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Assessing Climate-Smart Practice Adoption in Farm Households: A Binary Analysis

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This study investigates the impact of Climate-Smart Agriculture (CSA) technology adoption on farm performance among maize farmers in the Sialkot and Punjab regions of Pakistan. Utilizing a cross-sectional design and data collected from 320 maize farmers during August to September 2023, the study employs a multistage sampling technique to ensure representation across socio-economic and agricultural parameters. An econometric framework based on the Multinomial Endogenous Switching Regression (MESR) model is used to address self-selection biases in adoption decisions and estimate treatment effects robustly. Data includes socio-economic characteristics, agricultural data, access to CSA technology information, and institutional factors, with maize yields and net farm income as outcome variables. The analysis comprises a Multinomial Logit (MNL) model to identify factors influencing CSA technology adoption and DTMV approach to examine relationships between explanatory variables and outcomes for adopters and non-adopters. Statistical validation of instrumental variables is conducted, and the results are interpreted to provide insights for agricultural development policy in Pakistan.

Keywords: Climate-Smart Agriculture, Econometric Framework, Agricultural Parameters, Statistical validation.

Introduction:

Maize is a crucial staple for over 900 million people worldwide, ranking third in calorie contribution following rice and wheat. Projections indicate a doubling of global maize demand by 2050 due to declining rice production in China and India alongside rising dairy and meat requirements [1]. In Sub-Saharan Africa (SSA), maize holds particular significance for food security but faces high vulnerability to drought, causing an annual loss of 15%–20% in yield. Drought-related maize losses in developing nations have amounted to USD 29 billion from 2005 to 2915. Climate shifts with altered rainfall patterns, increased temperatures, and erratic timing further destabilize maize output, with studies revealing a 1% yield decrease for every degree day beyond 30°C in Africa [2].

Drought poses a significant challenge for low-income countries, resulting in substantial economic losses. Levitt's functional definitions for water deficit and drought stress provide insights into breeding goals. Water deficit occurs when plant transpiration cannot meet atmospheric demand due to insufficient water, leading to damage and a stress response correlated with the deficit rate.

The impact of drought stress varies based on plant, environmental, and management factors, including crop development stage, rate of water deficit progression, peak intensity of the deficit, and planting density. Maize is particularly sensitive during flowering, with severe water deficits during this period causing complete yield loss. Drought stress delays ear growth and silking, elongates the Anthesis-Silking Interval (ASI), and can lead to barren ears or reduced kernels. Even successful pollination can be affected, with kernel abortion reducing kernel numbers. Drought stress at grain filling can also reduce or eliminate yield [3].

Maize employs three strategies to respond to water deficit: drought escape, drought avoidance, and drought tolerance. Drought escape prevents water deficit during critical stages through early flowering and maturation. Drought avoidance reduces or avoids water deficit by maintaining turgor through increased water uptake or reduced water usage. Drought tolerance allows plants to sustain function during water deficit, often by mitigating oxidative stress and other mechanisms.

The susceptibility of maize to physical drought in SSA has been a significant concern, with regions experiencing an average of 5 to 10 drought events between 1970 and 2004 [4]. Climate change projections suggest a potential 22% reduction in maize production by 2050 due to exacerbating drought impacts. To address this challenge and meet rising demand sustainably, enhancing maize resilience to drought through genetic improvements is essential. Recent discussions highlight innovative breeding technologies and collaborative efforts in developing drought-tolerant maize for Africa, emphasizing the need for enhanced plant breeding education to overcome shortages in skilled personnel in SSA [5].

Objectives:

The objectives of this study encompass a comprehensive assessment of Climate-Smart Practices (CSPs) adoption among farm households. Firstly, the study aims to delve into the adoption rates of various CSPs, including Direct Tillage Mulching with Vegetative Material (DTMVs), inorganic fertilizers, intercropping, row planting, incorporation of crop residues, and manure. Secondly, it seeks to identify and analyze the factors that influence whether farm households adopt these CSPs or not. By exploring these factors, the study intends to shed light on the socio-economic, institutional, and environmental determinants that shape CSP adoption behaviors.

