The moderating role of digitalisation on smart-green production willingness in agriculture

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Abstract: In the era of the modern 4.0 economic revolution, most countries worldwide are well aware of the need to develop smart agriculture because the negative impacts of climate change are becoming increasingly evident on a large scale. Agricultural development is becoming a trend on a global scale at a rapid rate. Therefore, this study investigates the role of digitalisation in increasing smart-green production willingness in the agriculture sector from the farmers' perspective through the interaction with deforestation, mechanical power, organic fertiliser, and renewable organic resource. This study conducted multiple analyses to test these proposed relationships. The results found that the interactions between digitalisation with mechanical power, deforestation, and renewable organic resource enhance the smart-green production willingness. This study also contributes several implications to literature and practices based on these findings.

Keywords: digitalisation; deforestation; environment protection; smart-green agriculture; carbon emission; green production; innovation.

Reference to this paper should be made as follows: Hanh, N.T., Chi, N.T.K., Hoang, L.N., Chi, N.P., Uyen, N.T.T. and Nhu, N.T. (2024) 'The moderating role of digitalisation on smart-green production willingness in agriculture', *Int. J. Sustainable Agricultural Management and Informatics*, Vol. 10, No. 1, pp.27–47.

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1 Introduction

Chi (2022) argued that agriculture is an economic sector with a critical position in an emerging economy. Although agriculture's share in GDP is decreasing, agriculture still plays a strategic role in the long term, an important foundation for the country's security, security and people's well-being (Lele and Goswami, 2020; Papadopoulou et al., 2023; Vu et al., 2022b). In international integration, climate change, epidemics, and especially the Fourth Industrial Revolution, digital transformation in agriculture is an inevitable trend, the critical point for sustainable development of the agriculture sector (Kyrylov et al., 2022; Debow et al., 2023; Hoang Vu et al., 2021). This study investigates the role of digitalisation on smart-green agriculture production in a transition economy.

Rapid urban development can make food production difficult because the area of agricultural land is shrinking (Ziem Bonye et al., 2021l; Lee et al., 2019). Therefore, many cities around the world have been switching to using smart technology to develop smart agriculture to provide food and fresh food, creating green space and fresh air for people (Mohamed et al., 2021; Edewor et al., 2023; Suzuki and Hoang Nam, 2018).

The significance of digitalisation in agriculture has been verified (Mittal and Mehar, 2016). However, using ICT in agriculture only sometimes leads to higher productivity and profitability for all farmers (Eitzinger et al., 2019). Therefore, despite the positive results of mobile applications in improving smallholder agriculture (Tata and McNamara, 2018), many farmers are still in the 'shadow' due to a lack of technology accessibility, especially in transition economies (Eitzinger et al., 2019; Spilioti et al., 2023). Notably, essential obstacles hinder the digitalisation of agriculture, (i.e., use of mobile phones/apps and IT), especially for rural smallholder farmers, including lack of connectivity, lack of digital capacity, poor usability of IT applications, and digital illiteracy (Eitzinger et al., 2019; Mittal and Mehar, 2016). Failure to address these shortcomings will eventually lead to farmers facing a new era of digital poverty. However, there is little research on the IT adoption and the digitalisation effect on agricultural production, particularly smart-green agriculture production.

The new global economy requires agricultural products to be produced responsibly, especially in terms of biodiversity conservation and emission reduction, to mitigate and adapt to the impacts of climate change. Many studies suggest green innovation in agricultural production (Chi, 2022; Mazhar et al., 2021). However, the research about the influence of digitalisation on smart-green production and environment protection through the interaction among digitalisation and deforestation, mechanical power, renewable organic resource, and organic fertiliser still needs to be explored.

According to Rahman et al. (2022), agriculture production is a crucial area to apply AI application. Puupponen et al. (2023) also confirmed the AI application on environmental protection and climate-friendly agriculture. Along with the strong development of science, technology, and innovation, digital transformation has been identified as a pillar of fast and sustainable development and one of the breakthroughs contributing to productivity, quality, efficiency, and competitiveness (Andrade et al., 2020). The digitisation of the agricultural industry is considered an effective solution to overcome the inherent weakness of the agricultural sector, which is fragmented, small, and unconnected production (Chi, 2022; Wang et al., 2022). Lioutas et al. (2021) implied that farmers have firmly applied information technology in management, production, and business, analysing data on land, soil, natural conditions, weather, traceability, and market demand.

