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Conceptual Framework to Integrate Economic Drivers of Decision Making for Technology Adoption in Agriculture †

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Abstract: This study evaluates how much technology adoption could cost in a variety of crop-production scenarios. Cost-reduction simulations consider scenarios of higher input use efficiency such as reducing the usage of diesel, labor, irrigation, fertilizer, herbicide, and seed, among others. The scenarios aim to increase yields by integrating the effect of each input-reduction on the total operating costs. Agricultural production estimates for Nebraska in the US indicates that a technology that saves 1% of diesel is cost-effective, costing between USD 0.15/ha and USD 0.32/ha (for corn). Improvements on input use efficiency should be prioritized to incentivize technology development and adoption. This study balances input costs and crop production, allowing the identification of adoption cost thresholds tailored to specific farming scenarios. It also enabled interpretations regarding optimal scenarios for technology adoption. In addition, this study indicates that irrigated systems foster the adoption of technologies more than in dryland cropping systems.

Keywords: profitability; agricultural management; sustainability; cost; efficiency

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1. Introduction

Food production is expected to intensify in the next 50 years to sustain the increasing demand of food supplies. Agricultural practices will determine the level of food production and, to a great extent, the state of the global environment [1]. Historically, agriculture has been associated with technological improvements such as those during the Green Revolution, and more recently in information technologies and robotics [2]. The integration of such improvements in agricultural practices have led to the maximation of production and economies and, sometimes, increasing environmental degradation [3]. Sustainable agriculture can be seen as a broad term that merges elements of sustainable development in the form of resource conservation, technologic suitability, social compliance, and economic viability with agroecosystem resilience, human livelihoods, and agricultural productivity [4,5]. A sustainable intensification of agriculture might be possible if the use of external inputs, the improvements of management techniques and practices, and the efficient use of natural resources and purchased inputs are balanced [3,6]. However, the operationalization of novel technologies, designed to minimize resource loss or maximize production, are also limited by triggers of innovation, growth, and prosperity [2,7].

In agriculture, technology enables labor efficiency, increases in revenues, and food security; yet, technological innovations are not adopted immediately or completely throughout a population [8–10]. The diffusion of new technologies through users and markets depends on understanding of the economics, innovation, and cross-sectional patterns of technology adoption [11]. In food production, precision agriculture (PA) exemplifies the introduction of technology, widely benefiting from constant innovations such as optimizing soil sampling, mapping yield variability, variable rate application of inputs, non-invasive sensing of plant status, soil conductivity, and auto guidance systems [2,9,12,13].

This study estimates the cost thresholds for technological adoption based on distinct scenarios of crop budgets, assuming improvements in production costs effect (less input consumption maintaining yield or more yield maintaining input levels). A cost threshold is the investment that would tie the profit improvement, leading to no profit change. These production scenarios will support a framework aimed to help producers or technology suppliers to determine a cost threshold based on their own production costs driven. The scenarios evaluated in this study are representative of Nebraska's crops which account for USD 11.7 billion (5th place in USA) being ranked as the main state producing corn (3.7 million ha), soybean (2.0 million ha), and wheat (1.0 million ha) [14].

2. Material and Methods

Technological adoption for Nebraska's farming is assessed through the development of production scenarios based on the input demands and yields observed. The proposed scenarios for corn production are built by a panel of experts and reported in the Nebraska Crop Budget [15], Table S1. We considered two basic effects of technology adoption to determine the economic threshold: (1) cost reduction (less inputs applied or lower prices) and (2) income increase (through higher yield or better price due to higher quality). The thresholds for technologies involve an increase in yield, data of the expected yields and market prices to determine the cost limits (Equation (1)). The variation of income (yield × market price) represents how much could be paid for a given technological option and is calculated as follows:

$$ET = Y \times d\% \times P, \quad (1)$$

where ET (economic threshold) is the cost limit for adopting an increasing yield technology (USD ha^{-1}); Y, is yield (t ha^{-1}); d %, is the expected change on yield (%); and P, is the market price of the product (USD t^{-1}). The effect on the production cost was estimated through sensitivity analyses of input variables such as diesel, labor, irrigation (when applicable), fertilizer, herbicide, interest rate, repair cost, land ownership, and seed, changing individually +10% of their original cost value. For example, the expected increase in input use efficiency (i.e., fertilizer, herbicide, and seed) could be achieved by the site-specific application, high assimilation of nutrients by plant roots, and improved quality of seeds.