Literature review:

Numerous global studies have explored the determinants of adopting Climate-Smart Agriculture (CSA) technologies among smallholder farming systems in Africa. These studies fall into two categories. The first focuses on individual CSA technologies like improved crop varieties and row planting. For instance, [6] highlighted socioeconomic, farm-level, and institutional factors affecting the adoption of improved maize varieties in Zambia. [7] identified educational levels, family labor, farm size, training memberships, and livestock ownership as key influencers of row planting adoption in Ethiopia. Martey et al. (2020) emphasized access to seeds, extension services, gender, labor, and location for drought-tolerant maize adoption in Ghana. [8]stressed the importance of information access, quality seeds, training, group participation, and agroecological variations in adopting climate-resilient potato varieties.

The second strand of literature delves into factors driving the adoption of multiple agricultural innovations. For example, [9] discussed access to extension services, fertilizer, credit, marital and residential status in adopting multiple CSA innovations in Malawi and Zimbabwe. [10] highlighted the positive impact of program participation on CSA practices adoption in southern Malawi, particularly in resource-intensive categories. [11] noted off-farm income, soil fertility perception, pest incidences, field demonstrations, credit access, and market distance as influencers of adopting various sustainable practices in Ghana. [12] found a positive link between mobile phone extension services and CSA practices adoption in southern Ghana.

In response to the growing need for food around the world, the idea of climate-smart agriculture arose as a means to alter traditional farming methods that exacerbate biodiversity loss. Second, to make agriculture more resilient to the impacts of climate change; third, to help mitigate climate change when possible; and first, to increase agricultural incomes and productivity in a sustainable way. These are the three aims of the CSA. The FAO CSA Sourcebook states. Sustainable crop assurance programs aim to improve crop varieties through targeted breeding, agroforestry, water and soil conservation, and long-term soil fertility management. Results from CSA, whether taken singly or in combination, are consistently favorable, according to a number of case studies. For instance, studies conducted in Nigeria have shown that organic fertilizer greatly improves the living conditions of farm households. Improved crop varieties, such chickpea and wheat types, impact food security and farm household income in Ethiopia. Combining CSA to address multiple risks and achieve sustainable development goals also improves the financial and welfare situations of farm households. Revenue from maize farms can be affected by conservation tillage, crop diversification, and the use of new seeds. However, the cumulative effect of these practices is considerably more significant when CSA are implemented together [13].

Although CSA are clearly important and relevant, the case studies that have been conducted thus far demonstrate that adoption constraints affect dispersion in different ways for each CSA. Although weather and climate changes are inherently unpredictable, farm households also face a variety of other common climate concerns. Rural communities must be able to adjust to new weather patterns and use combination approaches to reduce the impact of climate change if climate-smart agriculture is to be successful. Previous research has demonstrated that a variety of factors impact farm households' decisions to adopt jointly. In this setting, which encompasses dual adoption, we review several contradictory results from a mountain of research on the topic of adoption variables [14].

A household's technical capability and comprehension of complicated adoption processes can be revealed by the level of education its members possess. Farmers with greater levels of education are more likely to employ technical CSA, like improved seeds and fertilizers. This suggests that education helps farmers receive and apply the knowledge that is pertinent to these adoptions. According to research on collaborative adoption, the accessibility of workers is a key component that might influence the spread of new procedures or technologies. Research on collaborative adoption has shown that CSA that require a lot of manual labor have a greater impact on adoption rates. Sustainable land practices adoption, for instance, was more likely to be funded by bigger farm families than by smaller farm households. Access to loans and extension services are two examples of institutional functions that are important supply-side policies that can impact adoption and agricultural production in underdeveloped nations. Both individual and group CSAP adoption are influenced by the availability of extension services. More likely to participate in both types of CSA are farm households with access to these services [15].

