An Exploration of Preferences for Soil Health Practices in Potato Production

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Selected Poster prepared for presentation at the 2022 Agricultural & Applied Economics Association Annual Meeting, Anaheim, CA; July 31-August 2

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Abstract

This paper explores potato farmers' willingness to adopt new production practices based on the underlying attributes of each potential practice. Specifically, we use a choice experiment where hypothetical practices can vary in their effect on pests, fertilizer requirements, irrigation need, additional soil testing/education, and expected net returns. We find that farmers are indifferent to all attributes except the threat of pests, and fertilizer and irrigation requirements. Farmers would be willing to accept $25 less in net returns per acre to reduce pest threats. By comparison, expected net returns per acre must increase substantially for farmers to willingly implement practices that increase fertilizer requirements ($139) or irrigation needs ($117). Additionally, this paper provides helpful descriptive statistics on current production practices and soil health perspectives for potato growers from across the United States.

Key Words: Potato, Soil Health, Choice Experiment,

JEL Code: Q10 ; Q20 ; Q57

Introduction

The potato industry accounts for approximately 15 percent of all vegetable farm sale receipts in the United States (USDA ERS 2016) and is the third most important food crop for direct human consumption worldwide—after rice and wheat (CIP, 2017). In the U.S., potatoes account for roughly 450 thousand hectares with a farm-gate value of $4 billion (Potato Statistical Yearbook, 2017). Moreover, yields for potato production on premium acres has increased at a rate unseen by other field crops and most other vegetables. Much of these gains have occurred because of changes in intensive margins, which has the added benefit of increasing land availability for buffers strips and other conservation practices like CRP. However, these intensive production practices severely impact soil health with implications for both on-farm and off-farm ecosystem function.

Potato production degrades soil health and reduces ecosystem services through several mechanisms. For example, potato fields are generally prepared with a chisel or moldboard plow followed by shallow disking; 25-30 cm hills are formed at planting to promote an environment conducive for tuber development. At harvest, a potato digger is used to lift the tubers from approximately a 30 cm depth. Potato farmers across the United States also rely heavily on chemical inputs such as fertilizers, pesticides, and herbicides. While these chemical inputs increase on-farm yields, they can degrade soil and water quality, wildlife habitat—particularly for avian populations—and human health (Bennett, Gong and Scarpa 2018; Willis and McDowell 1982; Dodd and Sharpley 2015; Jabbar and Grote 2019; Khan and Damalas 2015). While these practices are necessary for profitable potato production, they significantly disturb the soil and affect microbial development, organic matter, and a host of other soil health metrics.

Potatoes are also uniquely susceptible to pathogens. Soilborne pathogens account for half of all annual U.S. crop loss ($4 billion) and present substantial challenges for U.S. potato production. Examples of significant soilborne diseases include potato early dying (a disease complex involving the fungus *Verticillium dahliae*), common/powdery scab, and nematodes. Valuing soilborne pathogen loss in production is difficult because infection usually reduces plant growth and tuber quality rather than directly inducing plant death. Current management practices to reduce the impact of soilborne diseases include chemical fumigation, crop rotation, irrigation and fertility management, and the use of disease resistant potato cultivars. In recent years, increasing economic pressure to shorten potato rotations, due to low relative profitability of common rotation crops (e.g., wheat), has exacerbated disease pressure. Potato growers are increasingly aware that current crop management practices reduce soil health and may increase soilborne pathogen pressures that reduce yields. As such, researchers are interested in finding win-win solutions in which naturally occurring, healthy soils can reduce the need for conventional inputs without losses in potato yield or quality. Or, when such solutions are not possible, the extent to which farmers would be willing to risk yield and quality losses.

