



Adoption of Sustainable Agriculture Practices among Farmers in Kentucky, USA

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Abstract

Promoting the sustainable agricultural practices at an individual farm level is essential to ensure agricultural sustainability. This study analyzed whether and how various factors related to farm or farmers' characteristics influence the adoption intensity of sustainable agriculture practices. We used a negative binomial regression model to fit the data collected from a mail survey of farmers in Kentucky, USA. Our results showed that the adoption intensity of sustainable agriculture practices varied significantly among agricultural districts in Kentucky. Farmers who grew row crops, had irrigation facilities, and were in favor of crop diversification were significantly more likely than their respective counterparts to adopt more sustainable agriculture practices. Similarly, having a college education and participating in the Tobacco Buyout Program also positively and significantly affected the intensity of adopting sustainable agriculture practices among Kentucky farmers. In contrast, a lack of adequate knowledge about sustainable farming and an unfamiliarity with technology significantly and negatively related to less adoption of sustainable agriculture practices.

Keywords Adoption intensity · Best management practices · Small farmers · Negative binomial regression · Kentucky

Introduction and Relevant Literature Synthesis

The US Congress (1990) defined sustainable agriculture as an integrated system of animal and plant production practices that satisfy human food and fiber needs, enhance environmental quality by making the most efficient use of

non-renewable resources, sustain the economic viability of farm operations, and enhance the quality of life. Sustainability in agriculture is a complex and dynamic concept, including a wide range of environmental, social, economic, and resource use issues that changes with the time, location, society, and priorities. It is intended to minimize external inputs added to maximize agriculture output or production and maintain farm resources, achieving socioeconomic, environmental, and economic welfare, along with quality of life, without harming the environment, public health, communities, or animal welfare (Kornegay et al. 2010; Pretty 2008). Sustainable agriculture entails understanding the benefit of ecological and agronomic management, especially in regard to its manipulation and redesign to shift a farming system toward a natural system without reducing productivity (Pretty 2008).

Ensuring sustainability in agriculture requires the integration of sustainable agriculture practices (SAPs). Sustainable agriculture adopts productive, competitive, and efficient practices while protecting and improving the environment and the global ecosystem as well as the socioeconomic conditions of local communities. SAPs do not exclude external inputs but encourage incorporating them to complement local resources (Zaharia 2010). SAPs

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are not “one-size-fits-all” prescriptions, but are uniquely designed for the best management practices to address the uniqueness of farming systems (Lashgarara 2011).

Pretty (2008) traces the study of SAPs back to 1950s. Rural sociologists (see Ryan and Gross 1943; Ruttan 1996) were the pioneers in technology adoption–diffusion studies during the early 1940s to late 1950s; these studies were continued by economists and other researchers afterward (see Foster and Rosenzweig 2010). Griliches (1957) wrote one of the influential papers on hybrid corn technology adoption and diffusion. Later, the National Research Council also published reports on “Alternative Agriculture” in 1989 and “Towards Sustainable Agricultural Systems in the 21st Century” (Kornegay et al. 2010). Prokopy et al. (2008) summarize 45 studies related to sustainable agriculture practice adoption among US farmers from 1982 to 2007, and in a follow-up study Baumgart-Getz et al. (2012) summarize the variables affecting the adoption of these practices. Other studies (Knowler and Bradshaw 2007; Knowler 2015) have summarized the factors influencing the adoption of conservation agricultural practices. Liu et al. (2017) provide a summary of 16 studies with emphasis on agricultural best management practice adoption and their abilities to improve hydrology and water quality.

The adoption of sustainable agriculture possesses several long and short-term benefits. In the long run, the adoption of SAPs can replace some or all external inputs in agriculture systems (Pretty 2008). SAPs help to maintain the water table, increase carbon sequestration, improve soil fertility, and protect land from erosion reducing sediments load from agriculture lands, as well as bring socioeconomic benefits, such as an increase in net present value, reduction on-farm costs, labor and time saving (Knowler and Bradshaw 2007; Pretty 2008). There are also some negative aspects associated with sustainable practices, like no tillage, which is known to increase herbicide use, require special machinery use, and increase the incidence of fungal diseases. However, the overall benefits of conservation programs for reducing soil erosion and improving water quality have been validated by the Natural Resources Conservation Services of United States Department of Agriculture (NRCS 2014). Design, promotion, and adoption of location-specific SAPs are one of the important tools for protecting the environment, water quality, and agricultural land and reduce overall investment to implement conservation programs (Greiner et al. 2009; Mullendore et al. 2015).

Previous studies have shown that Kentucky farmers have been adopting soil and water conservation-related SAPs. Cropping systems, such as no-tillage practice, spread widely during the 1950s in Kentucky (Coughenour 2003). Recent studies by Da Costa et al. (2012) and Zhong et al. (2016) emphasize the adoption of conservation practices to improve water quality. Despite the widespread benefits and

positive impacts of SAPs in farming, the adoption intensity of these practices has not been studied well. A limited amount of research focusing on the adoption of only a few conservation-related practices are found in the context of Kentucky. Thus, we included 31 different SAPs commonly adopted among Kentucky farmers to understand how farmers respond to the adoption of a set of SAPs. These practices were identified through workshops and group discussions with local farmers throughout the state of Kentucky. So, the originality of the paper lies in its identification of the most commonly adopted SAPs throughout Kentucky. It is well understood that not all practices are equally effective toward improving soil and water quality and hence developing sustainable agriculture. Their effect varies based on the physical characteristics of the landscape (Rittenburg et al. 2015). SAPs that are most commonly studied in the context of Kentucky, as well as the SAPs identified as commonly adopted by Kentucky farmers, are provided in Table 1. The overall objective of this research is to investigate factors that influence the adoption intensity of these identified SAPs in Kentucky.

The rest of the paper proceeds as follows. In section 2, we provide the broad literature related to SAPs. We present the conceptual model in section 3. We explain data and model related details in section 4. In section 5, we describe the results and implications. We conclude the paper in section 6.