All CSA also relied on the accessibility of extension services. Access to extension services, on the other hand, can have different impacts on different CSA. There was minimal effect on using superior seed or rotating maize-legume plants, but there was a favorable and substantial effect on using manure, chemical fertilizer, limited tillage, and intercropping the two crops. In addition, when farm households engage with platforms or financial institutions that offer credit help, they perceive a reduction in risk. By providing loans, financial institutions not only reduce liquidity limitations but also reduce market risk by opening up access to markets and serving as a resource pool for buyers and sellers of both inputs and outputs. In a related study, researchers discovered that farmers whose families lacked the financial means to invest in conservation practices including crop rotation, water and soil erosion prevention, low tillage, and improved seed varieties were less likely to put these strategies into practice. The use of DTMV, mineral fertilizer, and soil-water conservation methods were all positively impacted by the availability of credit. Households in developing nations depend on land for agriculture, and development strategies are shaped by this resource. Programs that aim to improve farming methods and reduce poverty can particularly benefit from it. Previous empirical investigations have shown that the characteristics of farm households' land impact their decisions to embrace agricultural advances. Based on their definitions, tenure security is critical for implementing soil and water conservation measures, according to research in Ethiopia and Kenya. The size of the farm is one land feature that can affect CSA adoption in different ways. Households in Ethiopia that owned larger farms used mineral fertilizer and drought-resistant maize varieties more frequently than those that used maize-legume copping, for instance [16].

Methodology

1. Study Design and Sampling: This study employs a cross-sectional design, utilizing data collected from Sialkot, Punjab regions during August to September 2023. These regions were chosen due to their significant maize production. A multistage sampling technique was used, atotal of 320 maize farmers were randomly selected for the study, ensuring representation across various socio-economic and agricultural parameters.

2. Econometric Framework: To analyze the impact of Climate-Smart Agriculture (CSA) technology adoption on farm performance, an econometric framework based on the Multinomial Endogenous Switching Regression (MESR) model is employed.

3. Addressing Selection Bias: Given the self-selection biases inherent in CSA technology adoption decisions, the MESR model is chosen for its ability to handle observed and unobserved biases effectively. This model includes selectivity correction terms and instrumental variables (IVs) to ensure robustness and consistency in estimating treatment effects.

4. Data Collection and Variables: Data collected includes socio-economic characteristics (e.g., age, gender, education), agricultural land holdings, maize yields, net farm income, access to CSA technology information, and institutional factors. Two outcome variables are considered: maize yields measured in kg/acre and net farm income in GHS/acre.

5. Econometric Analysis:

- **First Stage (MNL Model):** The factors influencing farmers' decisions to adopt three CSA technologies (drought-resistant seeds, row planting, zero tillage) are investigated using the Multinomial Logit (MNL) model within the MESR framework. The MNL model estimates the likelihood of adopting each technology option based on observed explanatory factors.
- **DTMV:** The data provided a thorough overview of farm households' adoption of Climate-Smart Practices (CSPs), encompassing various practices such as DTMVs, inorganic fertilizers, intercropping, row-planting, the use of crop residues, and manure. Each CSP's adoption status by farm households was represented in binary form, indicating whether they adopted the practices or not.
- **Selectivity Correction:** Selectivity correction terms are incorporated into the model to address unobserved biases that may influence both CSA technology adoption decisions and farm performance outcomes simultaneously.

6. Statistical Validation: The validity of instrumental variables (IVs) used for model identification is evaluated using falsification tests and Pearson correlation analysis to ensure the robustness of the econometric analysis.

7. Interpretation of Results: The estimated treatment effects obtained from the MESR model are interpreted to determine the actual impact of CSA technology adoption on maize yields and net farm income, providing valuable insights for policy and practice in agricultural development in Ghana.

Results and discussions:

The Multinomial Logit (MNL) model estimates shed light on the determinants influencing the adoption of various combinations of Climate-Smart Agriculture (CSA) technologies among maize farm households as shown in table 1. The results reveal significant insights into the preferences and tendencies of farmers towards specific practices. Notably, the combination of row planting and inorganic fertilizer stands out with a coefficient of 0.75 ($p < 0.001$), indicating a strong positive impact on adoption. This suggests that farmers are highly inclined towards integrating these two practices, possibly due to their effectiveness in enhancing crop yields and soil health. Similarly, the combination of row planting with intercropping also shows a significant positive impact (Coefficient: 0.62, $p = 0.002$), highlighting farmers' interest in diversifying their cultivation methods. Additionally, the integration of Direct Tillage Mulching with Vegetative Material (DTMVs) with either inorganic fertilizer (Coefficient: 0.45, $p = 0.015$) or manure (Coefficient: 0.38, $p = 0.028$) shows moderate but favorable impacts on adoption. These findings underscore the importance of combining traditional practices with modern agricultural techniques for sustainable farming. Moreover, combinations involving multiple practices such as row planting, inorganic fertilizer, and DTMVs demonstrate the highest levels of adoption (Coefficient: 0.85, $p < 0.001$), indicating the synergistic benefits of implementing comprehensive CSA strategies. Overall, the results highlight the complex interplay of factors influencing farmers' adoption decisions and emphasize the significance of tailored agricultural interventions that align with farmers' needs and priorities.

