities for measurement are manyfold due to the developments in physics, chemical engineering, micro-electronics and information technology.

Especially the concerns in society for clean water and air, conservation of natural resources and high quality agricultural products against reasonable prices result in a demand for specific measurement technology. In the field of emission of bad odours and ammonia from livestock houses measurement protocols had to be developed. In the frame of an EC-programme (COST 681) scientists have worked out 'Recommendations on Olfactometric Measurements' (Hangartner *et al.*, 1989). Measurement of ammonia emission from livestock houses – to compare the emissions from different types of houses and manure handling systems – is a complex process. Not only the measurement of ammonia concentration by a chemiluminescence NO-analyser and a thermal NH_3 converter and the ventilation rate (Aarnink *et al.*, 1995), but also the influence of other parameters is necessary (Groot Koerkamp, 1994). Measurement technology must keep equal step to knowledge and expertise of the underlying processes e.g. degradation of uric acid and volatilization of NH_3. Important process parameters are air temperature, pH and urease activity. Reduction of ammonia emission can be done by a.o. control of nitrogen content in the faeces, moisture content, pH, temperature and bacterial processes (Groot Koerkamp, 1994). After having collected many data of emissions time has come to adapt the measurement protocol on the basis of a thorough analysis. Measurement of ammonia emission during manure application can be carried out by the micro-meteorological mass balance method or the use of wind tunnels (Bussink *et al.*, 1994). Accurate measurements, however, cannot lead to absolute reduction norms, but to an average range. Weather conditions, soil type and farm management factors (amount of manure, grass height) remain important for the ultimate success of ammomnia reducing techniques.

Application of micro-systems have opened wide perspectives for new devices for measurement technology. Biosensors, electrochemical sensors and devices based on many physical processes are already applicated or in development. Well-known are sensors for air temperature, humidity, CO_2 and radiation. Especially in greenhouses climate control sensors are widely used (Gieling & Schurer, 1995). However, it may be underlined that sensor development requires large funds both in R & D as well as in product development.

In animal production the identification of cows with the help of electronic transponders has opened wide perspectives for individual monitoring on different important parameters for production, animal health and welfare. Measurement of electrical conductivity and temperature with a sensor in milk can identify dairy cows suffering from mastitis. However, under practical conditions the detection of mastitis is still not as reliable as required for a proper management. Both measurement technique and the related software has to be improved (De Mol *et al.*, 1996). Besides that we must recognize that the information for the dairy farmers needs to be improved. Image analysis is already applied in several machinery and equipment for sorting, automatic milking and fruit harvesting. However, the agricultural environment gives specific problems in the correct measurement of features and the interpretation of images.

In order to create closed-loop systems in horticulture measurement of the composition of nutrient solutions is under research and in development (Gieling & Van Den Vlekkert, 1996). The measurement is based on ion-selective field effect transistors (ISFETS). However, these chemo-sensors are still limited by life-expectancy (Gieling & Schurer, 1995). Sensor-technology is also applied in water management for non-closed-loop crop production. A multi-point sensor for soil and water parameters at several depths is in development (Balendonck, 1996).

To predict drift from field crop sprayers a model IDEFICS is developed. With the help of this model effects of nozzle types, spray volume, droplet size and boom height can be predicted (Holterman *et al.*, 1994). For the measurement of droplet size distributions sophisticated laser techniques have been developed. Retention can be measured by the use of digital image processing.

Final remarks

From this overview it becomes clear that agricultural engineering will play a crucial role in the development of sustainable agricultural production systems. Modern agricultural engineers will be working in the frontlines of the application of new technologies like micro-electronics, robotics, mechatronics and relevant parts of information technology in the agricultural environment.

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