Factor Influencing SAPs Adoptions

The adoption decision-making process of SAPs is influenced by several factors, such as farmers’ knowledge and skills, the existence of and connections to a market for the commodities they produce, agricultural policies, and regulations, available resources, geographic features of the farm, and economic, social, and conservation motivations (Greiner et al. 2009; Kornegay et al. 2010; Lashgarara 2011). Farmers with irrigation facilities are more likely to adopt soil conservation practices like cover crops (Carlisle 2016; Snapp et al. 2005).

Socio-demographic factors such as age and land tenure, and cognitive factors such as knowledge and attitude toward a program, are also believed to influence the adoption of SAPs (Kabii and Horwitz 2006). Older farmers are less likely to adopt new practices that they are not very familiar with (Baumgart-Getz et al. 2012; Kabii and Horwitz 2006). But, farmers are positive and more likely to adopt SAPs with a higher level of formal education (Soule 2001; Upadhyay et al. 2003). Factors such as income, education level, access to information, capital, positive environmental attitudes, environmental awareness, and farm size generally have a positive impact on the adoption rate of SAPs

Table 1 Commonly adopted sustainable agriculture practices among farmers in Kentucky, USA

Some commonly adopted and studied SAPs in Kentucky and included in this research:

Animal for land reclamation: small mammals such as mouse help to loosen the mined surface, which favors quick succession (Larkin et al. 2008).

Biological pest control: pest is suppressed by their natural enemies (Filho et al. 1999).

Conservation tillage: tillage and cultivation practice that incorporate crop residue into the field (Coughenour 2003).

Composting: waste recycling technique converting waste into nutrient-rich humus with high soil organic matter using microbes (Filho et al. 1999).

Cover crops and green manuring: use of legumes such as clover, vetch, and non-legumes such as rye, wheat to improve soil fertility and reduce erosion and incorporate into the soil as green manure (Gillespie et al 2007).

Crop rotation: system of rotating legumes and non-legumes crops in the same field to maintain soil fertility (Kornegay et al. 2010).

Improved water management: improve irrigation facility to reduce irrigation water losses (Kornegay et al. 2010).

Increase biodiversity: diversify flora and fauna in the farm (Kornegay et al. 2010).

Integrated pest management: a pest management strategy using biological, chemical and physical, cultural production cost and protect the environment (Kornegay et al. 2010).

Mulching: a shallow layer of grass or crop residues at the soil/air interface to improve soil quality and moisture retention (Filho et al. 1999).

Precision agriculture: observation, measurement, and response based farm management strategy to address inter and intra-field variability in crops and increase farm efficiency, productivity, and economic returns (Kornegay et al. 2010).

Reduced chemical fertilizer use: reduced in the use of chemical fertilizers (Kornegay et al. 2010).

Reduced chemical pesticide use: reduce the use of chemical pesticides (Kornegay et al. 2010).

Other commonly adopted SAPs in Kentucky as identified by this research through the workshops and group discussions:

Alley cropping: planting trees or shrubs with agronomic, horticultural, or forage crops cultivated in the alleys between woody plants (Kornegay et al. 2010)

Controlled grazing: the grazing of animals is controlled by rotating and striping field letting field to recover before a successive round of grazing (Gillespie et al 2007).

Crop and livestock production system integration: an integrated system where crop and livestock enterprise are combined and benefitted from each other (Kornegay et al. 2010).

Cultural pest control: managing the crop, weed, disease, and pest complex by manipulating cultural practices (Kornegay et al. 2010).

Fallow management: the use of the fallow period to conserve rainfall as stored soil water and reduce soil erosion (Kornegay et al. 2010).

Farm machinery adjustment: adjustment in planting, spraying, and harvesting farm machinery operation, calibration, repair, and their safety (Kornegay et al. 2010).

Table 1 (continued)

Forest stewardship: forest conservation and development of forest in own farmland.

Land reforming: forming terrace, reducing slope, and other slope stabilizing technologies to reduce surface runoff of water and topsoil.

Local or native crops: locally available crops or local varieties (Kornegay et al. 2010).

Multi-species grazing: grazing more than one species of livestock such as chicken, duck, goat, and horse in the same land (Kornegay et al. 2010).

Polyculture farming: different and less competitive crops grown together to optimize biomass yield and improve environmental quality (Kornegay et al. 2010).

Reforestation: reestablishing forest in barren land or farmland.

Ridge tillage: scalping and planting on ridges built during cultivation (Kornegay et al. 2010).

Sprayer calibration (and application accuracy): calibrate sprayers to use optimum amount of chemicals as well as other spraying inputs in the farm.

Varietal mixture of single crop: mixing a different variety of same crops. also known as Cultivar Mixtures (Kornegay et al. 2010).

Windbreaks and shelterbelts: create wind barriers and provide shelter to crops by planting tall, dense and strong trees along the edge of farmland (Kornegay et al. 2010).

(Carlisle 2016; Prokopy et al. 2008). Hall et al. (2009) found that among floriculture farmers with a farm size of 1–5 acres, there is a significant and positive relationship to the adoption of SAPs, but not with other land sizes.

Access to quality information and extension training have a positive and significant impact on the adoption of best management practices (Baumgart-Getz et al. 2012). Farmers with better knowledge, education, and access to information are more likely to adopt. In addition, knowledge, education, and access to information help to reduce other perceived barriers regarding sustainable practices (Carlisle 2016). Also, networking and outreach activities among farmers motivate them to adopt and expand the adoption of SAPs. In Kentucky, conservation agriculture was widely spread among farmers as a result of networking and the innovation of the system. The overall impact from conservation practices has been better synergy between the environment and agriculture in Kentucky (Coughenour 2003).