Given the importance of soil characteristics (water retention, organic matter concentrations, microbial community composition, etc.) in potato production and its implications for broader ecosystem services, soil scientists, agronomists, and biogeochemists are working to better understand the effects of particular practices on soil health. However, suggested practices from this research must be aligned with producer acceptability for adoption to occur. To assure this alignment, we conduct a survey to elicit potato farmers' perspectives and current practices around soil health. As part of this survey, a discrete choice experiment (DCE) is used to identify farmer's willingness to adopt a hypothetical new practice based on its potential to increase net returns while reducing or increasing pest threats, irrigation and fertilizer inputs, and work requirements. The ultimate goal of this work is to provide a direction for future research by elucidating current soil health practices and acceptability in the potato industry. While innovative soil health and agronomic research is essential, understanding farmer preferences will help guide research towards adoptable technologies and practices.

There is a substantial body of literature examining farmer adoption, but it is often conducted *ex-post*, whereas this paper is intended to inform future agronomic and biogeochemical research into acceptable technologies and on-farm practices. While previous work has provided context and a foundation on which we build, we do not define a specific technology or practice. Rather, hypothetical practices with specified attributes are presented to survey respondents. For example, in past studies, farmer adoption of new technologies has been linked to their income sources, where herbicide-tolerant soybean adoption is positively and significantly related to off-farm household earnings (Fernandez-Cornejo, Hendricks and Mishra 2005). Water concerns are also linked to the adoption of new irrigation technologies (Caswell 1991) and compatible solutions, including cover-crops, reduced tillage, intensive margins, and soil amendments (Manning, Goemans and Maas 2017; Alonso-Ayuso, Gabriel and Quemada 2014; DeVincentis et al. 2020; Hansen et al. 2012). On the other hand, policies, particularly those related to the USDA Risk Management Agency, can impede adoption of novel practices (Woodard et al. 2012), as can markets and macro structures (Pannell, Llewellyn and Corbeels 2014; Duke et al. 2022). A separate branch of literature investigates farmer adoption as an adaptation strategy under climate change (Alpizar, Carlsson and Naranjo 2011; Bradshaw, Dolan and Smit 2004; Zilberman, Zhao and Heiman 2012), which is beyond the scope of this work, but it is worth noting that a recent study found no relationship is a farmer's likelihood to adopt based on historical experienced weather (Maas et al. 2020).

While these studies provide a foundation to understand how farmers have (or have not) adopted existing technology, they provide limited insight into how farmers *may* act under hypothetical new technologies and practices. As such, this study uses a DCE so that future adoption decisions based on specific practice attributes can be evaluated.

While DCE is commonly used in environmental, health, and other non-market valuation studies (Carson and Czajkowski 2014; Hoyos 2010; Ryan, Gerard and Amaya-Amaya 2008; Awad, Maas and Wardropper 2021), its use in hypothetical on-farm decisions is limited, particularly in the U.S. Of the studies that do exist, several significant results have emerged. DCE-based evidence suggests that farmers in India are willing to pay significant price premiums for drought tolerant crop varieties that reduce yield variability (Arora, Bansal and Ward 2019). Work based in Germany suggests the preference for adopting GMO's is heavily based on the profit difference between GM and non-GM varieties. Several studies examined the willingness of farmers to adopt environmentally-friendly practices (e.g. chemical-free, Conservation Reserve Program enrollment, etc.) based on third-party payments (Bennett et al. 2018).[1] To our knowledge this is the first DCE targeting potato growers and focusing on internal decisions (as opposed to external conservation payments).

[1] While the aim of our study is similar to Bennet et al., 2018, which investigates the adoption of practices likely to improve soil health and reduce environmental degradation, we frame our increase-in-profit as changes in per acre returns. This was done for two reasons. First, the aim of our research project is to identify on-farm soil health practices with innate private benefits. Second, we elected to use private market monetary incentives due to concerns over payment vehicle bias likely to arise in government-farmer relations.

Methods

Survey Methods

The DCE and survey were conducted via multiple channels, both in-person and online. One notable difference between in-person and online surveys is the compensation for participation. Online participants were entered into a raffle to win $50 dollar gift cards while in-person participants were automatically given $20 gift cards. In-person surveys were conducted at the American Potato Exposition and at state-level potato conferences, including the Idaho Potato Conference. Guaranteed payments in these cases were required to ensure participation. Online surveys were conducted primarily through email lists from practitioners' journals (e.g., *Spudman*) and consultants (e.g., *Miller Research*). This method of data collection may suffer from certain biases, but given the difficulty in randomly identifying participants from the entire potato farming population, it was necessary to feasibly elicit responses. Surveys were conducted across two years, starting with the first *Spudman* email solicitation made in December 2020 and a follow-up email sent a week later, through the Idaho Potato Conference held in January 2022.

