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A Model for the Effective Adoption and Integration of Precision Agriculture in the Secondary School Agriculture Curriculum: Evidence from Kisii and Nyamira Counties, Kenya

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Abstract
Precision Agriculture (PA) is a data-driven approach that enhances efficiency, productivity, and sustainability in agriculture, but its integration into secondary school curricula remains limited, particularly in developing countries. This study developed an empirically grounded model for the adoption and integration of PA into Competency-Based Education (CBE) in secondary schools in Kisii and Nyamira Counties, Kenya. The model was developed from information on teachers' preparedness, the influence of resources and infrastructure on PA implementation, and barriers to effective PA implementation. A concurrent mixed-methods design was employed, involving 353 agriculture teachers and 254 principals. Questionnaires, interview guides, and observation checklists were used to collect data on the aspects that underpinned this model. Quantitative data were analyzed using correlation and multiple regression analyses, while qualitative data were analyzed thematically. Hierarchical Multiple Regression (HMR) was then used to develop the model. HMR coefficients (Beta weights) were used to indicate the relative strength and direction of each factor in the conceptual model diagram. Findings revealed that teacher preparedness is the strongest predictor of PA implementation ($R^2 = 0.784$), institutional resources act as enablers ($R^2 = 0.107$), and systemic barriers function as suppressors ($R^2 = 0.095$). The study proposes a three-layer adoption model integrating teacher capacity, institutional support, and systemic constraints. The model provides a scalable framework for integrating emerging Precision Agriculture into secondary education systems.

Keywords: Precision Agriculture, Curriculum Integration, Competency-Based Education, Teacher Preparedness, Institutional Resources, Systemic Barriers

Introduction

Agriculture remains a central pillar of Kenya's economy, employing a significant proportion of the population and contributing substantially to food security and national development (The Kenya Institute for Public Policy Research and Analysis (KIPPRA), 2024). However, the sector faces increasing challenges, including population growth, land fragmentation, declining soil fertility, and climate variability. These challenges necessitate adopting efficient and sustainable farming practices. Precision Agriculture (PA), which relies on technologies such as Geographic Information Systems (GIS), Global Positioning Systems (GPS), and data analytics, provides a viable solution by enabling site-specific management of agricultural inputs (Erickson et al., 2021).

In the education sector, Kenya has adopted Competency-Based Education (CBE), which emphasizes the development of practical skills, critical thinking, and problem-solving abilities. Agriculture, as a practical subject, is well-positioned to integrate PA concepts to prepare learners for modern agricultural practices. However, despite the inclusion of some technology-related concepts in the curriculum, the actual implementation of PA in secondary schools remains limited (Kenya Institute of Curriculum Development, (KICD), 2019). The gap between curriculum intentions and classroom practice raises concerns about students' preparedness to engage in modern agriculture. This gap is particularly evident in Kisii and Nyamira Counties, where agriculture is the primary livelihood, yet land sizes are shrinking, and productivity challenges persist. Therefore, there is a need to develop a structured model that explains how PA can be effectively adopted and integrated into secondary school agriculture curricula.

Precision Agriculture refers to the application of technology and data analytics to optimize agricultural inputs, improve productivity, and minimize environmental impact (Shannon et al., 2018). It involves using tools such as sensors, drones, and mapping technologies to monitor and manage variability in agricultural fields (Balafoutis et al., 2017). By applying inputs such as fertilizers and water at the right time and place, PA enhances efficiency and sustainability.

In a worldwide perspective, adoption models for PA have been developed primarily for commercial farming rather than for educational settings. A review of over 100 studies by Lowenberg-DeBoer (2019) manifested that adoption is influenced by the size of the organization, the likely profit from the adoption, the level of education, the risk associated with the adoption, and the enabling conditions, such as access to technology and training, with guidance systems (e.g., auto-steer) adopted fastest and complex tools (e.g., VRT) slowest. Say et al. (2018) conducted a study comparing developed and developing countries and found that, in countries with limited resources, high costs, poor infrastructure, and knowledge gaps, innovation adoption tends to be low.