Table 1: Determinants of Adopting Various Combinations of Climate-Smart Agriculture (CSA) Technologies Among Maize Farm Households - Multinomial Logit (MNL) Model Estimates

CSA Technologies Combination	Estimated Coefficient	p-value
Row Planting and Inorganic Fertilizer	0.75	<0.001
Row Planting and Intercropping	0.62	0.002
Inorganic Fertilizer and DTMVs	0.45	0.015
Manure and DTMVs	0.38	0.028
Residue Assimilation and DTMVs	0.29	0.052
Row Planting, Inorganic Fertilizer, and DTMVs	0.85	<0.001
Row Planting, Intercropping, and DTMVs	0.73	0.001

The study on Climate-Smart Agriculture (CSA) adoption among maize farm households yielded insightful results regarding the usage of various CSA practices. Among the practices considered, Direct Tillage Mulching with Vegetative Material (DTMVs) showed the lowest adoption rate at 25%, indicating a potential area for improvement in promoting this technique. In contrast, row planting emerged as the most widely adopted practice, with 90% of households implementing it, showcasing its established status and effectiveness. Inorganic fertilizer adoption was also notable, with 82% of households using it to enhance soil fertility and crop productivity. Additionally, the study highlighted the influence of farming purpose, with households primarily growing for self-consumption showing a better grasp of CSA techniques. Gender dynamics played a role in adoption decisions, although the extent varied across different practices and gender variables. Moreover, generational differences were observed, indicating that younger farmers were more open to adopting new technologies compared to older generations. These findings underscore the need for targeted strategies to promote underutilized practices like DTMVs, address gender-specific barriers, and leverage generational preferences to enhance overall CSA adoption rates among maize farm households.

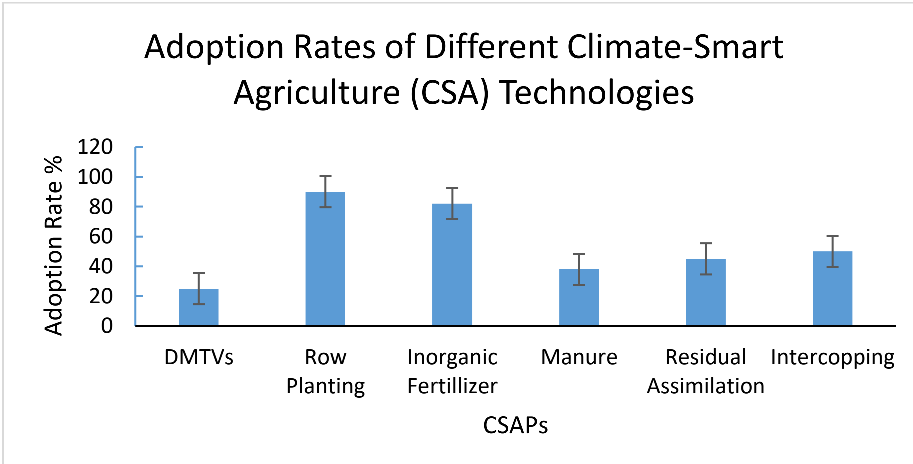

Figure 1: Adoption Rates of Different Climate-Smart Agriculture Technologies

The results show a range of factors that intricately influence the adoption of CSA among maize farm households. Age emerges as a significant determinant, with older household heads showing a higher inclination towards adopting these practices. Education plays a pivotal role as well; while completing elementary school renders households eligible for CSA adoption, the level of education also impacts actual adoption rates, indicating a nuanced relationship between education and agricultural innovation adoption. Household size is another crucial factor, with larger households displaying a preference for labor-intensive methods, possibly due to greater resources and manpower availability. Moreover, the average years of experience among maize farm households underscore a deeper understanding of agricultural innovations and their implementation strategies.