The survey consists of two components. Component 1 collected information on farm characteristics, as well as farmers' perspectives and practices as they relate to soil health. The complete survey is included in supplemental material, but this component included questions on location and size of the respondent's operation, leasing arrangements, end-markets, rotations, soil practices, *inter alia*. Beyond being selective in where and how the survey was conducted, each survey begins with the eligibility question "Are you currently a potato farmer involved in on-farm management decisions?". If participants answer no to this question, the survey is terminated. Given the difficulty in eliciting farmers participation, Component 1 includes all responses available for each question. As such, sample sizes vary by question since some participants skipped questions and others terminated the survey before completion. Collecting this information also allows us to examine heterogeneity in farmer preferences, with the expectation that farm size and location influence technology adoption and risk tolerance.

Component 2 is a DCE that varies across four attributes with pseudo-randomly generated levels. Two hypothetical practices are presented along with a status quo option to not adopt either practice based on their attributes. Figure 1 is a sample screenshot of what respondents may see.

Respondents select on option per choice set, and are presented sequentially with six unique choice sets.

	Option 1	Option 2	Neither Option
Effect on pest management	Reduced threat of pests (can confidently reduce pesticide use)	Increased threat of pests (may need to increase pesticide use)	I would not change my practice
Effect on fertilizer requirements	Reduced need for conventional fertilizer	Increased need for conventional fertilizer	
Effect on irrigation	Significant increased need for irrigation	Slight increased need for irrigation	
Level of work or inconvenience needed	Significant increase in soil testing and monitoring	Significant additional education/learning required	
Average increase or decrease in annual per acre profit.	$-250.00	$100.00	
	○	○	○

Figure 1: Sample screenshot from DCE choice set.

Table 2 presents a complete list of selection levels available for each attribute, including a status quo option to allow for non-adoption. Note that attribute levels are ordinal but are not represented as specific percentage increases. This choice was made based on the objectives of this paper and the substantial uncertainty and future practices effect on pests, for example. This setup is more likely to capture heuristic decision making (when % changes to particular attributes are largely unknown). As such, exact willingness-to-pay estimates are difficult to determine for specific changes in attribute level. Additionally, this choice dictates the use of dummy variables in the econometric model, which has implications for interpretability (Bech and Gyrd-Hansen 2005).

Table 2: Choice Attributes and Levels

Effect on pest management	Reduced threat of pests (can confidently reduce pesticide use) Increased threat of pests (may need to increase pesticide use)
Effect on fertilizer	Reduced need for conventional fertilizer

requirements	Increased need for conventional fertilizer
Effect on irrigation	Significant increased need for irrigation Slight increased need for irrigation
Level of work or inconvenience needed	Significant increase in soil testing and monitoring Significant additional education/learning required
Average increase or decrease in annual per acre profit.	$ 0 $ 100.00 $ -100.00 $ 250.00 $ -250.00

While the range of profit per acre levels are substantial (-250 to 250), potatoes have a net-return above operating costs unseen in many field crops. For example, enterprise budgets from the University of Idaho Agbiz website suggest Russet Burbank potatoes with fumigation in the Magic Value can garner over $1,400 per acre net returns.

Statistical Methods

Descriptive statistics of respondents are provided to highlight the current state of the industry and farmers perspectives around soil health. Mean scores and standard deviations are calculated for each survey question. Responses to these questions are used to identify heterogeneity in respondent preferences based on farm characteristics.