Researchers have found that the relationship between farm size and the adoption of soil health-related practices is complicated. Farmers with sloping or highly erodible land are more likely to adopt soil conservation practices (Carlisle 2016; Soule et al. 2000). A study among Brazilian farmers found that the likelihood of the adoption of environmentally friendly practices decreased with an increase in farm size but increased with an increased awareness about the negative effect of chemicals on health and the environment (Filho et al. 1999). However, the use of erosion control practices had a positive relationship to farm size among

farmers in eastern Uganda (Barungi et al. 2013). Small farmers are more motivated to adopt soil health-related practices and relate their adoption behavior to environmental problems than large farmers. Also, small farmers identify the problem of soil erosion faster than larger farmers but are less likely to adopt technologies to reduce erosion. This may be due to higher investment in technologies required per unit of land (Carlisle 2016).

Awareness, attitudes, available resources, and incentives influence the adoption of environmentally friendly practices among Michigan farmers (Swinton et al. 2015). The study concluded that farmers' hesitation to adopt such practices were attributable to the misperception that SAPs are less profitable or that SAPs require skilled and expensive labor. However, farmers who have already adopted SAPs develop positive attitudes about practices and are motivated to adopt more, in contrast to non-adopters, who are motivated by potential yield benefits. The protection of the environment, land conservation, belonging to the land, motivation to make changes, and off-farm benefits are some of the motivations to adopting SAPs (Carlisle 2016).

Policies can have both positive and negative relationships on the adoption of SAPs. Policies like Farm Bill conservation programs have a positive impact on the adoption of SAPs. Farmers who have already participated in conservation programs are motivated to make long-term investments in adopting SAPs (Coughenour 2003; Carlisle 2016). A conservation reserve program was helpful in increasing the adoption of SAPs to reduce erosion, but the pace of adoption is slow. However, the Risk Management Agency policy prevents the adoption of cover crops, as farmers may lose their insurance after adopting those cover crops (Carlisle 2016).

The adoption of SAPs has been well accepted as one of the tools for achieving environmental improvement in agriculture (Greiner et al. 2009). Kabii and Horwitz (2006) found that conservation easement is affected by socioeconomic factors, farm attributes, geography, behavior, attitude, and knowledge. Similarly, Knowler and Bradshaw (2007) summarize factors influencing the adoption of conservation tillage all around the world. Prokopy et al. (2008) summarize the US-based research focusing on the adoption of SAPs during the last 25 years. Mullendore et al. (2015) found that place attachment and place identity among farmers in the Midwestern U.S. have significant effects on conservation practices adoption. Similarly, among Michigan farmers, the adoption of new, environmentally friendly management practices was influenced by attitudes, available resources, and incentives (Swinton et al. 2015). In aggregate, the existing literature collectively indicates that the adoption of SAPs is affected by various socioeconomic factors, demographics, farm attributes, knowledge, behavior, and attitudes, not only in the USA but throughout the

world. Also, factors that affect the adoption of SAPs are not consistent throughout the world in the sense that one variable that appears to be statistically significant in one location with a positive sign may not necessarily be statistically significant and possess the same direction in other locations (Baumgart-Getz et al. 2012). However, research focus on the determinant variables of SAP adoption that are generally significant across different geographical areas can improve the overall adoption rate of SAPs (Prokopy et al. 2008).

A table summarizing the major influencing factors is presented in Table 2.

Research Method

Study Area

The study area of this research is the state of Kentucky, USA (Fig. 1). Western Kentucky contributes significantly to the state's agricultural sector. This region is more mechanized than the other parts of the state. Central Kentucky is more urbanized compared with other regions. It has three big cities and several other small and growing urban centers. However, this area also has the highest number of farmers. This region is known for having large acres of farmland and a large number of farmers. Eastern Kentucky has fewer agricultural enterprises compared with other regions of the state. This region features the Appalachian Mountain range and is also well known for coal mining and reclaimed lands.

According to the Agriculture Census of 2012, Kentucky has ~77,000 farmers and 13 million acres of land used for agriculture. The average size of a farm is 169 acres. The majority of the farmers have < 500 acres. Most of the farm operators in Kentucky are small farmers with an age of over 45 years. Looking at the trend over some decades, the number of farmers is decreasing, the average size of each farm is increasing, and the average age of farmers is also increasing (NASS 2015).

The adoption of SAPs also varies with the agriculture district in Kentucky. Western Kentucky is well known for commercial agriculture production and flat plains. So, the use of precision agriculture, computers, and large farm machinery are some of the most commonly adopted practices in that region. However, Eastern Kentucky is well known for coal mining. So, practices such as the use of animals for land reclamation are more applicable to Eastern Kentucky (Larkin et al. 2008). Some SAPs that have a common application, such as the reduced use of chemicals, cover cropping, and green manuring, the use of manure as fertilizer, and controlled grazing are also some of the most commonly used practiced throughout the state.

Table 2 Relevant literatures and summary of major findings

Reference	SAPs types	Study area	Relevant findings to SAP study
*Baumgart-Getz et al. (2012)	BMPs	USA	Access to and quality of information, financial capacity, connection with extension agents and farmer's network have the largest impact on adoption.
*Carlisle (2016)	Soil health practices	USA	Combining education, research, policy, measure to overcome equipment barriers, and addressing farm and food system context increase the adoption of soil health practices.
Da Costa et al. (2012)	Watershed conservation	Kentucky, USA	Counties with more farms and larger farms are more likely to participate in the conservation program. The adoption depends upon land characteristics of individual plots.
Gillespie et al. (2007)	16 BMPs in cattle industry	Louisiana, USA	Farmers do not adopt technologies because of unfamiliarity, non-applicability, high cost, preference towards technologies. Education and extension activities are important to improve the adoption of BMPs.
Hall et al. (2009)	Sustainable floriculture practices	USA	The concerns about the implementation (e.g., easiness) and the risk associated with the implement are two major important factor affecting adoption of SAPs beside location and farm size.
*Kabii and Horwitz (2006)	Conservation easement programs		Landlords' demographics, land tenure nature, knowledge, and awareness about the program, financial circumstances, and participation risk perception, benefit of programs, incentives, and compensation are important factors that affect the participation of conservation programs.
*Knowler and Bradshaw (2007)	Conservation agriculture		The variable explaining the adoption of conservation practices is also localized alike conservation practices themselves. So, policy development and planning attempts to improve adoption should be localized to address location-specific needs and demands.
Mullendore et al. (2015)	Conservation behavior	Midwest USA	The sense of place or place attachment and the place identity have a significant effect on the specific conservation behavior but not in the overall.
*Prokopy et al. (2008)	Best management practices	United States	Education level, income, farm size, access to information, positive environmental attitudes, environmental awareness, and utilization of networking have more often positive relation with the adoption of best management practices.
Singer et al. (2007)	Cover crop	US Corn Belt: IL, IN, IA, MN	Crop diversification plays an important role in the adoption of cover crops and availability of cost-share program would enhance the use of cover crop among corn belt farmers.
Wilson et al. (2014)	Nutrient management practice	Ohio, USA	The attitude toward the adoption of practice to improve nutrient management is driven by farmer's attitudes, perceived risks, and response toward the negative impact of nutrient losses from a farm in the environment. Younger farmers are already engaged in and have more positive attitudes toward management practices.
Zhong et al. (2016)	BMPs via water quality trading program	Kentucky, USA	Farmers who participate in the conservation program are more likely to adopt BMPs. The attitude of farmers towards BMPs and conservation practices are more important when adopting BMPs among farmers.