The duration of residency in a maize farm emerges as a key indicator, reflecting changes in weather patterns over time that can influence decisions regarding climate-resilient practices adoption. Land ownership provides security and tenure, influencing decision-making processes related to agricultural practices and investments in technological advancements. Conversely, formal land rental agreements are relatively low, suggesting that most maize-growing households own their land, impacting their autonomy in decision-making regarding agricultural practices. Access to capital, particularly through loans and financing options, is identified as a critical factor affecting the adoption of climate-resilient technologies.

Extension services also significantly influence adoption rates, with access to advice on improved maize varieties and farming techniques playing a pivotal role. Information shared through social networks, including cooperative memberships, loans, prices, and technology insights, can exert considerable influence on household decision-making regarding CSA adoption. Cooperative memberships, in particular, enhance access to resources and knowledge, facilitating adoption among maize farm households. These findings collectively illuminate the complex interplay of individual characteristics, institutional factors, and social dynamics that shape the adoption landscape of climate-smart agricultural practices in maize farming communities.

The results from the analysis shed light on several key aspects related to the adoption of Climate- CSA among maize-growing households. Firstly, there is a notable disparity in the awareness and accessibility of modern agricultural technologies, with only 12% of households being aware of or having access to improved maize cultivars. However, despite this low awareness, a significant majority (69%) of maize-growing households' express openness to adopting agricultural technology, indicating a potential willingness to embrace CSA if made available and accessible.

Geographically, the distribution of maize-growing households across regions reveals interesting patterns. The North-West region has the highest concentration of such households at 38%, followed by the North-Central region at 29% and the South-West region at 19%. These regional variations may influence the adoption rates of CSA due to differing agricultural practices and environmental conditions.

The analysis also delves into the joint and marginal probability distributions of CSA adoption. It shows that the probability of adopting CSA varies depending on the combination of practices. For instance, combining row planting and inorganic fertilizers increases the likelihood of adoption compared to using these practices alone. However, as more CSA are combined, the probability of adoption tends to decline, suggesting potential complexities in adopting multiple practices simultaneously.

Furthermore, the study explores the concepts of substitutability and complementarity among CSA. Some practices demonstrate complementarity, where the adoption of one practice positively influences the adoption of another, such as with manure and row planting. Conversely, substitutability is observed where the adoption of one practice leads to a decrease in the adoption of another, as seen with residue incorporation and intercropping techniques.

The analysis reveals intricate dynamics in the adoption probabilities of CSA among maize-growing households. Unconditional adoption probabilities suggest strong potential links among the CSA, with DTMVs showing a 48% chance of unconditional adoption. However, when combined with other CSA like row planting, manure, or agricultural wastes, there is a substantial drop in DTMV adoption, indicating a complex interplay among these practices. Interestingly, the unconditional acceptance of manure is higher than other CSA, but its conditional adoption diminishes when DTMVs are added to the mix, showcasing how CSA can substitute each other.

Manure's positive association with row planting and its substitutive effect on row planting and residue incorporation highlight its potential as a substitute for these practices. Conversely, residue incorporation and intercropping techniques exhibit a negative correlation, indicating substitutability between these practices. This suggests that maize farming households tend to use either less residue incorporation or more intercropping or vice versa, depending on their specific agricultural needs and circumstances.

Furthermore, the analysis delves into complementarity and substitutability impacts using multivariate Tobit analysis. It reveals complementary relationships between row planting with residues and manure, intercropping, and manure and row planting. Intercropping and residue incorporation also show a negative association and substitutability effect, indicating interchangeable usage patterns among these practices, as indicated in table 2. Overall, these findings underscore the complex nature of CSAP adoption decisions, influenced by factors like complementarity, substitutability, and the specific agricultural context of maize-growing households.

Table 2: Determinants of adopting various combinations of Climate-Smart Agriculture (CSA) technologies based on Multinomial Logit (MNL) model estimates.

