RECENT INNOVATIONS AND ISSUES IN TRACTORS AND FIELD CROP MACHINERY IN NORTH AMERICA

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ABSTRACT

The tractors and field crop machinery used in North America are produced by a mature industry. Recent technological innovations include machinery for spatially-variable crop production, electronics for machine control and tractor-implement communications, low-emission and alternative fuel engines, flexible power transmission, and larger and more sophisticated equipment. Trends and issues are discussed.

Keywords: tractors, machinery, spatially-variable, electronics

INTRODUCTION

Technical innovations and technical and social-economic issues are promoting change in North American agricultural field machinery and the machinery manufacturing industry. The 1980s and early 1990s were difficult times for North American farmers and North American equipment manufacturers. Low crop prices hurt farmers leading to financial losses which in turn caused farm consolidations and deferred machinery purchases. These farm problems, combined with relatively few revolutionary technological advances, caused the agricultural field machinery market to be very depressed. The farm machinery industry retrenched with major consolidations and personnel reductions. Although there are significant concerns about the implications of the U.S. federal government's agricultural legislation, the recent industry situation has been much improved. Higher crop prices are allowing farmers to be able to purchase more machinery. Expanding agricultural product markets, especially in Asia, are generating confidence in the future demand for crops. In addition, the contemporary machinery industry is restructured and able to make a substantial profit at the current sales levels. There have also been technological innovations which have contributed to the contemporary health of the industry or which have the potential to do so in the near future. This paper discusses some of those innovations and issues involved in their adoption. Many of the issues are technical, such as performance and tractor-implement compatibilities. Others, such as political support and interfaces with the agricultural infrastructure, are not technical.

SPATIALLY-VARIABLE CONTROL

Spatially-variable control (also variously known as site-specific, precision, pin-point, prescription, etc.) of crop production is the technical innovation which has generated the greatest amount of excitement in North America. Automatic mapping of yields, soil characteristics, soil fertility, and pests is now a common technique. These maps, after appropriate management input and computer processing, are used to control subsequent field operations, especially the application of inputs such as fertilizers and pesticides. Both the mapping and the subsequent field operations are no longer static, but variable on a geographic basis. The success of these techniques is largely due to innovations in global positioning systems (GPS), geographic information systems (GIS), sensors, and control technologies. This paper describes some of the key innovations and existing implementations. Further information is available in the literature, such as the special issues (Volume 11 No. 1 and Volume 14 No. 2/3) of the journal Computers and Electronics in Agriculture or the proceedings of the second conference on site-specific management (Robert, et al., 1995).

Grain Yield Mapping

The most successful implementation of spatially-variable crop production has been the adoption of automatic yield mapping during grain harvesting. Although this technology has been the subject of research for over a decade (e.g., Schueller and Bae, 1987 and Searcy et al., 1989), it is just in the last few years that it has become commercially popular. Equipment is now sold by both aftermarket suppliers, such as MicroTrak and AgLeader, and by original equipment manufacturers, such as Deere and Case.

The key element in a grain combine yield mapper is the grain flow measurement device. This sensor attempts to measure the flowrate of grain as the crop is being lifted in the clean grain elevator or as it enters the grain tank. Different measurement schemes include measuring the grain flow by momentum change force, light beam interruption, or gamma radiation attenuation.

If the harvester speed and effective harvesting width are known, the grain yield can then be calculated on a area, rather than time basis. In North America yield is usually expressed as bushels per acre or tons per hectare. A differential global positioning system (DGPS) determines the position of the harvester in the field and a map can then be generated of the grain yield. This is very useful to the farmer in that it shows the results of his management decisions. It is especially useful for detecting problems within fields.

The commercial successes and above simple explanation may be misleading. The need to compensate for the flow delays from the harvester's cutterbar to the flow measurement point, the inaccuracies in flow, cutting width, or position measurement, concerns with map generation and smoothing, and other issues make this an area of much needed research and development. Schueller (1992) and Birrell et al., (1996) are examples of discussions of these issues in the literature.

Efforts are underway in various locations to extend the concept of yield mapping to other crops, particularly cotton, forage, sugar beets, sugar cane, and fruit. Generally, the most difficult aspect is developing an accurate and robust sensor for sensing yield.

Fertilizer and Pesticide Application

The first commercialization of spatially-variable agriculture was the application of fertilizers and pesticides. Based upon the patent of Ortlip (1986), a system was developed which automatically varied the rates and mixtures of these crop inputs (Lullen, 1985). This system has become popular because farmers feel it allows them to minimize expenditures on fertilizers and pesticides without adversely affecting crop production and while minimizing environmental impacts.

Such a system will have a predetermined map of desired application rates for the field stored in the computer. As the mobile applicator travels across the field, the position of the applicator within the field is determined by a DGPS unit. The application rates corresponding to the current position are then commanded to the applicator's flowrate control hardware. The fertilizers and pesticides are thereby applied according to the predetermined map. Of course, there are also issues of accuracy and dynamic response, as described by Schueller and Wang (1992) and Paice et al., (1996).