*Review or meta-analysis paper

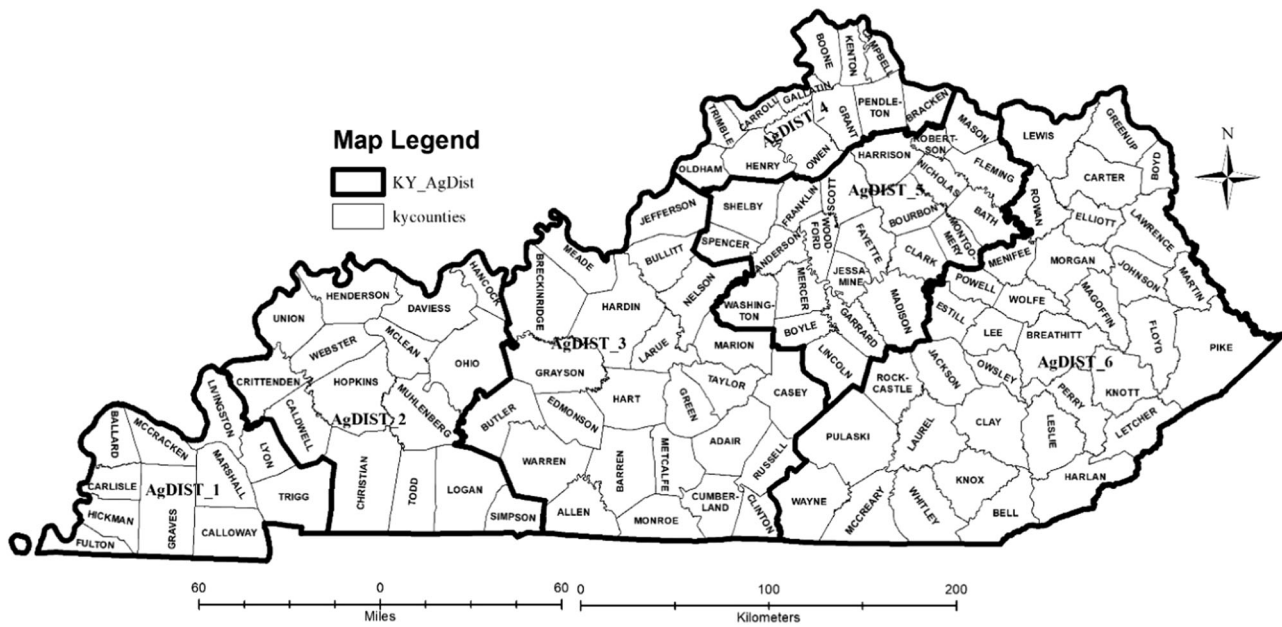


Fig. 1 The state of Kentucky with the six crop growing regions and counties

Sampling Procedure Applied

A survey questionnaire was developed to ask respondents about their farm characteristics, current farming practices, and knowledge and attitudes toward SAPs. The survey questionnaire was tested among small farmers all over the State of Kentucky at the “Third Thursday Thing”—an outreach program on every third Thursday of each month—at the Kentucky State University Research Farm. The final survey questionnaire incorporated suggestions made by the participants. The annual gross sales value of farm outputs and agriculture districts were used for a double-stratified sampling to select samples from all agriculture districts. The annual gross sales value and agricultural districts were taken as reference, with stratification for the proportional representation of farmers with different income levels throughout the state and farmers from different agriculture districts with different agricultural characteristics, respectively.

Data Collection Techniques Used

A mail survey, followed by phone calls, was conducted by The National Agriculture Statistics Service of the United States Department of Agriculture (NASS/USDA) from 10 September 2015, to 13 January 2016. One thousand surveys requesting information for the production year 2014 were mailed to farmers across Kentucky from the North Carolina Print Mail Center. Survey responses were returned and documented at the Regional and Field Office (RFO) of USDA/NASS in Louisville, Kentucky. Surveys were randomly cross-verified by the USDA/NASS staff and

demographic and farm attributes summaries were cross-checked with the 2012 United States Census of Agriculture.

Definition of Variables

Dependent Variable

We find that the majority of the farmers are non-adopters of SAPs. Only 34.68% of farmers have adopted SAPs, and 65.32% of farmers have not adopted any type of agricultural practices that were identified as the most commonly adopted SAPs among Kentucky farmers by this research. Among adopters, the majority of farmers have adopted 1–7 different practices. About 22.37% of farmers have adopted 1–7 practices, 9.39% of farmers have adopted 8–14 practices, and only 0.65% of farmers have adopted more than 21 SAPs. At most, a single farmer has adopted up to 28 different types of the most commonly adopted SAPs identified in this research (Table 3).