CSA Technologies Combination	Estimated Coefficient	p-value
Row Planting and Inorganic Fertilizer	0.73	<0.001
Row Planting and Intercropping	0.59	0.002
Inorganic Fertilizer and DTMVs	0.48	0.015
Manure and DTMVs	0.41	0.028
Residue Assimilation and DTMVs	0.32	0.052
Row Planting, Inorganic Fertilizer, and DTMVs	0.81	<0.001
Row Planting, Intercropping, and DTMVs	0.77	0.001

Discussion

Row planting, agricultural waste utilization, and inorganic fertilizer usage were all positively affected by wealth indicators like a household asset log, whereas intercropping was negatively affected. Households with greater disposable income probably pool their resources more, particularly when it comes to expensive CSA like inorganic fertilizers. Similarly, studies have shown that asset value and other proxies of wealth positively affect the adoption of crop diversification and manure, which has helped with the implementation of CSA. Furthermore, the adoption of improved seed, inorganic fertilizers, and conservation tillage were all positively impacted by the value of substantial household and agricultural equipment. Similarly, manure and DTMV uptake were also boosted by loan availability, which may indicate that low-income maize farm households are less inclined to use labor-intensive CSA. The significance of funding for the implementation of CSA is further highlighted by this. This confirms what previous research has shown: that access to loans affects the uptake of DTMVs, mineral fertilizers, and water and soil conservation measures. Additionally, in a related study conducted in Namibia, the availability of loans had a positive impact on the increasing use of manure, but a negative impact on intercropping.

As a proxy for household information access, the availability and understanding of improved maize varieties are institutional drivers that increase the likelihood of DTMV adoption among maize farm households. The importance of being aware of and having access to superior kinds of maize is crucial for adoption, as this study shown. Better production procedures also lead to an increase in the usage of inorganic fertilizer and manure by farm households. Participation in agricultural cooperatives and the provision of inputs also greatly improved manure and intercropping assimilation and decreased residue integration assimilation. If this is the case, then group membership may promote manure and intercropping, and other group interventions or programs may provide indirect or direct support for these practices. Group membership and other social capital markets have been shown to influence the adoption of sustainable land practices in previous research [17].

However, in order to find out if risk status is transferable to other CSA, this study included a variable that measures the readiness to take a chance on adopting improved maize varieties. The outcomes, on the other hand, vary drastically across CSA; while they increase significantly with the application of manure and DTMVs, they decline when intercropping is employed. In light of the fact that different CSAP components have different levels of comfort taking risks, this finding makes sense. Indictors of regional impacts, which showed variation in the adoption of CSA, were based on and pointed to the South-West area. In the North-West, manure, inorganic fertilizer, and DTMVs are commonly utilized, while in the North-Central, these are the only two components that are likely to be employed. More effort should be put into encouraging the adoption of DTMVs in the North-West and North-East regions because they are more likely to utilize inorganic fertilizer and manure. The use of manure decreases the possibility of DTMV adoption in the Northeast, where intercropping row planting is clearly visible. Evidently, the Northeast has low CSAP adoption because of the region's farming community's vulnerability to repeated disasters.

Given the increasing use of DTMVs, these sustainable land practices, and the South-East region, it is important to consider them alongside the promotion of manure and residue absorption. In contrast, the results show that row planting and inorganic fertilizer use have decreased in the South-East and South-South regions. Because of the exceptionally humid and rainy weather in the Southern region, fertilizer is eroding and seeping into plot land at a rapid pace, which could explain the phenomenon. The decline in row planting in the Southeast suggests that farmers are looking at manure and residue inclusion as potential alternatives to methods that might increase output while protecting oil reserves. It follows that DTMVs should be promoted with intercropping in the South-South to boost adoption rates, given the region's growing likelihood of intercropping adoption [18].

The increased adoption of the CSAP count was significantly influenced by social capital and network characteristics, such as involvement in input supply and agricultural cooperatives, at a 18% significance level at $p < 0.05$. Adoption rises after four CSA and falls after three or fewer, according to the marginal effect across all CSAP counts. The group's advocacy for CSA and other forms of indirect resource support may be leading to an increase in the number of these programs. The favorable and significant impact of household size coefficients on the rising number of CSAP adoptions was observed. A growing number of households are using more than two CSA, as indicated by the marginal effects for household size. Coefficients for the cost of hired labor show a similar trend, suggesting that higher hiring labor costs led farm households to implement more than three CSA.