In 2023, Abdillah proposed an organizational precision agriculture technology (PAT) adoption model that emphasized the sustainability, stakeholder collaboration, and phased implementation. However, in educational contexts, particularly in the secondary school agricultural education, the concept of model is still new, or rather, models are scarce and still emerging, underscoring the need to conduct this study and develop the model based on the outcomes. Clemons et al., (2020) and Reynolds (2022) applied Rogers' Diffusion of Innovations (DOI) to the U.S. secondary agriculture teachers, and highlighted that the attributes of innovation are relative advantage, compatibility, complexity, trialability, observability and the channels of communication are the predominant predictors in the adoption of PA without indicating clearly how the attributes interact thus necessitating the urgency to conduct this study and develop an appropriate model that can be used to integrate and implement precision agriculture in the secondary school education programs. Manning et al. (2022) synthesized 28 studies on the integration of agricultural technology (AgTech) in schools and concluded that effective models require professional development (PD), resource provision, curriculum alignment, and community partnerships. Akwah (2024) emphasized in-service training needs as a core component of any adoption pathway.

In Sub-Saharan Africa, adoption models for PA remain underdeveloped, with most of the literature focusing on farmer-level barriers rather than on education systems (Njoroge, 2025; Nyaga et al., 2021). Nxumalo (2025) in South Africa highlighted the need for context-specific models that address digital divides, high costs, and low digital literacy. In Kenya, no published models exist specifically for PA integration in secondary schools. General studies on agricultural education innovation (Kyule, 2017; Recha et al., 2024; Aholi, 2018) identify barriers but stop short of proposing structured frameworks. This study fills that gap by synthesizing empirical findings from the current study into a localized, multilevel adoption model tailored to the unique agroecological, socioeconomic, and educational realities of Kisii and Nyamira Counties.

Theoretical Framework

The model integrates three complementary theories: Diffusion of Innovations Theory (Rogers, 2003). Diffusion of Innovations Theory explains how innovations spread through social systems over time via five stages: knowledge, persuasion, decision, implementation, and confirmation. In this model, teacher preparedness represents the "knowledge" and "persuasion" stages, while institutional resources and policy support facilitate "implementation" and "confirmation." Innovation attributes (e.g., perceived complexity of PA tools, compatibility with CBE) and communication channels (e.g., PD workshops, peer networks) are critical moderators.

Constructivist Learning Theory (Piaget & Vygotsky); This theory underscores the need for active, experiential learning. PA integration requires teachers to facilitate hands-on activities (e.g., soil mapping, sensor data interpretation), making preparedness and infrastructure essential for creating meaningful learning zones of proximal development.

Systems Theory (Bertalanffy, 1968): views secondary agricultural education as an open system with inputs (teacher training, funding, policy), processes (curriculum delivery, PA instruction), outputs (student competencies), and feedback loops (assessment, stakeholder evaluation). Barriers act as negative inputs disrupting system equilibrium, while enablers restore balance.

These theories converge to position the model as multilevel: distal factors (demographics, policy) → core mechanism (teacher preparedness) → proximal enablers/constraints (resources/barriers) → outcome (effective PA implementation).

Methodology

The study employed a mixed-methods research design to capture both quantitative and qualitative data. This study involved 254 secondary schools from the two counties, 353 teachers of agriculture, and 254 principals. Proportionate random sampling was used to select schools, and purposive sampling to select principals and teachers of agriculture. Data were collected using questionnaires from teachers, interviews was used to collect data from principals, observation checklists were used to collect data on farms, laboratories, ICT tools, demonstration plots, and PA technologies where available thus giving a true picture of the ground, thus complementing other methods of data collection and document analysis also used to collect data on policies, curriculum documents, and institutional records that support or hinder the integration of PA it was adopted to enhance the robustness of the study by triangulating evidence from multiple sources.

Quantitative data were analyzed using correlation and multiple regression analyses, while qualitative data were analyzed thematically. Hierarchical Multiple Regression (HMR) was then used to develop the model. HMR coefficients (Beta weights) were used to indicate the relative strength and direction of each factor in the conceptual model diagram. This approach enabled a comprehensive understanding of the factors influencing PA implementation and informed the development of the proposed model.