Improvements on the usage/cost of diesel could be achieved by variation in the price and/or machine efficiency. More efficiency in labor could be achieved by lowering wages, improving efficiency, or even the cost one could pay for unmanned vehicles (when a 100% improvement and no labor costs of field activities). Production costs are composed by the input requirement (i.e., fertilizer, seed, pesticide, etc.) and their respective prices as in Equation (2):

$$OCIi = ADi \times IPi \times ASi, \quad (2)$$

where OCIi is the operational costs of the i^{th} input (USD ha^{-1}), AD is the doses applied of the i^{th} input (kg ha^{-1}, L ha^{-1}, unit ha^{-1}), IPi (Table S2) is the input prices of the i^{th} applied input (USD kg^{-1}, USD L^{-1}, USD $unit^{-1}$), and ASi is the share of areas in which the i^{th} inputs are applied (%). The total production cost reduction was divided by the percentage change applied, resulting in an economic improvement of 10% (USD ha^{-1}) associated with the cost of the technological adoption. Assumptions about the size and age of the equipment were made according to [15]. The labor wage was USD 20 h^{-1}.

3. Results and Discussion

For profit to be achieved, the cost of technology should be below the values stated in Table 1. For instance, if there is a tractor equipped with a more efficient diesel engine, providing 10% less fuel consumption, a corn producer in a situation of system 17#15 will benefit if he or she pays less than USD 3.16 ha^{-1} for this asset to operate. This value is the threshold of the additional cost of this tractor to represent a benefit. The same solution for situation 17#17 will be worthy if it costs less than USD 1.53 ha^{-1}. Knowing the cost limit across different scenarios may require R&D companies to just know how much area the distinct systems represent, avoiding unviable solutions.

Table 1. Cost threshold for 10% higher efficiency on input use for studied scenarios.

Scenario	Diesel	Fertilizer	Labor	Herbicide	Irrigation	Seed	Production System
	USD ha^{-1}						
17#15	3.16	9.71	4.53	16.52	0.00	6.99	Corn, Conventional
17#16	2.97	14.31	3.97	15.62	0.00	6.40	Corn, Conventional
17#17	1.53	15.99	2.46	11.73	0.00	3.61	Corn, No-till
17#23	1.63	15.91	2.84	18.92	0.00	4.05	Corn, Ecofallow
17#24	18.73	18.95	12.66	7.26	30.07	28.54	Corn, Ridge
17#25	18.88	19.64	12.95	8.23	30.07	28.89	Corn, Ridge
17#26	3.16	28.32	9.11	13.78	4.23	11.19	Corn
17#27	12.60	27.65	4.85	20.37	21.23	15.9	Corn, No-till
17#29	18.78	26.59	7.47	13.55	30.74	23.87	Corn

In terms of cost reduction, seed, fertilizer, irrigation (when applicable), and herbicide should be the focus for improvement in corn scenarios. In these scenarios, seed was the highest or the second highest in priority for 14 scenarios (all, except 17#15, 17#23, 17#24, and 17#29). Fertilizer was of priority for 12 of the scenarios. Irrigation of priority was for three out of nine irrigated scenarios. Herbicide application was one of the main variables for five scenarios (all dryland). The exceptions were for the less intensified scenario (17#15), for which ownership was second, and for scenario 17#24, in which field efficiency was second.

The effect of labor reduction can be used to estimate how much the user could pay for unmanned vehicles in their production systems, which would be considered a 100% improvement (i.e., no labor cost), keeping all other input requirements the same. This consideration is aligned with [16], who concluded that spraying using UAV, agricultural income, and hours worked in agricultural production contribute positively to adopting technologies. For instance, for a corn scenario (17#17), a full unmanned mechanized operation would be worthwhile below USD 24.60 ha^{-1}, while for other scenarios (17#23 and 17#24), it would be viable around USD 125 ha^{-1}. In a 5-year period for corn production (2012–2016), the variations in commodity prices and crop yields show lower average yields (7.7 t ha^{-1} in 2012 and 9.9 t ha^{-1} in 2013) and better prices (USD 263 and USD 242 t^{-1}, respectively) than those high average-yield years (10.7 to 11.0 t ha^{-1}, 2014–16), with USD 137 to USD 162 t^{-1}.

Technology adoptions may be more economically suitable when the environmental conditions are not favorable for high yields. Consequently, the investment in technologies in years with higher yields may lead to unwanted consequences due to the decrease in prices and greater effort to raise revenues. This result suggests that international-market trends should be monitored by producers to manage risks of adopting high-value technologies. For a more universal technology adoption framework that includes the adoption of complex technological arrays such as in PA or the shift of large-scale farming management practices, long term analyses can be more beneficial. A farm manager would be more confident to adopt the technology based on scenarios involving long-term economic cycles.

4. Conclusions

The priorities for technology development and adoption in Nebraska were the efficient use of seeds, fertilizer, irrigation, and herbicide application. Thus, an efficient, productive system led to reductions in the total production costs. The proposed approach estimates how much producers can pay for technological adoption considering the specific characteristics of their production systems. In addition, we identified that the years with high yields might be the least suitable for a profitable technology adoption due to the lower market prices and the consequent lower incomes.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/engproc2021009043/s1, Table S1: Characteristics of production systems evaluated for 2017 [15], Table S2: Cost of some agricultural inputs [15].

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