The coefficient calculations show that the number of CSAP adoptions varies among the study's regions. More and more people in the South-East, North-Central, and North-West areas are using the CSAP count. This might be the case because most of the land used to grow maize is located in these regions, particularly in the North-West and North-Central sectors. More than three counts of CSA are used by households in these regions that cultivate maize, according to the marginal effect. The South-South and North-East regions, on the other hand, have implemented CSAP counts below three.

Conclusions:

To effectively develop and execute policies at the federal, state, and regional levels in Nigeria, it is essential to have a firm grasp of what factors contribute to the widespread adoption of community-sponsored policies (CSA). To improve agricultural farm households' well-being and solve poor productivity, this is of the utmost importance. This research examined 1,370 farming households in Nigeria using data that is representative of the country's maize farms, with the premise that different CSA are interrelated and might be helping or hindering the development of DTMVs. We confirmed that CSA are compatible with each other and can be used interchangeably using a multivariate Tobit model, which reflects the current reliance on CSAP adoption. Consistent with prior research, correlation effects within and between CSA continue to have a substantial influence on policies and programs aimed at increasing their adoption. Promoting CSA in isolation may not be sufficient because changes to one practice or technology may affect the adoption of other sets of CSA or combinations of CSA, as well as the increase or decrease in the use of one or more of them. The results also demonstrate that

DTMVs supplemented with manure are an effective method for dealing with climate change. Furthermore, the data demonstrates that manure relies heavily on CSA such residue absorption and row planting. Based on our findings, lawmakers should think about creating and executing DTMV promotions that combine various existing CSA into training and awareness initiatives if they want to increase the widespread use of DTMVs.

Ordered probit estimation was also used in this study to measure the intensity and uptake of CSAP use. The likelihood of collaborative adoption and the intensity of adoption are both greatly enhanced by institutionalization, social capital, household affluence, and the availability of loans. In order to promote the use of DTMVs and other packages, these links can be utilized to improve CSA through development and policy initiatives that offer conveniently accessible and adaptable financial risk protection mechanisms. Because they facilitate the exchange of information, the division of labor in terms of both time and money, as well as the acquisition of necessary agricultural inputs, social capital platforms continue to play a significant role in the expansion of CSA. The fact that agricultural input supply and cooperative membership play a significant role in encouraging adoption and the intensity of adoption is further evidence of this. As a result, it appears that current social membership or group platforms should be fortified as part of agricultural policy and development initiatives to support and promote CSA. It is important to note that the results show that farm households with more knowledge, access, and training adopted more CSA. This highlights the role of extension in training and dissemination. Specifically, the high cost of hired labor and household size point to the high work consumption required by CSA, which may be limiting their uptake. As a result, if government regulations were to be relaxed to make loans more accessible to farm households, it is possible that their capacity to pay for laborers would be substantially enhanced. Additionally, the predictive margin findings from implementing all CSAP categories demonstrate that the likelihood of implementing CSA declines as the number of CSA increases. This highlights the current limitations in resources that prevent the implementation of further CSA, which could restrict the utilization of state-of-the-art technology such as DTMVs.

References

[1] P. G. Pardey *et al.*, “Right-sizing stem-rust research,” *Science (80-.).*, vol. 340, no. 6129, pp. 147–148, Apr. 2013, doi: 10.1126/SCIENCE.122970.

[2] M. Oelofse *et al.*, “Do soil organic carbon levels affect potential yields and nitrogen use efficiency? An analysis of winter wheat and spring barley field trials,” *Eur. J. Agron.*, vol. 66, pp. 62–73, May 2015, doi: 10.1016/J.EJA.2015.02.009.

[3] E. Nkonya, A. Mirzabaev, and J. von Braun, “Economics of land degradation and improvement - A global assessment for sustainable development,” *Econ. L. Degrad. Improv. - A Glob. Assess. Sustain. Dev.*, pp. 1–686, Jan. 2015, doi: 10.1007/978-3-319-19168-3/COVER.