Vietnam is selected as the context of research because of three reasons. Firstly, Vietnam is located in a tropical and subtropical climate with monsoons, sunshine, abundant rainfall, and high humidity. This climate is creating and bringing several benefits for agricultural production. Secondly, Vietnam is a transition economy making significant efforts to improve agricultural production. Since agriculture in Vietnam has made tremendous progress since 1986, the strong development of the agriculture industry has helped Vietnam significantly improve food security, contribute to poverty reduction and socio-economic stability, and become one of the top five agricultural exporters in the world. Thirdly, Vietnam's current agricultural growth model still needs to reveal more concerns about quality and sustainability. In particular, growth in the agriculture sector today is partly due to environmental sacrifices. Therefore, smart-green agricultural production will be considered the mainstream agricultural development model. This is of particular concern in emerging nations, where greenhouse gas emissions (GHGs) and environmental pollution are alarming (Anser et al., 2020). Consequently, this study will contribute empirical evidence for other countries which have the same characteristics of agricultural production, like Vietnam.

Moreover, with a transition economy, Vietnamese Government has many priority policies for agriculture such as tax exemption, capital support for people, training courses for farmers, and activities for agricultural extension in the local provinces (VIDI, 2023; Vu and Nguyen, 2022). Consequently, this study aims at identifying the impact of deforestation, mechanical power, renewable organic resources, and organic fertiliser on smart green production willingness through the moderating influence of digitalisation. This study employed quantitative analysis to test the effect of five factors (deforestation, mechanical power, renewable organic resources, organic fertiliser, digitalisation) on smart-green agriculture production and environment protection in which digitalisation plays moderator. The study's findings contribute to agriculture production research and practice.

2 Literature review and hypotheses development

2.1 Smart-green agriculture production

According to Campbell et al. (2020), the concept of climate-smart agriculture – CSA was built in 2010 and confirmed by the World Bank, and the Food and Agriculture Organisation. Increasing crop productivity and decreasing gas emissions are the foremost advantages of CSA. CSA integrates the benefits of climate resilience, reduced gas emissions, and sustainable production (Abegunde et al., 2020) because agricultural production itself is a factor of GHGs and global warming (Gebresamuel et al., 2021). On the other hand, Patil and Chetan (2018) suggested the new concept of smart-green production in agriculture is smart greenhouse – SGH. SGH is an agriculture model which aims at crop protection from environmental change and is equipped with digital innovation (i.e., humidity and CO_2 sensors and light-water sensors, heater-sprinkling, and local blockchain). Based on these previous studies, this paper suggests the concept of smart-green production in agriculture is developed with digitalisation to meet food security and protect the environment.

Farmers' willingness to adopt smart-green agriculture production in this study is defined as farmers' readiness to transform the traditional agricultural production into smart-green agricultural production.

2.2 Hypotheses development

Gray and Rupe (2015) firstly defined digitalisation as the 'integration of multiple technologies into all aspects of daily life that can be digitised'. Digitalisation is considered the most 'significant technological trend' which change society, production, and business (Parviainen et al., 2017). Digitalisation is defined as the use of digital technology to obtain revenue, improve business process, and support an environment for digital business (Klerkx et al., 2019). Digitalisation is also a term describes digital technology to create the 'harvest value' in new ways (Gobble, 2018). Reis et al. (2020) identify digitalisation to highlight the differences between technological conditions for social change and actual change. The digitalisation in agriculture is enabling access to smart-green agricultural production (Klerkx et al., 2019).

According to Rahman et al. (2022), agriculture production is a key area to apply digitalisation. Puupponen et al. (2023) also confirmed the digitalisation on environmental protection and climate-friendly agriculture. Along with the strong development of science, technology and innovation, digital transformation has been identified as a pillar of fast and sustainable development and one of the breakthroughs contributing to breakthroughs in terms of productivity, quality, efficiency and competitiveness (Andrade et al., 2020). The digitisation of the agricultural industry is considered an effective solution to overcome the inherent weakness of the agricultural sector, which is fragmented, small and unconnected production (Chi, 2022; Wang et al., 2022). Lioutas et al. (2021) implied that farmers have strongly applied information technology in management, production and business; analysing data on land, soil, natural conditions, weather, traceability, market demand. Application of internet of things (IoT) technology includes block chain, biotechnology, genetics, genomic analysis, tissue culture (Shen et al., 2022; Vu et al., 2022a).