Findings of the Study

The findings indicate that teacher preparedness has a strong positive influence on PA implementation ($r = 0.836$, $p < .001$; $R^2 = .784$), as shown in Tables 1 and 2. Teachers with higher levels of ICT competence, subject knowledge, and teaching experience are more likely to integrate PA into their lessons. Institutional resources, including ICT laboratories ($\theta = .252$, $t = 4.87$, $p < .001$) and funding ($\theta = 0.156$, $t = 3.03$, $p = .003$, $R^2 = .107$), show a moderate positive influence on PA implementation, as indicated in Tables 3 and 4. Schools with better infrastructure provide more opportunities for practical learning and technology integration. However, barriers had negative influence on PA implementation ($r = -0.143$, $p < .007$), $R^2 = .095$ (Table 5 and 6), inadequate funding ($\delta = -.169$, $p = .002$), poor infrastructure ($\delta = -.176$, $p = .001$) being the predominant barriers. These barriers reduce the effectiveness of both teacher preparedness and institutional resources.

Table 1: Relationship Between Teacher Preparedness and Implementation of Precision Agriculture (PA)

Implementation	**Pearson Correlation**	1	.836**
	Sig. (2-tailed)		.000**
	N	353	353
Teacher prep	Pearson Correlation	.836**	1
	Sig. (2-tailed)	.000**	
	N	353	353

Table 2: Multiple linear regression of teacher preparedness and PA implementation in secondary schools in Kisii and Nyamira Counties, Kenya

Model	**Sum of squares**	**Df**	**Mean square**	**F**	**Sig**
Regression	75.643	11	6.877	112.297	.001b**
Residual	20.820	340	.0.61		
Total	93.43	351			

Dependent Variable: PA implementation R Square =0.784 predictors: (constant), interpret soil basic report, PhD vs diploma, male vs female, postgraduate vs diploma, bed vs diploma, master's vs diploma, years taught, laptop familiarity pa, soil mapping, BSc vs diploma, age.

Table 3: Relationship between infrastructure and resources and infrastructure on PA implementation

		PAI	R&I
PAI	Pearson Correlation	1	.403
	Sig. (2-tailed)		.034**
	N	353	353
R&I	Pearson Correlation	.103	1
	Sig. (2-tailed)	.034**	
	N	353	353

Table 4: Multiple linear regression of institutional factors and resources and PA implementation in secondary schools in Kisii and Nyamira Counties, Kenya

Model	**Sum of squares**	**Df**	**Mean square**	**F**	**Sig**
Regression	10.338	6	1.723	6.889	.001b
Residual	66.538	346	.250		
Total	96.875	352			

R Square =0.107

Table 5: Correlation between PA Implementation and Barriers

		PAI	Barriers
PAI	Pearson Correlation	1	-0.143
	Sig. (2-tailed)		.007**
	N	353	353
R&I	Pearson Correlation	-0.143	1
	Sig. (2-tailed)	.007**	
	N	353	353

Table 6: Multiple linear regression of barriers and PA implementation in secondary schools

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9.174	5	1.835	7.256	.000[b]
	Residual	87.499	346	.253		
	Total	96.674	351			

R Square =0.095

Proposed Model for PA Integration

The study proposes a three-component model for the adoption and integration of PA: Teacher Preparedness (Core Driver), accounting for the largest proportion of explained variance ($R^2 = .784$) and exhibiting a strong positive association with implementation ($r = .836$, $p < .001$), thereby justifying its placement as the core mediating mechanism in the model. This component is the central determinant of PA implementation, as shown in Figure 1. It includes subject-matter knowledge, ICT competence, Pedagogical skills, and Attitudes toward innovation. Background characteristics, particularly age ($\beta = .702$, $p < .001$) and years of teaching experience ($\beta = .071$, $p = .009$), exerted significant, though largely indirect, effects, supporting their conceptualization as distal determinants whose influence operates primarily through preparedness. Institutional Resources (Enablers): contributed additional explanatory power to PA implementation, with ICT laboratories ($\theta = .252$, $p < .001$) and PA funding ($\theta = .156$, $p = .003$) emerging as significant predictors, although the overall model explained a comparatively smaller proportion of variance ($R^2 = .107$), thus positioning these factors as contextual enablers rather than primary drivers, these factors support and enhance PA implementation as indicated in Figure 1. They include ICT infrastructure, School farms and laboratories, financial resources, and administrative support. Barriers (Constraints): These factors limit the effectiveness of implementation. Inadequate funding ($\delta = -.169$, $p = .002$) and poor infrastructure ($\delta = -.176$, $p = .001$) significantly and negatively predicted PA implementation, collectively accounting for modest variance ($R^2 = .095$) and reinforcing their role as constraining forces that suppress effective implementation. They include Inadequate funding, Poor infrastructure, and policy gaps.