“Manure distribution as fertilizer” is the most adopted practice by farmers followed by the “reduced use of chemicals.” Agriculture practices such as precision agriculture, polyculture farming, reforestation, and mulching are adopted by only a few farmers. The results suggest that the easiness in the adoption process, technical skills requirements, investment, and income play important roles in farmers’ decisions of whether and which SAPs to adopt for their farm. Highly adopted practices among Kentucky farmers are less expensive as well as easy to adopt, and the least adopted practices are highly skill based and investment

Table 3 Sustainable agriculture practices adopted by farmers ($N = 230$)

Number of practices	Number of farmers	Percent
0 (not adopted)	150	65.32
1–7	51	22.37
8–14	22	9.39
15–21	5	2.27
22–28	2	0.65

demanding. The most commonly adopted practices and their adoption intensity are shown in Fig. 2.

The dependent variable (SAPs) is the count variable (non-negative whole numbers) that shows the total number of SAPs adopted by Kentucky farmers who responded to the survey. The value of the dependent variable ranged from 0 to 28 (Table 3). The description of variables and their descriptive statistics are given in Table 4.

Independent Variables

Based on the review of influencing factors provided in section 2, the adoption of SAPs is affected by various socioeconomic factors, demographics, farm attributes, knowledge, education, behavior, and attitude. Fourteen explanatory variables related to these factors were used for the analysis: Crops (row crops growers), *Veggies* (vegetable growers), *Livestock* (livestock farmers), *Irrigation* (irrigation facilities in farm), *Diverse* (in favor of farm diversification), *Solo Proprietorship* (single owner of farm), *Off-Farm Work* (working off-farm for income), *Age* (year), *TBP* (participation in Tobacco Buyout Program), *College Degree* (education level of farmers with college degree or above completed), and *Land Operated* (Acres). Three barriers to the adoption of SAPs—*Happy* (happy with current practices reflecting the attitude of farmers toward SAPs), *Implementation Difficulty* (perceived difficulty of implementation), and *Inadequate Knowledge*—were also used as independent variables in the model. These were the top three barriers marked by respondents to the survey. Six dummy variables were created based on the crop growing regions of Kentucky to examine spatial impacts of on the adoption of SAPs. These crop growing areas are shown in Fig. 1.

Econometric/Empirical Model

Condition for SAPs Adoption Consideration

Farmers adopt SAPs for various reasons. Some farmers adopt SAPs because they believe these practices increase

yield (and consequently the net returns) associated with farming, whereas others believe that SAPs are good for the environment. Also, there are farmers who adopt SAPs while considering economic and environmental benefits. Whether farmers adopt the technology for a yield or profit reason or for an environmental quality reason, they believe that adopting SAPs gives them higher utility than not adopting the technology. We believe that farmers adopt a higher number of SAPs because they perceive a number of SAPs adoption or more SAPs applied in more acres of land gives them higher utility than otherwise. We can write this as: $U_{SAPs \text{ adoption=yes}} > U_{SAPs \text{ adoption=no}}$. The probability of adopting SAPs can be shown as:

$$\begin{aligned}
 P_i &= \text{Prob}[U_{\text{adopt}} > U_{\text{not adopt}}] \\
 &= \text{Prob}[X_i \alpha_1 + e_{1i} > X_i \alpha_0 + e_{0i}] \\
 &= \text{Prob}[X_i (\alpha_1 - \alpha_0) > (e_{0i} - e_{1i})] \\
 &= \text{Prob}[X_i b > e_i] \\
 &= F[X_i b].
 \end{aligned}$$

Here, X is a matrix of explanatory variables, b (and α) is the parameter vector, ϵ (and e) is error term, F is the cumulative distribution function, $i = 1$ when SAPs are adopted, and $i = 0$ when no adoption occurs (Gillespie et al. 2007).

Data Analysis Techniques Applied

Data were analyzed using SPSS 24.0. To address the disproportionate response rate among strata, the post-stratification weight was applied before analyzing the data using the equation:

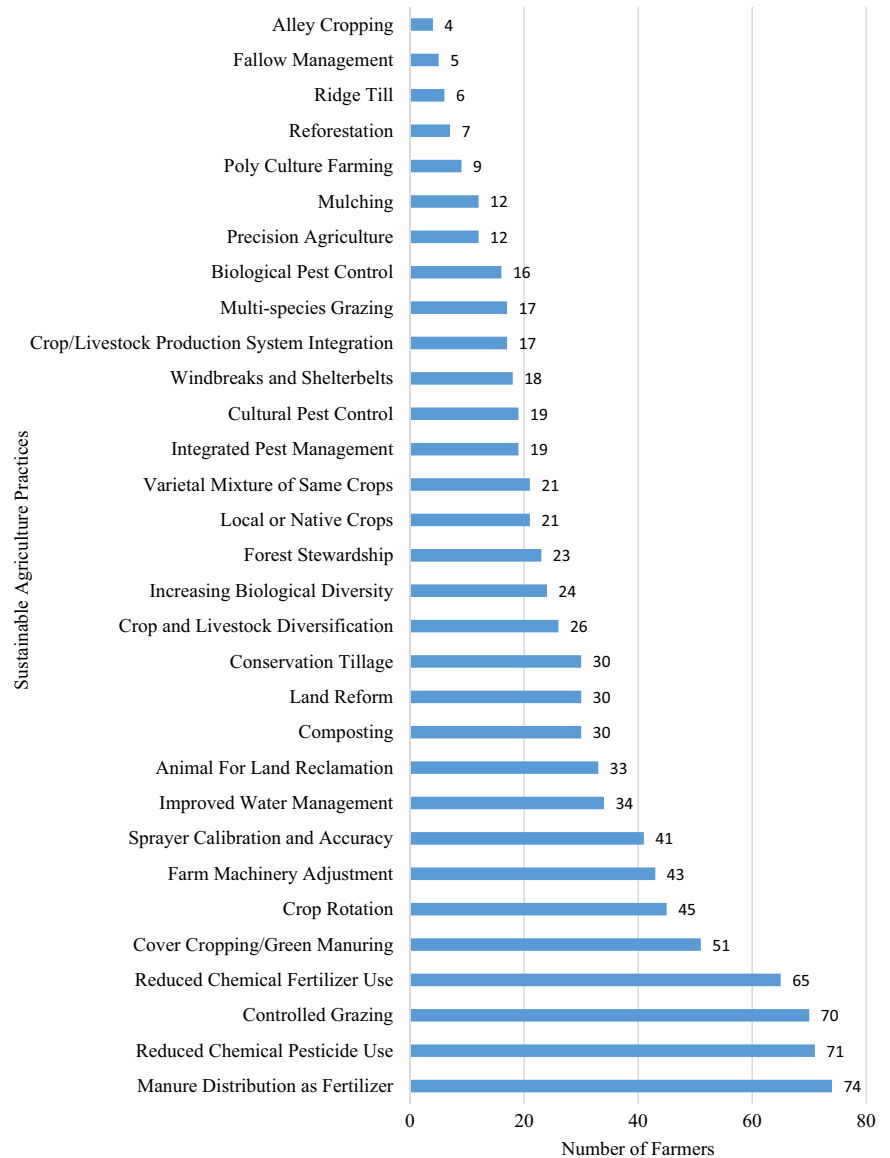
$$W_{ih} = rP_h / r_h$$

For each sample case in the post-stratum h , where r_h is the number of survey respondents in the post-stratum h , P_h is the population proportion from the US Census 2012, and r is the respondent sample size (Little 1993).

When the variable of interest is a count variable, which is our case with the total number of SAPs adopted by farmers, a count data model such as the Poisson regression model is used. In the Poisson distribution, mean and variance are assumed equal, which generally is not the case. When this mean-variance equality assumption is violated, it is called an over dispersion problem. In such cases, the Poisson regression parameters will be inefficient. We can estimate a negative binomial model that produces coefficients that are robust to distributional misspecification as long as the dispersion parameter is known, and the variance function is correctly specified.

The number of SAPs adopted by farmers is a function of several independent variables identified in Table 2. The

Fig. 2 Most commonly adopted sustainable agriculture practices among Kentucky farmers



model can be written as:

$$S(SAPs_i|X_i) = \lambda_i = \exp(b_o + b_1X_1 + b_2X_2 + \dots + b_nX_n)$$

where, *SAPs*, is the number of sustainable agricultural practices adopted by farmer *i*, *b_o* is the intercept of the regression model, *b₁*, *b₂*, ..., *b_n* are coefficients of respective predictors *X₁*, *X₂*, ..., *X_n* (Coxe et al. 2009). *λ_i* is the intensity of rate parameter.

Results and Discussion

We compare the mean and variance of the number of SAPs practiced by farmers and find that those are not equal. In addition, the likelihood ratio χ^2 -test is conducted to find if the dispersion parameter alpha is equal to zero. The test statistics

indicate that SAPs are overdispersed and are not sufficiently described by the Poisson distribution. Therefore, we estimate a negative binomial regression (NBR) model to understand the role of different influencing factors on the adoption intensity of SAPs by Kentucky farmers. The result of the NBR model Table 5 shows that variables *Crops*, *Veggies*, *Irrigation*, *Diverse*, and *College Degree* were positive statistically significant at a 1% level. Also, variable *TBP* was positive and significant at a 5% level. Variables *Implementation Difficulty* and *Inadequate Knowledge* were statistically significant at a 1% level, and *Age* was statistically significant at a 5% level, but all of these variables had negative signs in the model. Regional variables were statistically significant in the model at various significant levels. *AgDist_2* and *AgDist_4* were significant at a 1% level with

Table 4 List of variables and their descriptive statistics

Variables	Variable name	Mean	Variance
Dependent variable			
SAPs	Number of SAPs adopted by farmers	2.52	21.16
Independent variables			
Crops	Row crop farmers; yes = 1; otherwise = 0	0.54	0.15
Veggies	Vegetable growing farmers; yes = 1; otherwise = 0	0.16	0.02
Livestock	Livestock farmers; yes = 1; otherwise = 0	0.81	0.16
Irrigation	Irrigation facility in farm; yes = 1; otherwise = 0	0.04	0.04
Diverse	In favor of diversifying farm; yes = 1; otherwise = 0	0.42	0.24
Sole proprietorship	Farm with sole proprietorship; yes = 1, otherwise = 0	0.75	0.19
Off farm	Working off farm; yes = 1; otherwise = 0	0.49	0.25
Age	Age (years)	62.85	149.81
TBP	Participated; yes = 1; otherwise = 0	0.42	0.38
College degree	Formal education: college degree or above; yes = 1; otherwise = 0	0.20	0.16
Land	Total land operated (acres)	169.60	300804.59
Happy	Happy attitude (a reason for not adopting SAPs); yes = 1; otherwise = 0	0.43	0.25
Implementation difficulty	Perceived difficult of implementation of practices; yes = 1; otherwise = 0	0.05	0.05
Inadequate knowledge	A reason for not adopting SAP; yes = 1; otherwise = 0	0.15	0.13

positive signs, whereas *AgDist_3* and *AgDist_5* were significant at a 5% level and both have negative signs.

We interpret the regression results as incident rate ratios by exponentiating the regression coefficients (the last column in Table 3). When interpreting these coefficients, we hold all other variables, except the one we are interested-in in the model, constant. Therefore, all our interpretations of coefficients explained below should be understood that way. The variable *Crops* (farmers growing row crops) and *Veggies* (farmers growing vegetables) are a significant predictor of the adoption of SAPs in Kentucky. The results show that the incident rate for SAP adoption for farmers growing row crops were 2.294 times greater than the incident rate for the farmers without row crops. The incident rate for farmers growing vegetables was 1.511 times the incident rate for the farmers not growing vegetables. Several researchers have identified the importance of cover crops to improve soil health, reduce pest infestation, weed control, and reduce the use of chemicals (Lichtenberg 2004; Singer et al. 2007; Snapp et al. 2005; Teasdale 2013). In addition, the adoption of sustainable agriculture is a common practice among vegetable farmers. The use of approaches that can enhance vegetable production safely has been increasing with the increased interest of consumers in organic and healthy vegetables (Simmons 2008).