Deforestation can also be considered as the removal of forests which leads to some imbalance both ecologically and environmentally (Aragão et al., 2014; Vu et al., 2022b). What makes deforestation so alarming is the immediate and long-term effects it will have if it continues at its current rate. Mechik and von Hauf (2022) predicted that the world's tropical forests will be wiped out if deforestation continues at its current rate. The world's forests form a huge carbon store, containing about 861 gigatons of carbon (Adeyemi and Adeleke, 2020). When trees are cut down, they release stored carbon into the atmosphere. Since 2000, the world has lost about 10% of its tree cover, which has become the main cause of global warming (Wolf and Ripple, 2022). However, digitalisation is introduced as a important channel to reduce deforestation such as transferring data in highly digitalised smart cities (Omran and Schwarz-Herion, 2020), or digitalising analog maps for controlling forests from deforestation (Faingerch et al., 2021), or converting deforestation data into a digitalised map format by a scanner (Pacheco, 2002). Based from the previous findings, we suggested that:

H1a Digitalisation enhances the relationship between deforestation and smart green production willingness.

According to Daum and Kirui (2021), mechanical power describes the use of technologies to replace human labour in the entire agricultural value chain. The transformation from traditional agriculture to smart-green agricultural production needs the digitalisation adoption in whole process, which produces higher yields (Adu-Baffour et al., 2019). Digital transformation of the agricultural sector includes basic activities such as applying modern technology in farming, linking value chains and changing management methods (Daum et al., 2022). Currently, there are many modern technologies applied in agricultural farming. Examples include IoT and field sensors, machine learning and analytics, and crop monitoring drones (Rejeb et al., 2022). Saha et al. (2018) also confirmed that digital transformation in agriculture is not only reflected in the application of technology in production and value chain linkage, but also in changing the operation management method of enterprises. As a result, agricultural enterprises can operate efficiently, increase productivity at back-off departments and save costs (Dutta and Mitra, 2021). They also stated that the application of new technical technologies and mechanical power in farming helps farmers achieve higher productivity and efficiency. At the same time, all stakeholders in the ecosystem also benefit (Akhter and Sofi, 2022). Therefore, we suppose that digitalisation together with mechanical power will lead to smart-green production willingness in agriculture. The hypothesis is follows:

H1b Digitalisation enhances the relationship between mechanical power and smart green production willingness.

In a research of Shtull-Trauring and Bernstein (2018), digitalisation has positively impact on green agriculture in Israel through increasing crop yields and decreasing gas emission in a difficult condition where Israel does not have abundant water, fertile soil, only desert. They have applied technology to turn the desert into artificial fields, raising shrimp and fish in glass cages (Korringa, 2017). Globally, the agricultural transformation is happening rapidly, with information communication technology (ICT) and digitisation being the central factors behind this novel transformation. The use of mobile application software by most of the stakeholders in agriculture improves resource efficiency and helps reduce production-related costs while increasing crop yields (Qiang et al., 2020).

Obi et al. (2016) demonstrated that the agricultural production process also generates a large amount of waste and by products, which, if not managed properly, will cause environmental pollution and waste organic matter. With the help of digital transformation, this resource is exploited and used well, not only bringing economic efficiency but also contributing to environmental protection and reducing GHGs (Schandl et al., 2016). Livestock waste is managed in many ways: Composting, treatment with microbial products, biogas works (Awasthi et al., 2022). However, the current use and processing of agricultural waste and by-products is still not synchronised, efficient, wasteful, and has not yet created high value-added products (Garcia and You, 2017). Currently, there are many good models that apply the circular economy principle associated with green growth, using by-products in agriculture, forestry and fishery as a renewable resource (Genovese et al., 2017). Therefore, we hypothesise:

H1c Digitalisation enhances the relationship between renewable organic resource and smart green production willingness.