Model Interaction

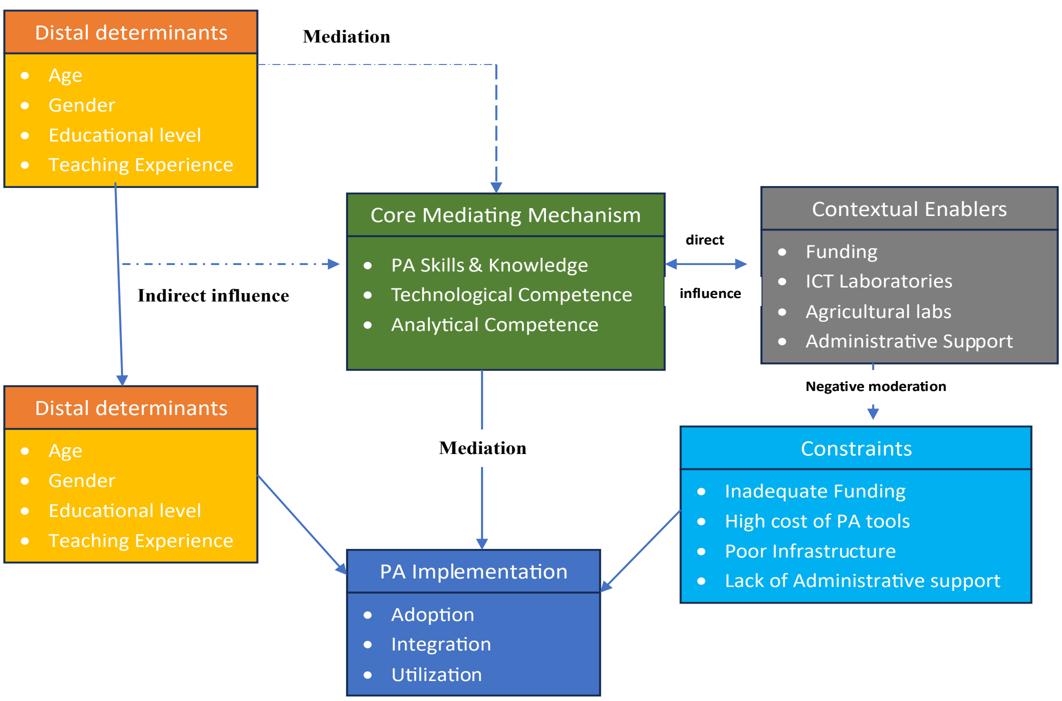

Figure 1: The model for the effective adoption and integration of PA in the agriculture curriculum in secondary schools.
Source: Onyancha FG. 2026

The model suggests that the interaction of these components influences PA implementation:

PA Implementation = Teacher Preparedness + Institutional Resources – Barriers

This formulation aligns with Constructivist Learning Theory, which emphasizes experiential, learner-centered approaches supported by enabling environments. It also reinforces the notion that effective implementation requires a balance between capacity, support, and constraint mitigation.

In the broader context, the findings underscore that integrating PA into secondary education is not merely a technical issue but a systemic transformation process. As noted by Shannon et al. (2018), PA represents a paradigm shift toward data-driven agriculture, requiring corresponding changes in education systems to prepare future farmers. Therefore, failure to address teacher preparedness, infrastructure gaps, and systemic barriers risks widening the gap between curriculum policy and classroom practice.

Discussion of the Findings

The findings of this study strongly establish teacher preparedness as the most influential determinant of Precision Agriculture (PA) integration in secondary school agriculture curricula. The high explanatory power ($R^2 = 0.784$) and strong positive relationship ($r = 0.836$, $p < .001$) indicate that teachers' competencies in ICT, pedagogy, and subject content are central to translating curriculum reforms into practice. This finding is consistent with prior studies, which argue that teacher capacity is the cornerstone of successful educational innovation (Heidenreich et al., 2018; Food and Agriculture Organization, 2021). Teachers act as change agents, and their ability to interpret and implement new technologies determines the extent to which innovations such as PA are adopted in classrooms. From a theoretical perspective, this aligns with Everett Rogers' Diffusion of Innovation Theory, which emphasizes that knowledge, skills, and attitudes are critical in influencing adoption decisions. Teachers who are knowledgeable and confident in using PA tools are more likely to progress from awareness to implementation stages.

