GLOBAL ADOPTION OF PRECISION AGRICULTURE TECHNOLOGIES: WHO, WHEN AND WHY?

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ABSTRACT

The adoption of precision agriculture technologies has been uneven, both geographically and temporally. The economic theory of induced innovation predicts that new technologies will be developed and adopted where they make more efficient use of the scarcest productive resources. Indeed, adoption of precision agriculture technologies has been fastest where labor is costly but land and capital are relatively less costly. Where precision agriculture is being adopted, the uneven adoption rate is tied to normal cycles for replacing the expensive machinery in which many precision agriculture technologies are embodied. Equipment replacement decisions are affected by many factors exogenous to the farm, such as bank interest rates and commodity prices. Adoption is likely to continue in labor-scarce, land-abundant countries, with rates of adoption accelerating when commodity prices are high and interest rates low.

UNEVEN ADOPTION OF PRECISION AGRICULTURE TECHNOLOGIES

Although spatial precision agriculture (PA) encompasses four key information technologies, farmers tend to use it in one of two major ways. The four PA technologies include location determination (via the Global Positioning System, GPS), computerized geographic information systems (GIS), computer-guided controllers for variable rate application (VRA) of crop inputs, and sensing technologies for automated data collection and mapping. The GPS and GIS technologies underpin both of the major PA practices that farmers have begun to adopt. One of these is nutrient management; it involves spatially referenced soil sampling, often linked to VRA fertilizer spreading. The other is yield monitoring, usually tied to yield mapping. In North America adoption is emerging for variants of these, such as VRA seeding and pesticide spraying, as well as remote sensing of plant vigor (Daberkow and McBride, 2000). However, this paper will focus on yield monitoring and VRA fertilization, the two PA technologies that are well enough established for adoption patterns to be discerned.

Some farmers adopt while others do not

Technology adoption can be examined across time or space. Either way, the pattern of PA technology adoption has been uneven. Despite the rapid growth of global commerce and the widespread availability of equipment for VRA and yield monitoring, adoption rates appear to differ sharply from one country to another, at least based on the informal data available

(Norton and Swinton, 2001). Yield monitors are being adopted rapidly in Argentina, but less so in Brazil or in France. Site-specific fertilizer use is rare in Argentina, despite the growth of yield monitor use (Lowenberg-DeBoer, 1999). In Malaysia, site-specific fertilization is being applied to rubber plantations, but not to rice fields. Even within a country such as the United States, PA adoption rates vary by a factor of ten - from 11.3% of farms in the Midwestern "Heartland" to only 1.1% in the Southeastern Seaboard in 1998 (Daberkow and McBride, 2000). In general, we observe that in favored areas adoption of yield monitoring or VRA fertilization has surpassed 5 percent only in the United States and Canada. It would appear that adoption rates in the 1-5 percent range (again, only for favored subregions) may pertain in Australia, Brazil, Denmark, United Kingdom, and Germany. With the exception of a few yield monitors in South Africa and some VRA fertilization in isolated plantation agriculture enclaves, adoption of PA technologies is virtually unknown in Africa and Asia.

Rate of adoption is not smooth

Judging from trends observed in the United States, PA technology adoption is uneven not only geographically, but also temporally. Figure 1 illustrates the trend for the percentage of cropland under yield monitors, which exceeds the percentage of farm adopters due to the relatively large size of farms that adopt most PA technologies. The uneven adoption trend contrasts sharply with the rapid, smooth adoption of hybrid maize following its commercial introduction about 80 years ago (Griliches, 1957; Lowenberg-DeBoer, 1998). Given the potential benefits of precision agriculture for farm profitability (Swinton and Lowenberg-DeBoer, 1998) and environmental protection, these uneven adoption patterns may seem puzzling.

ECONOMIC PRINCIPLES BEHIND THE ADOPTION PROCESS

Farmer objectives and constraints

Agricultural technologies can be viewed as means by which farmers seek to achieve their production objectives. Farmers have many objectives, including risk management, quality of life, and environmental stewardship. But for the majority of farmers who rely on agricultural income, expected profitability is the *sine qua non* - they must earn enough to stay in business.

In attempting to produce profitably, farmers are constrained by limited access to essential productive resources such as land, labor, equipment, buildings, and management knowledge. Profitable farming calls for using these resources up to the point where the cost of additional resource use is no longer compensated by the value of the resultant gain in output. The profitability appeal of VRA input control has been the potential to tailor input use site-specifically, increasing it where justified by expected yield gains or reducing inputs where the costs exceed the expected benefits (Swinton and Lowenberg-DeBoer, 1998).