The variable called *availability of irrigation facility* had a positive and significant effect on the adoption of SAPs among Kentucky farmers. The incident rate for farmers with irrigation facilities on the farm (*Irrigation*) was 1.876

times the incident rate for farmers without irrigation facilities.

The incident rate for farmers in favor of farm diversification (*Diverse*) was 2.072 times than that of their counterparts. A significant predictor of the adoption of SAPs is whether farmers are in favor of diversifying their farms. Those farmers who were in favor of diversifying were also likely to adopt more SAPs compared with farmers who did not favor diversification. Farmers diversify their farms by adding high-value crops, short season crops, vegetables, or cover crops, which are helpful in weed control, reduce the use of chemicals, improve soil health and fertility, and ensure improved crop production (Lichtenberg 2004; Singer et al. 2007; Snapp et al. 2005; Teasdale 2013).

Also, the incident rate for farmers who participated in the Tobacco Buyout Program (*TBP*) were 1.286 times that of farmers who did not participate in the TBP. The US government has collectively spent billions of dollars in designing policies that shape agriculture and facilitate the conservation programs through different farm bills (Mullendore et al. 2015). These Farm Bill programs also transition farmers from tobacco to different crops that may have provided positive motivations for farmers who participated in the TBP program to adopt SAPs. Lichtenberg (2004) found that the adoption of several soils and water conservation practices are responsive to the USDA/NRCS cost-sharing program. The increase in the cost of the practice reduces the adoption of conservation practices among

Maryland farmers. Also, the interaction between different conservation practices may be less costly in reducing the share of the cost. It may increase the adoption of conservation practices. Several other researchers also have found that the adoption of management practices related to soil health was enhanced by the Farm Bill Conservation Program (Carlisle 2016; Coughenour 2003; Soule 2001).

Several studies about SAPs show that policy factors play an important role in the adoption process. A few policy-related studies have been done in relation to SAPs in Kentucky. Cuoghenour (2003) studied the innovation of no-tillage cropping practices. Zhong et al. (2016) studied farmers' participation in cost-share conservation programs in the Kentucky watershed. Also, Da Costa et al. (2012) studied the impact of the Agriculture Water Quality Act in the adoption of SAP and participation in conservation programs in Kentucky. Larkin et al. (2008) studied the use of small mammals in the coal-mining reclamation process in Kentucky.

We have included some policy-related factors, such as farmers' "happy" attitudes, implementation and knowledge barriers, TBP as policy-related variables that are identified as important in the adoption of SAPs through literature review and interaction with farmers.

The incident rate for farmers with formal education above the college degree (*College Degree*) was 2.097 times compared with farmers without a college degree. Kabii and Horwitz (2006) also found that the attitude of farmers plays a role in the adoption of conservation agriculture. Lashgarara (2011) found that the education, knowledge, and attitude of farmers are significantly correlated with the adoption of sustainable agriculture adoption. Baumgart-Getz et al. (2012) mentioned that attitude had a positive and significant influence on the adoption of agricultural best management practices. The chains of practices created following from the previous one (also called a "foot in the door" model) could lead to the complete transformation of farming systems (Wilson et al. 2014).

The percent change in the incident rate of SAPs' adoption is a decrease of 1% for every single year the farmer's age (*Age*) increases. Increasing farmer age had a negative impact on the adoption of SAPs among Kentucky farmers. This is consistent with several other studies. This could be because younger farmers have more positive attitudes toward sustainable practices compared with older farmers, who are relatively hesitant to change farm practices from traditional to SAPs (Baumgart-Getz et al. 2012). The incident for farmers who perceive that the technology is difficult to adopt (*Implementation Difficulty*) were 4.892 times less compared with farmers who do not perceive implementation difficulties associated with SAPs. The incident rate for farmers with an inadequate knowledge of technologies (*Inadequate Knowledge*) was 0.532 times less than

farmers who do not perceive that they have an inadequate knowledge to adopt SAPs. These incident rates suggest the need for extension activities, training, and education to improve the adoption of SAPs. Swinton et al. (2015) reported that owing to a perception of lower profitability farmers are unwilling to adopt new technologies.

Hall et al. (2009) identified implementation concerns and perceived risk of failure as two major barriers to the adoption of sustainable agriculture and recognized the importance of education and training to overcome these barriers. These barriers can be overcome through education, extension, and outreach activities (Baumgart-Getz et al. 2012; Kornegay et al. 2010). These findings validate the importance of education to reduce knowledge barriers, as well as the perceived difficulty of implementation among farmers. Carlisle (2016) also suggested that education in combination with other activities such as research and policies are essential to mitigate the adoption barriers related to soil health equipment adoption.

The incident rate of adopting SAPs for farmers living in Agriculture District 2 (*AgDist_2*) and Agriculture District 4 (*AgDist_4*) were 2.352 times and 1.76 times more, respectively, compared with the farmers living in Agriculture District 6 (*AgDist_6*), the reference group. However, farmers residing in Agriculture Districts 3 (*AgDist_3*) and 5 (*AgDist_5*) possess behavior that is the opposite compared with the above two districts. The incident rate for these farmers in agriculture districts 3 and 5 were 0.676 and 0.669 times, respectively, compared with the reference group (*AgDist_6*). The result clearly shows that the issue of sustainability in agriculture is highly localized. Thus, the solution also should be location specific. A blanket approach to solving the problems of agriculture sustainability may not be equally valid and equally adaptive in the same state or same country. Sustainable agriculture and SAPs are localized by nature and should be addressed locally. However, the solution should have a more significant impact on solving this global problem.