Furthermore, the strong mediating role of teacher preparedness supports Ertmer's (2005) distinction between first-order barriers (external) and second-order barriers (internal), noting that internal factors such as beliefs and competence are often more decisive. The study also reveals that teacher demographic characteristics, particularly age and teaching experience, exert indirect effects on PA implementation through preparedness. This finding is supported by Tondeur et al. (2017), who argue that exposure to technology and prior training significantly shape teachers' readiness to integrate digital tools. Younger teachers may demonstrate greater technological adaptability, while experienced teachers bring pedagogical mastery, suggesting the need for targeted, differentiated professional development programs. Institutional resources were found to have a moderate but significant influence on PA integration ($R^2 = 0.107$), with ICT infrastructure and funding emerging as key enablers. This supports earlier findings by Manning et al. (2022), who observed that access to infrastructure enhances technology integration by enabling practical and experiential learning. Similarly, Balafoutis et al. (2017) emphasize that PA relies heavily on technological tools such as sensors, drones, and GIS systems, which require adequate institutional support to be effectively utilized in educational contexts.

However, the relatively lower explanatory power of institutional resources suggests that availability does not guarantee utilization. This finding corroborates Ertmer's (2005) research, which highlights that infrastructure alone cannot drive integration without corresponding teacher competence and motivation. In line with Ludwig von Bertalanffy's Systems Theory, the effectiveness of PA integration depends on the interaction between system components, teachers, resources, and policies rather than the presence of any single factor in isolation. The study further identifies systemic barriers as significant constraints to PA implementation, with inadequate funding and poor infrastructure exerting negative effects. These findings are consistent with Bagheri & Naier (2022), who report that high technology costs, lack of training, and weak institutional support are major impediments to PA adoption, particularly in developing countries. Similarly, the Food and Agriculture Organization (2021) highlights that limited access to digital infrastructure and capacity-building opportunities continues to hinder agricultural innovation in Sub-Saharan Africa. Importantly, the results demonstrate that barriers function as suppressor variables, weakening the positive effects of both teacher preparedness and institutional resources. This interaction effect aligns with Bingimlas (2009), who argues that external constraints, such as a lack of funding and policy support, can significantly undermine technology integration efforts, even when teachers are willing and capable.

Conclusion and Recommendations

This study developed a comprehensive model for the effective adoption and integration of Precision Agriculture into secondary school agriculture curricula. The model emphasizes the central role of teacher preparedness, supported by institutional resources and constrained by systemic barriers. The findings highlight the need for coordinated efforts to enhance teacher training, improve infrastructure, and address policy gaps to achieve successful implementation. The study recommends the following, based on the findings:

1. The Ministry of Education and the Kenya Institute of Curriculum Development (KICD) should incorporate explicit, measurable Precision Agriculture performance competencies (with at least 4–6 observable indicators per grade level) into the agriculture curriculum during the 2028–2032 CBE review.
2. Kisii and Nyamira County Governments Should Establish a dedicated County Precision Agriculture in Education Support Fund (KES 5–15 million annually per county) to finance the procurement of basic PA starter kits for 20–30 pilot schools per year and Internet connectivity subsidies for agriculture departments.
3. School Boards of Management and Principals should ring fence a minimum of 8–12% of school capitation and other internally generated funds for agriculture and ICT development in the 2026–2029 School Improvement Plans.

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Author's Contributions
OFG designed the study, collected and analyzed data, and wrote the manuscript. OJB, OKO, and NAC supervised the study.

Consent to Publish
All authors (and participants of the study) approved that this manuscript be published.

Competing Interests
The authors declare that they have no competing interests.

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Ethics Declarations
Research was approved by the Kenyan National Commission for Science, Technology, and Innovation, ref number: NACOSTI/P/25/4182570. The authors adhered to all suggested ethical standards throughout the study.

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