Choice experiment methodology is derived from random utility theory in which individuals choose between alternatives that provide the greatest utility (McFadden 1974). In any DCE, respondents are asked to choose between a set of goods comprised of different underlying attributes; rational individuals then choose the alternative that gives the highest level of utility. Mathematically, this decision can be represented as $U_{ikn} > U_{ijn}$ such that for any individual, *i*, alternative *k* is preferred to alternative *j* at time *n*. Random utility also suggests that any utility level, $U_{ikn}(°) = V_{ikn} + e_{ikn}$, is additively separable into components, $V(°)$, which is deterministic, and *e*, which is stochastic in nature. As such, the probability that individual *i* chooses option *k* over any other option *j*, in choice set *C* can be written as:

$$\Pr_{ikn} = \Pr\left(V_{ikn} + e_{ikn} > V_{ijn} + e_{ijn}\right) \quad \forall \mathrm{k} \neq \mathrm{j} \in \mathrm{C_n}$$

which can be rewritten as: $\Pr\left(V_{ikn} - V_{ijn} > e_{ijn} - e_{ikn}\right)$. Thus, making particular assumptions about the error component in each utility function allows us to estimate the probability that one choice preferred to another, given the attributes of that choice. The non-stochastic component utility assumes the form $V_{ijn} = x_{ijn}\beta_i$ such that the random coefficients β_i allow for individual's correlation across alternatives.

Using a mixed multinomial logit to estimate this model does not require the assumption of independent and identically distributed error such that (conditional on knowing β_i) the probability of individual *i* choosing alternative k at time *n* is:

$$L_{ikn} = \frac{e^{\beta_i' x_{ikn}}}{\sum_{j=1}^{J} e^{\beta_i' x_{ijn}}}$$

This is the conventional conditional logit as derived by McFadden (1974). Ultimately, we can model the probability of choices across time, n, the unconditional probability of which is the integration of the conditional probability across all β (Train 2003, Hole 2007). Thus, unconditional probability is a weighted average of a product of logit formulas evaluated at different values of β, with the weights determined by a given density function (Hole 2007). The final expression is solved approximately using simulation methods derived by Train (2003) and operationalized in Stata's *mixlogit* command.

Results

Many of the farm characteristics collected in our survey do not have national Census or surveyed estimates from which we can compare our own results. Despite this limitation, we attempt to verify the representativeness of our sample with data that do exist. For example, our results

Table 1) suggest that 27% of income is gained from off-farm activity. ERS estimates suggest a similar proportion of off-farm income. Midsized family farms have an average income of \$168,831, \$59,319 of which is earned off-farm. Very large family farms have an average income of 1.37 million, with only \$101,053 coming from off farm income (ERS 2021). Our results are roughly in line with these off-farm income data, assuming potato growers are medium-to-large scale operations, which is reasonable since potatoes are a particularly high-value field crop with specialization requirements. One area of potential concern in our results involves end-markets. Our sample over represents producers in the fresh pack market, with average percent of potatoes sold to fresh market at 46%. Nationally, the NPC estimates that between 25-30% of potatoes are sold in the fresh market (NPC Potato Yearbooks 2017-2020).

Summary of the Potato Industry

Table 1: Farm Descriptive Statistics

Farm Characteristics	Mean	Std. Dev	N=
Average acres in potatoes each year	1657	4484	127
% of Potatoes for fresh pack (omitting seed growers)	46%	42	100
% of Potatoes for processing (omitting seed growers)	43%	39	100
% of Income gained from off-farm activity	27%	33	116

Information on land leases is crucial to understanding what practices may be effective in establishing soil health, which is a multiyear process. Clearly, incentives to maintain soil health depend on the tenure length of the lease. First, there is potentially less incentive for growers to be concerned with soil health for short-term land leases. Second, lease-leaser relationships allow for additional decision-making dynamics, where the active farmer may have varying amounts of autonomy in their decision set. Our results (Table 2) show that 69%[2] of potato farmers denote leasing at least some land, with the average leased land accounting for 53% of the total production area. 3-year leases appear to be the most common length, which coincides with the most common potato rotation length, though the average is 5.8 years since come contracts are considerably longer. While significant portions of potato production lands are leased, over 62%

[2] Percentages are reported relative to the number of responses per question, which may differ from the total number of respondents, since survey-takers were allowed to omit questions.

of farmers still make all farm management decisions, though 32% acknowledge some stipulations involving soil health.