Factor scarcity and the theory of induced innovation

A related principle of profitable farming is to balance input use so that no reallocation of inputs can reduce the cost of production. This principle means that in a country where land is costly compared with capital, farmers acquire enough equipment to plant and harvest crops at the optimal times, thereby maximizing returns to land. By contrast, in a country where capital is the more expensive resource, farmers will extend planting and harvesting periods to economize on equipment, even though this means lower yields per acre. This why Midwestern U.S. farmers, whose capital costs are relatively low, often own their own planters and combines; by contrast, Argentine farmers, who pay much higher interest rates, often depend on custom operators. This principle also implies that new technologies tend to be developed and adopted so as to economize on use of the scarcest or most costly input. Hayami and Ruttan (1985) illustrated the theory of "induced innovation" by contrasting land-scarce Japanese agriculture that innovated biochemical technologies to boost crop yields (and land productivity) versus labor-scarce U.S. agriculture that turned to tractor-led mechanical innovations to boost output per worker.

Two characteristics are likely to drive the adoption of PA technologies. First, considering that they improve the efficiency of input use in mechanized agriculture, they are likely to be adopted first in those places where input use is already relatively efficient. Second, because these technologies use costly capital to automate human information processing, they will be most attractive where capital is abundant relative to management labor. Figure 2 illustrates the efficiency and relative abundance of agricultural labor and tractors used to produce 100 metric tons of cereal crops in 1997 for selected countries and regions (FAO, 2000).

Evidence cited above suggests that rates of adoption of yield monitoring and VRA fertilization are highest in the United States, followed by Canada and Australia. These countries have seen adoption of one or both of these technologies on 5-15 percent of their planted area in cereal crops. All three countries abound in land, allowing them to make efficient use of labor and capital. All three lie on an efficient isoquant for producing 100 metric tons of cereals that envelopes the data in Figure 2, extending from the high-labor/low-capital point of sub-Saharan Africa to the low-labor/high-capital points of the USA and Canada. Moreover, all three countries have a relative abundance of capital compared to other countries on the frontier. The second tier of adopters appears to be led by Argentina (in yield monitors), along with Denmark, United Kingdom and eastern Germany. Argentina lies on the efficient frontier line illustrated, while the early European adopters are relatively more efficient in their labor and tractor use compared to other parts of Europe. In short, the induced innovation model seems to square well with observed adoption trends, at least based on the limited data available (Norton and Swinton, 2001).

Capital replacement and adoption of technology embodied in costly equipment

Technologies that require equipment tend to be "lumpy." That is to say use of the technology requires acquisition of a whole unit that is not easily subdivided. That unit may be a system that includes not only the equipment itself, but also the specialized inputs, services and skills that make it effective. For example, yield mapping requires not only the hardware of a yield monitor and GPS, but also mapping software, a computer with a PCMCIA drive, and the skills to operate the hardware and software, to make maps, and to interpret them (Lowenberg-DeBoer, 1998).

In contrast with lumpy equipment-based technologies, genetic technologies tend to be more easily adoptable in small increments. In the United States, the hybrid maize seed diffused in the 1930's and the genetically modified seeds diffused in the 1990's were adopted quickly for three reasons: 1) producers could easily test them on small areas, 2) seed is an annual expense, and 3) farmers' existing equipment was compatible with the new seed.

In the industrialized countries where mechanization spread during the 20th century, farmers have developed many ways to smooth the adoption of lumpy technologies. In some cases, a group of farmers may share a piece of equipment. In other cases, an entrepreneur will offer equipment services that reduce the need of a farmer to purchase. With precision agriculture this has happened particularly with intensive soil sampling and VRA fertilization. In the United States and Canada, very few farmers own VRA equipment; instead, most hire custom services. It is much easier to justify a $7.50/ha VRA spreading fee than a $250,000 investment in multiproduct VRA equipment. But even when a producer custom-hires VRA, the less-divisible information and skill components of the system still need to be developed, either on-farm or by crop consultants.

Even when a decision has been made to adopt some aspect of PA, the timing of that adoption may be delayed by problems in the equipment replacement cycle for the underlying machines on which GPS, sensors and other electronics are to be installed (Krause and Black, 1995). Some innovators have retrofitted existing machines, but many farmers are reluctant to do so. Lack of experience with electronics, cost of installation service and lack of standardization can reduce the cost effectiveness of retrofits. Many of the practical majority of farmers who care more about profits than being the first with new technology would prefer to have factory installed precision farming equipment. But buying that major machine presents financial and risk challenges. In the yield monitor case, the $7000 for a monitor and GPS is not a major financial obstacle for a commercial grain farmer in the USA, but the $200,000 for a new combine is a serious decision.