Other Operations

Various other operations have been investigated in the general trend toward spatially-variable crop production. Mapping of soil characteristics, especially fertility, has become a popular method to determine the causes of yield map variations and to provide a basis for spatially-variable fertilizer and pesticide application. There has been a substantial amount of effort to develop sensors to measure organic matter and nutrient levels (Hummel, et al., 1996). It is difficult to develop practical sensors which are accurate over a wide range of soil conditions. There has also been both commercial and university development of machines to better extract soil samples. These machines generally are guided to the sampling location by a DGPS system.

There has also been much discussion about spatially-variable control of planting, including planting population, planting depth, and variety. Variable rate planting population control has been commercially introduced.

EQUIPMENT ELECTRONICS

Another significant trend in North American equipment engineering has been a concern with electronic communications, both within a particular piece of agricultural equipment and between pieces of equipment, particularly between tractors and implements. The ability to communicate between pieces of equipment has been strongly advocated for over a decade by Ruckman (1986), Schueller (1988), Stafford and Ambler (1988), and others.

The difficult, but necessary, development of standards has been led by agricultural engineers such as Marvin Stone, John Stafford, and Herman Auernhammer of the U.S.A., United Kingdom, and Germany respectively. Standards such as ISO 11783, SAE J1939, and DIN 9684 are in various stages of development and promulgation. Such standardization will allow the tractor-implement system to operate in an optimum manner.

There has also been significant work on the better use of electronics on individual pieces of equipment. For example, the latest New Holland FX/96 harvesters have fiber optic communications and the Bosch-Intel Controller Area Network (CAN) to transmit control communications (Ameel, et al., 1996). Functions are described by software with flash memory to allow reprogramming.

The use of electronics is allowing new

capabilities. For example, the CEBIS system on Claas grain harvesters allows centralized control, monitoring, and crop setup. The harvester adjustments are changed from one crop to another at a touch of a button. The four-wheel-steer JCB Fastrac tractor can be set to five different steering modes depending upon the operator's desires for performance. Auernhammer (1989) describes much of the current state-of-the-art in electronics on agricultural machinery.

Vision for tractor guidance was an important topic for research about a decade ago (e.g., Reid, et al., 1985). It now appears that industry is nearing commercial introduction. New Holland is still in development on a swather guidance system with help from Carnegie-Mellon University. Units developed by the University of South Queensland in Australia are being tested on Case-IH tractors to accurately guide tractors along rows.

Another approach being researched is the use of high accuracy GPS for guidance. Carrier-phase GPS technology achieves centimeter-level accuracy. However, reliability and cost issues need to be resolved.

POWER UNITS

Tractors and self-propelled agricultural equipment use diesel engines. Recent commercial engine research and development has focused on improving fuel efficiency and reducing emissions. The work on emissions has been driven by the introduction and tightening of regulations. The strict requirements of California dominate. Better engine control has contributed to emissions reduction.

Many engines installed on agricultural equipment are being configured with a high torque rise so that the equipment can be marketed as being able to power through tough spots when the engine speed drops. However, public sector agricultural engineers have begun to question whether this torque rise is achieved by purposely limiting power at high speeds.

The use of electronics on engines continues to increase, allowing additional capabilities. Power is limited on some tractors in the lowest gear speeds to avoid excessive torques and forces in the final drive. Similarly, at least one model of tractors limits the engine speed in the highest (transport) gear speed to limit noise and fuel inefficiency.

Agricultural engines research at universities has been concentrated on renewable fuels, including various oils, alcohols, and esters. This work has political support due to the needs to protect the environment and to generate markets for surplus agricultural commodities. Substantial commercial success has eluded supporters however, except for the use of alcohol in gasoline for nonagricultural vehicles where the alcohol provides octane enhancement without the pollution of such alternatives as lead.

POWER TRANSMISSION

Agricultural tractors generally utilize durable, reliable, and economical gear and shaft transmissions to transmit the power from their engines to the driving wheels. Manual, powershift, and combination manual-powershift transmissions are all popular on tractors. Powershift transmissions are becoming more popular on larger tractors.

Hydrostatic transmissions have become popular on self-propelled equipment, such as harvesters. Their ease of use and infinite speeds more than compensate for their lower efficiency in operations where the quality of the performed operation is more important than the efficiency, especially because a substantial portion of the power is often consumed by non-tractive means. There has been some recent interest and commercial introductions of hydromechanical split-torque transmissions (Schueller and Khan, 1995). For example, in early 1996 Fendt introduced a 260 HP (190kW) tractor with a hydromechancial transmission capable of steplessly accelerating from 0 to 31 mph (50 kph). Although such transmissions have long been researched, they are now being commercially sold. Renius (1994a) discusses transmission developments in detail.