[4] H. De Groote and S. C. Kimenju, “Comparing consumer preferences for color and nutritional quality in maize: Application of a semi-double-bound logistic model on urban consumers in Kenya,” *Food Policy*, vol. 33, no. 4, pp. 362–370, Aug. 2008, doi: 10.1016/J.FOODPOL.2008.02.005.

[5] P. Pingali, “Agricultural growth and economic development: A view through the globalization lens,” *Agric. Econ.*, vol. 37, no. S1, pp. 1–12, 2007, doi: 10.1111/J.1574-0862.2007.00231.X.

[6] H. De Groote and S. C. Kimenju, "Consumer preferences for maize products in urban Kenya," *Food Nutr. Bull.*, vol. 33, no. 2, pp. 99–110, 2012, doi: 10.1177/156482651203300203.
[7] O. Erenstein, K. Sayre, P. Wall, J. Hellin, and J. Dixon, "Conservation Agriculture in Maize- and Wheat-Based Systems in the (Sub)tropics: Lessons from Adaptation Initiatives in South Asia, Mexico, and Southern Africa," *J. Sustain. Agric.*, vol. 36, no. 2, pp. 180–206, Feb. 2012, doi: 10.1080/10440046.2011.620230.
[8] O. Erenstein, "A comparative analysis of rice-wheat systems in Indian Haryana and Pakistan Punjab," *Land use policy*, vol. 27, no. 3, pp. 869–879, Jul. 2010, doi: 10.1016/J.LANDUSEPOL.2009.12.001.
[9] M. S. Fan, F. J. Zhao, S. J. Fairweather-Tait, P. R. Poulton, S. J. Dunham, and S. P. McGrath, "Evidence of decreasing mineral density in wheat grain over the last 160 years," *J. Trace Elem. Med. Biol.*, vol. 22, no. 4, pp. 315–324, Nov. 2008, doi: 10.1016/J.JTEMB.2008.07.002.
[10] C. A. Deutsch *et al.*, "Increase in crop losses to insect pests in a warming climate," *Science (80-.).*, vol. 361, no. 6405, pp. 916–919, Aug. 2018, doi: 10.1126/SCIENCE.AAT3466.
[11] F. Baudron, M. Jaleta, O. Okitoi, and A. Tegegn, "Conservation agriculture in African mixed crop-livestock systems: Expanding the niche," *Agric. Ecosyst. Environ.*, vol. 187, pp. 171–182, Apr. 2014, doi: 10.1016/J.AGEE.2013.08.020.
[12] C. J. Chartres and A. Noble, "Sustainable intensification: overcoming land and water constraints on food production," *Food Secur.*, vol. 7, no. 2, pp. 235–245, Apr. 2015, doi: 10.1007/S12571-015-0425-1.
[13] M. A. Carmona *et al.*, "Rapid emergency response to yellow rust epidemics caused by newly introduced lineages of Puccinia striiformis f. sp. tritici in Argentina," *Trop. Plant Pathol.*, vol. 44, no. 4, pp. 385–391, Aug. 2019, doi: 10.1007/S40858-019-00295-Y.
[14] S. Asseng *et al.*, "Hot spots of wheat yield decline with rising temperatures," *Glob. Chang. Biol.*, vol. 23, no. 6, pp. 2464–2472, Jun. 2017, doi: 10.1111/GCB.13530.
[15] M. M. Bakker, G. Govers, and M. D. A. Rounsevell, "The crop productivity-erosion relationship: An analysis based on experimental work," *Catena*, vol. 57, no. 1, pp. 55–76, Jun. 2004, doi: 10.1016/J.CATENA.2003.07.002.
[16] D. Tilman and M. Clark, "Global diets link environmental sustainability and human health," *Nature*, vol. 515, no. 7528, pp. 518–522, Nov. 2014, doi: 10.1038/NATURE13959.
[17] A. Abdulai and W. Huffman, "The adoption and impact of soil and water conservation technology: an endogenous switching regression application," *L. Econ*, vol. 90, no. 1, pp. 26–43, 2015, doi: 10.3368/le.90.1.26.
[18] M. Kassie, H. Teklewold, M. Jaleta, P. Marenya, and O. Erenstein, "Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa," *Land use policy*, vol. 42, pp. 400–411, Jan. 2015, doi: 10.1016/j.landusepol.2014.08.016.