CONCLUSIONS: LIKELY ADOPTION PATTERNS IN THE YEARS AHEAD

The basic patterns observed so far in adoption of precision agriculture technologies are likely to continue into the foreseeable future. Technology adoption will expand fastest in land abundant areas where human and financial capital are available and the use of labor and variable inputs is already quite efficient. This category includes the United States, Canada, Australia and parts of Argentina and Brazil. In areas with greater population pressure and less land for agriculture, but ample human and financial capital (e.g. Western Europe), adoption will expand more slowly unless and until environmental benefits are better documented. Elsewhere, there will likely be adoption in enclaves where land and capital are available and well-managed. Examples are plantation agriculture in parts of the tropics as well as large farms in northern Mexico and perhaps South Africa.

Although there has been little public policy involvement in PA so far, if environmental benefits from precision farming become documented, then it is possible that policy inducements could change the relative input/output prices faced by farmers so as to alter the spatial pattern of adoption. Hence, it is conceivable that nations like the Netherlands might accelerate adoption of PA technologies if they were shown to reduce excess nutrient applications.

As for the timing of adoption, that will continue to be uneven, due to the fact that most precision agriculture technologies are embodied in expensive equipment. Hence, if crop prices or variable input costs were to surge, then the incentive to adopt PA practices would surge as well. Otherwise, adoption is likely to continue its uneven pattern.

FIGURE 1: Percentage of U.S. corn, soybean and wheat land under yield monitors, 1996-1999 (Norton and Swinton, 2001; Daberkow, personal communication, 2001).

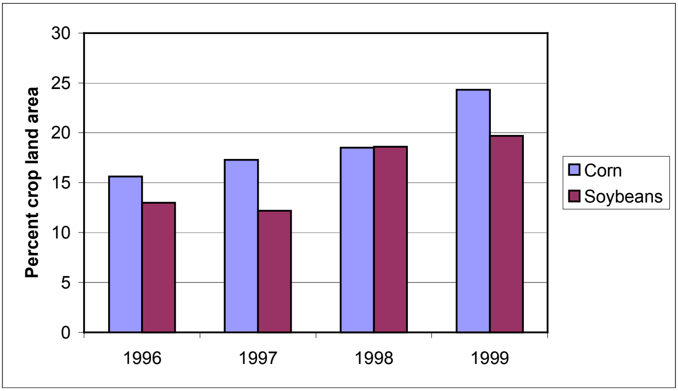
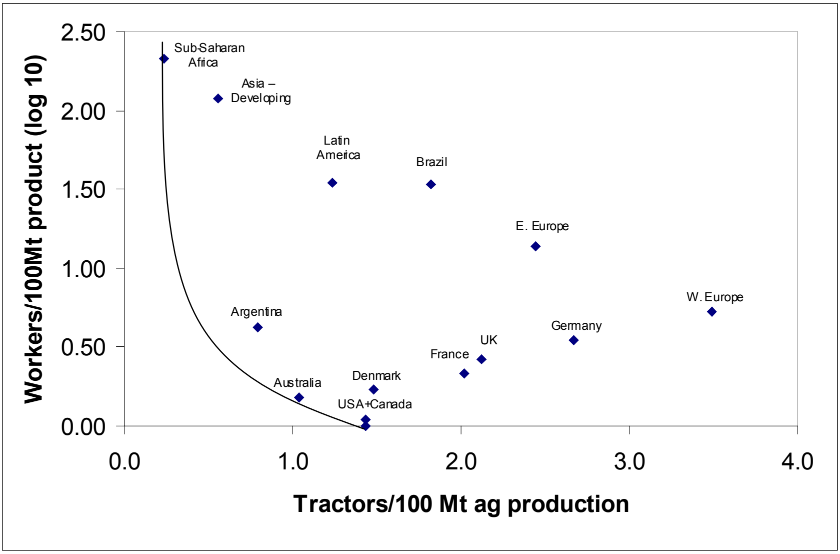


FIGURE 2. Combinations of economically active agricultural population (workers) and tractors associated with producing 100 metric tons of cereal crop production in 1997, selected regions and nations (FAO, 2000).



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