Power to operate implements has historically been transmitted between the tractor and implement by the PTO shaft and within the implement by shafts, gears, belts, and chains. These continue to be the dominant modes of power transmission, but hydraulics are increasing being used. Hydraulics have the advantages of allowing the easy transmission of power to remote locations on the machine and being easily controllable. An increasing number of hydraulic components are being controlled by electronics, especially through the use of solenoid valves. Improved efficiencies of hydraulic components, including the more frequent use of load-sensing systems, have reduced the energy efficiency penalty of using hydraulics.

A concern with the potential pollution of hydraulic oil leaks has led to an increasing use of O-ring connections instead of threaded connections in hydraulic systems. There have also been uses of environmentally-friendly oils. These oils have improved biodegradability and reduced toxicity, but temperature effects, long-term characteristics, and frictional behavior need to be carefully considered.

TRACTOR DESIGN

The recent trends in agricultural tractor design have been thoroughly described by Renius (1994b), especially from an European perspective.

Mechanical front-wheel-drive is achieving great popularity on large conventional tractors in North America, following the Western European example. The unconventional steering system geometries from New Holland and Deere have allowed these tractors to achieve small turning radii.

The most important equipment class for the major equipment manufacturers in North America is the large row-crop tractor. For example, Deere, Case-IH, and New Holland compete with their 8000, Magnum, and Genesis series in this class. These (and their competitors) are now modern, well-designed tractors which appear to be well-accepted in the marketplace. The class is expanding as Caterpillar has introduced the new 35 (171 HP/131 kW), 45 (200 HP/149 kW), and 55 (225 HP/168 kW) Challenger models. These Caterpillar tractors use 16 to 32 inch (400 to 800 mm) wide rubber tracks and appear to have less of the construction and mining equipment influence than the larger, earlier Challengers. Case-IH has also tested rubber tracks on a large four-wheel drive tractor. Engineers have debated the relative merits of tracks and tires with respect to compaction, traction, crop damage, and ride comfort.

There have been some recent introductions of innovative equipment in Western Europe which have received some publicity in North America. The Modulaire unmanned robotic tractor (Mononen, et al., 1995) from Finland has been operated in California. The bidirectional Xerion multipurpose vehicle from Claas of Germany has similarly sparked interest, as have gantry and cable systems. But North American commercial sales are of conventional tractors. Even the U.K.'s JCB Fastrac, which is fairly conventional despite its full suspension (coil spring on front and hydropneumatic in the rear) and 45 mph (75 kph) top speed (Clay, 1996), has not been adopted.

OTHER AGRICULTURAL VEHICLES

Due to heath, environmental, and regulatory concerns, the application of pesticides and even fertilizers is moving away from being done by farmers to an even greater dependence upon custom applicators. Specialized vehicles for applying such materials are becoming larger and more technologically sophisticated. The manufacturing industry for such equipment is also becoming more consolidated and engineering-oriented. Leading firms include AgChem, Tyler, and Willmar. The increasing popularity of spatially-variable application is also promoting these trends.

The current chemistries of pesticides and the trend towards integrated pest management (IPM) and other management strategies have caused a great increase in the use of postemerge self-propelled sprayers. These sprayers are substantially larger and more sophisticated than their predecessors.

There has also been some significant commercialization of several systems which use moving air to assist spray deposition. In addition, the pulse-width-modulation of spray is now available through high-speed solenoid control of individual nozzles.

There continues to be innovations in the separation sections of large grain harvesters. Deere has its CTS system for rice and has purchased the birotor technology from Agro Technology. Claas's Rotoplus combines a conventional threshing drum and impeller with twin separator rotors. Both conventional cylinder and rotary threshing and separating sections have maintained substantial market shares.

EQUIPMENT

The large self-propelled granular fertilizer applicators now more frequently use pneumatic distribution rather than spinner spreading. This is especially true when spatially-variable application is intended. However, farmers in the U.S.A. have generally been slower than those in Australia and Canada to adopt pneumatic towed fertilizer applicators and crop seeders. However, pneumatic seeders are becoming more popular in the wheat-growing areas.

Tillage equipment is greatly influenced by environmental concerns. In general there still is a trend to less tillage and more surface residue to reduce water and wind erosion. However, some are advocating more mechanical cultivation of growing crops to reduce the dependence on pesticides (Buhler, et al., 1995). Postharvest and preplant tillage equipment is being designed to handle more plant residue and to leave more of that residue on the surface. As a consequence, planters are now designed to be able to plant in soils with more trash cover. Planting on ridges is also increasing in popularity.

CONCLUSIONS

The tractors and field crop machinery used in North America are produced by a mature industry which offers a wide range of well-engineered and reliable models for varying field conditions. Recent technological innovations include technology and machines for spatially variable farming, increased use of electronics and on-board computers, automatic guidance systems, alternative fuels, more precise and flexible power transmission systems and steering systems, and larger and more sophisticated precision chemical application equipment.

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