Table 2: Land Lease Statistics

Land Leases	Mean	Std. Dev	N=
% Of growers who lease land	69%	--	135
Average % of land leased	53%	27	87
Average lease contract length (years)	5.8	5.1	89
% Of Lease contracts with specific “soil health” stipulation	32%	--	93

When considering adopting a new practice, potato farmers appear fairly myopic. When asked, “How many years are you willing to wait to see financial benefits from new practices or investments?”, the average farmer is willing to wait 3.2 years, and very few respondents are willing to wait more than 5 years (Figure 2).

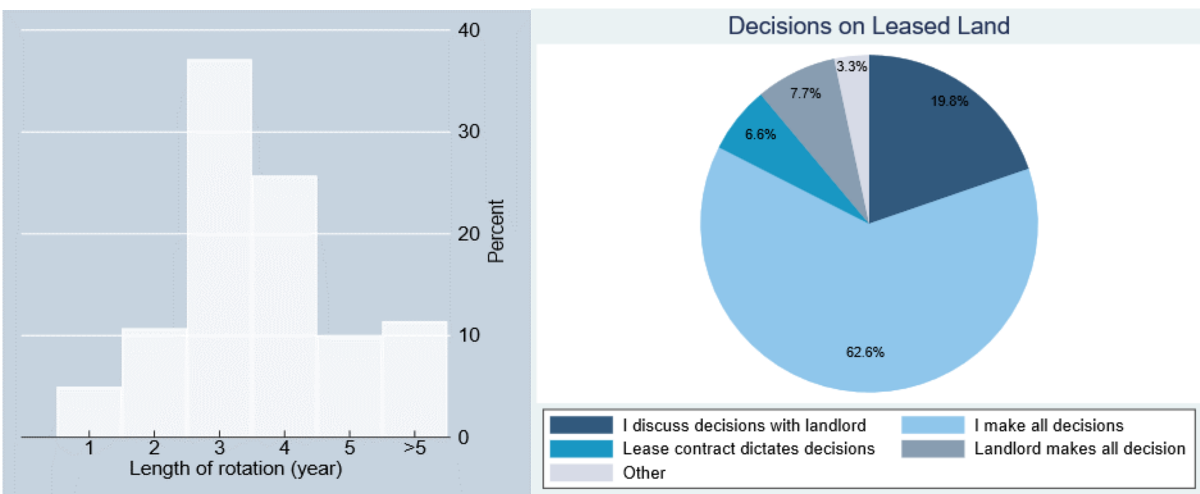

Figure 2: (Left) Histogram of crop rotation length; (right) degree of grower autonomy for leased land

As expected, potato farmers believe in the importance of, and implement practices for, soil health. The results (Table 3) show that 88% of respondents stated that soil health “very” or “extremely” important, 11% stated soil health was “moderately” important, and only 1 respondent stated it was “not important at all”. In terms of implemented soil practices, conventional fertilizer application is the most common (85%) followed by green manure (42%). Manure and inoculates were used the least frequently, at 24% and 20% respectively.

Farmers were also asked to identify major barriers to adopting a new management practice (rotation, soil amendment, etc.) on their operation. The uncertainty of economic benefits—both short and long run—appears to be the most significant barrier to adopting a new practice. Capital constraints also appear to be a significant impediment (Table 3). The last barrier commonly identified is an incompatibility with current growing system. In fact, written comments in the "other" category and anecdotal discussions suggest that cover crops in particular are difficult to adopt based on the length of the growing season.

Table 3: Coefficient and WTP Estimates

Barriers to Adoption	#	%
Capital constraints prevent the initial investment	47	35.1%
Complexity in implementation	0	0.0%
Incompatible with current crop/farm insurance requirements	9	6.7%
Landlord/rental agreement	1	0.7%
New practice is technologically incompatible with current system	35	26.1%
Uncertainty in long-run economic benefits	47	35.1%
Uncertainty in short-run economic benefits	64	47.8%

Choice Experiment Results

Results from the choice experiment suggest that potato farmers are sensitive to pests, fertilizer, and irrigation requirements, but indifferent to changes educational effort, work-level associated with adopting a new practice, and burden of soil testing. Coefficient estimates for each attribute are presented in Table 4 (column 1). Significant coefficients are transformed to willingness-to-pay (WTP) estimates (column 2).