In contrast to the common trend of farmers moving toward sustainable farming (Kornegay et al. 2010), we found that farmers in agriculture districts 3 and 5 are more profit-oriented than environmentally friendly, whereas farmers from agriculture district 4 are more environmentally friendly. Agriculture districts 3 and 5 have two major cities—Lexington and Louisville—as well as several small and medium sized growing towns. Farmers from these regions might be motivated by the growing commodity market in this region. However, agriculture district 4 lies in between two major cities, Louisville and Cincinnati. As they are not part of major cities but are located in between them, environmental pollution coming from these surrounding cities might be a big concern to farmers in agriculture district 4.

Research conducted among New Zealand dairy farmers to understand the adoption of the best management practices suggests that farmers close to each other make similar choices owing to the potential for frequent interactions (Yang and Sharp 2017). The results of the current research are partially supportive of the previous studies. Specifically, results from agriculture districts 3 and 5 are consistent with the earlier findings, as they are neighboring districts and have a similar result in the model. However, the results from agriculture districts 2 and 4 contradict previous findings. Agriculture district 2 is primarily farmland with some coal mining areas. This region is also well known for large-size farm operations. A positive relationship with the adoption of SAPs in this region can be linked to the awareness among farmers of the negative impact of coal and coal-mining sites on the environment and agricultural commodities. Also, as large enterprise and agriculture have occupied this region and have been major parts of the economy for a long time, farmers in that region might have developed an awareness about the importance and role of SAPs for long-term sustainable agriculture enterprise.

This research included practices that are commonly adopted by Kentucky farmers. Some of them were previously researched and some of them are newly identified through the discussion and workshops. Not all practices included in this research are equally important for environment management (Lashgarara 2011), nor are uniformly adopted by farmers. However, this research identified new practices throughout the state that had not been studied before. In this context, this research played an important role in understanding the role of influencing factors in sustainable agricultural practice adoption intensity in Kentucky.

Conclusions

This study explored factors influencing the intensity of the adoption of SAPs among Kentucky farmers using negative binomial regression. Fourteen variables representing socioeconomics, demographics, farm attributes, attitudes, knowledge, and behavior were used in the analysis. Agriculture districts were also included in the model to account for the regional characteristics of SAPs. The text box summarizes the major findings of the research.

Adoption intensity of SAPs among Kentucky farmers has a positive and significant relationship with crop and vegetable growers with irrigation facilities, farmers in favor of diversification, farmers participating in the tobacco buyout program, farmers with a formal college degree or above education level, but has a negative and

Table (continued)

significant relationship with the age of farmers. Lack of knowledge and the perceived difficulty of implementation are two major and significant barriers to the adoption of SAPs. Last but not the least, the adoption of SAPs is localized very specifically: agriculture districts 2 and 4 have a positive and significant relationship with SAP adoption, but agriculture districts 3 and 5 are significant but negative.

This research provided important insights and corroborated some previous findings as well. The research into SAPs in Kentucky was itself limited in several ways: only a little research has been conducted so far in Kentucky to understand the adoption of SAPs; the research was limited to a small locality taking into account only a few practices that were mostly prioritized by governmental and non-governmental policies. The behavior and attitudes about SAP adoption throughout the state were not known. Also, the research surveyed farmers from all over the state and identified SAPs that were commonly adopted throughout the state through discussion and survey. More importantly, this research explored how farmers from different agricultural regions behave toward the adoption of SAPs. This result, on one hand, further verified previous findings that SAPs are localized in nature, and also gave a direction for policymakers to consider design policies when approaching farmers in the different agricultural district based on their interest in the Adoption of SAPs. For instance, it is easier for policymakers and extension workers to expand the SAPs in agriculture districts 2 and 4 compared to agriculture districts 3 and 5, as the former two are positive toward the adoption of SAPs, whereas later two are negative.

Policy-wise, this research has provided some insights for policymakers and extension practitioners. The positive relationship of crop and vegetable growers with irrigation facilities but not significant relationship with livestock farmers shows that crop and vegetable farmers should be approached to expand the adoption of SAPs. This research found that the farm diversification approach could be implemented to reduce the crop risk while introducing and expanding the adoption of SAPs. According to this research, educated and young farmers should be the major focus for expanding adoption. Also, education and extension activities play a vital role in the expansion of the adoption of technologies as knowledge and perception are major barriers among Kentucky farmers. However, the localized nature of adoption behavior and intensity of SAPs and the varied attitude toward the adoption of SAPs according to different agriculture district shows that the extension and education program also should be localized

Table 5 Parameter estimates obtained from a negative binomial regression model of factors affecting adoption of sustainable agriculture practices among kentucky farmers ($N = 205$)

Variables	Estimates (b)	SE	Exp (b)
Constant	0.024	0.423	1.024
Crops	0.830***	0.121	2.294
Veggies	0.413***	0.136	1.511
Livestock	0.228	0.143	1.257
Irrigation	0.629***	0.171	1.876
Diverse	0.728***	0.100	2.072
Sole proprietorship	-0.084	0.116	0.920
Off farm	0.063	0.120	1.065
Age (years)	-0.010**	0.005	0.990
TBP	0.251**	0.105	1.286
College degree	0.740***	0.136	2.097
Land	0.000	0.000	1.000
Happy	0.004	0.102	1.004
Implementation difficulty	-1.588***	0.180	4.892
Inadequate knowledge	-0.631***	0.158	0.532
AgDist_1	0.225	0.194	1.253
AgDist_2	0.855***	0.163	2.352
AgDist_3	-0.392**	0.161	0.676
AgDist_4	0.565***	0.159	1.760
AgDist_5	-0.402**	0.166	0.669

*** & ** = Statistically significant at 1 and 5% levels, respectively. SE is standard error

and should be designed based on the needs and attitudes of farmers.

There are some limitations of this study as well. To find the causal effects of some of the variables in the model, we need a more sophisticated econometric model. Adoptions patterns of some of the major SAPs identified by this study and the impacting factors for those adoptions can be further studied in future. In addition, efforts should be made to collect relevant data on risk, policy variables, cost-share payment, and other important socioeconomic factors to establish more robust conclusions on the causality of these variables in determining the adoption or adoption intensity of SAPs in Kentucky or elsewhere.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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