The estimates imply that soil testing requirements and additional work and education requirements are not important factors that influence potato farmer production practice adoption (highly insignificant). However, potato farmers are responsive to increased fertilizer requirements, where a practice that requires additional fertilizer would have to increase returns by at least $139.72 per acre for the average farmer to adopt it. Again, this estimate appears high for more conventional field crops, but in potato production (in Idaho) fertilizer accounts for $336 of expenditures per acre. As such, our estimate is just over a third of current costs. While enterprise budgets can be used to find break-even points in terms of fertilizer-yields relationships, the DCE allows us to elicit responses from decisions makers that inherently include perceptions about future prices and other relevant factors.

A similar—though somewhat smaller and less significant—result exists for increased irrigation requirements. If a practice increases irrigation requirements, the average farmer would need to expect an increased return of $117.96 per acre to adopt the practice.

Table 4: Coefficient and WTP Estimates

VARIABLES	(1) Coefficients	(2) $/acre
Price	0.00363***	--
	(0.000512)	
Reduced Pest Threat	0.930***	-$25.40
	(0.266)	
Increased Pest Threat	0.0923	--
	(0.257)	
Increased Fertilizer Requirement	-0.508***	$139.72
	(0.177)	
Decreased Irrigation Requirement	-0.153	--
	(0.215)	
Increased Irrigation Requirement	-0.429*	$117.96
	(0.255)	
Increased Soil Testing	-0.216	--
	(0.209)	
Increase in Work/Education	-0.0726	--
	(0.264)	
Observations	1,782	

WTP estimates are presented for significant coefficients.
Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Results in response to the threat of pests are less clear. Our estimates suggest that farmers would forego $25.10 in returns per acre to decrease the threat of pests. Curiously, however, the coefficient on increasing pest threats is highly insignificant. This result, or lack thereof, may partially be driven by the heterogeneity across farmers, where risk tolerances to pests are likely to vary by farm size, location, and market type (seed, fresh pack, processed).

Discussion

The objective of this study is to steer future soil health research in potato production by identifying farmer's willingness to adopt practices with specific soil health-related attributes. Primarily, we looked at changes in net returns, pest threats, irrigation requirements, fertilizer requirements, soil testing, and additional work/education.

Overall, potato growers appear less likely to adopt any practices that increase the need for irrigation or fertilizers. This result is not surprising given the high costs of fertilizer in potato production and the (general) inability of farmers in the West to acquire additional water. For example, every potato growing county in Idaho is already fully adjudicated (IDWR 2022), such that additional water supplies are either non-existent or prohibitively expensive. Accordingly, potential soil health practices that increase in-season irrigation requirements are likely a non-starter for many growers.

Concerns over the biases associated with stated preferences methods may be a concern in our analysis, though they are somewhat limited since there is no strategic advantage based on responses. A concern over hypothetical bias is still present, which may be particularly concerning given the nature of the problem. Moreover, exact WTP estimates should be interpreted with caution as the attributes were generally qualitive in nature such that an "increase in the threat of pests" does not provide specific monetary or probabilistic values.

The results presented herein should be viewed as preliminary. There is a strong need for further investigation and an increased sample size. The next steps of our research will investigate the farm characteristics most likely to drive heterogeneity in preferences. Given the substantial differences in potato enterprises across regions, we expect significant heterogeneity in farmers willingness to adopt a new practice based on its underlying attributes. Additionally, farm size, temporal preference, and market structure may also drive differences.

Overall, some results are encouraging. First, net returns are the most important feature of our model, which suggests that profitable practices will be adopted. To the extent that researchers can align profit incentives with novel soil health practices, adoption among potato growers appears likely. Farmers appear entirely willing to adopt practices the require additional soil testing, work, or education, all of which appear insignificant in the DCE regression.

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