Some previous scholars have demonstrated the impact of digitalisation on smart green agriculture. For example, Knickel et al. (2017) implied that digitisation can achieve not only selective improvement, but a more sustainable agriculture in general, in line with globally binding climate and biodiversity goals, further reducing threaten and at the same time can feed the growing world population. As it has been pointed out, this implies zero emissions, which can include offsetting residual emissions to a limited extent, efficient use of resources and the removal of environmentally harmful chemical preparation (Liao et al., 2022). With the support of digitalisation, farmers can produce high value-added agricultural products to reduce CO_2 emissions (Chang, 2022). In a transition economy like Vietnam, the 13th Party Congress affirmed that digital transformation is identified as one of the pillars of fast in developing smart green agriculture (Van and Phuong, 2022). The development of high-tech agriculture in agriculture production must be based on the data, especially the big data system of the industry, such as land, crops, livestock, fisheries, weather in efforts to protect environment and increase the crop yields (Lele and Goswami, 2017).

Towards a green agriculture, the use of organic fertilisers is one of the key factors (Baweja et al., 2019). In recent years, farmers in the province have begun to prioritise the use of organic fertilisers more and more (Bamdad et al., 2022). Using this fertiliser has helped people create clean products, which do not pollute the environment and limit the use of pesticides and chemical fertiliser (Liu and Wu, 2022). According to Maji et al. (2020), when farmers use organic fertilisers to replace inorganic fertilisers, chemical fertilisers in cultivation and agricultural production will bring four benefits: First, ensuring the living environment and more 'clean' water; the second is the farming environment, plants will be 'healthier', reducing dependence on the use of pesticides, as well as other pesticides; the third is to produce agricultural products that are 'cleaner' and safer, more valuable in the market, increasing the ability to export; and finally take advantage of agricultural by-products, organic waste in daily life to be reused into organic fertiliser production, promoting the development and application of organic fertilisers in agriculture and environmental protection. Therefore, with the support of digitalisation, the usage of organic fertiliser in agriculture production seems to be easier. The hypothesis is follows:

H1d Digitalisation enhances the relationship between organic fertiliser and smart green production willingness.

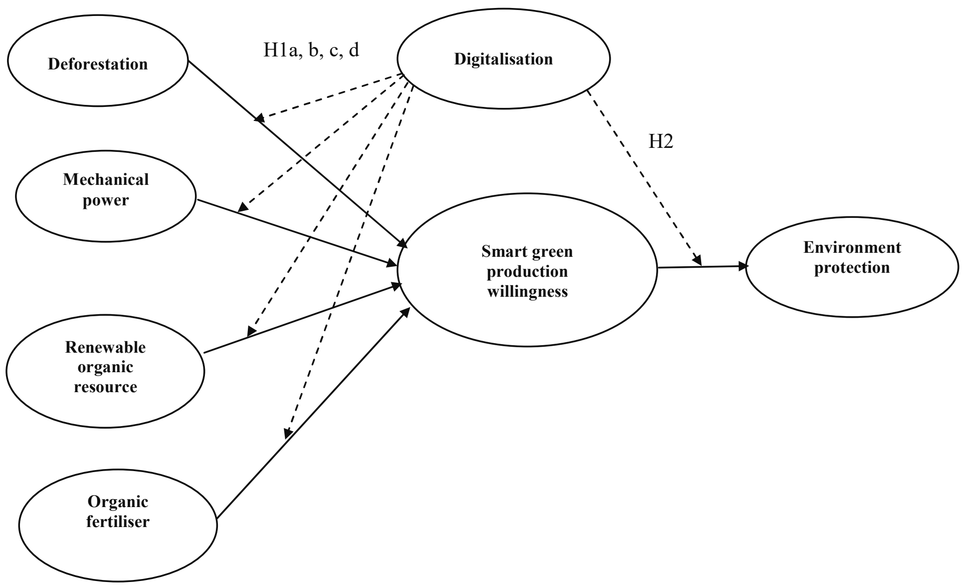
Balogun et al. (2020) addressed that digital transformation helps the agricultural industry reduce risks and damages caused by climate change. However, Praveen and Sharma (2020) stated that agriculture is an industry that is highly dependent on weather and climate. In fact, climate change with an increase in temperature and extreme weather has been having a direct impact on all areas of the agricultural sector (Ebele and Emodi, 2016), such as: reducing land area, reducing freshwater flow for serving. Agricultural production; increasing intensity of storms, sea level rise and disease; reduce biodiversity. The inevitable consequence is to reduce productivity, quality, and even loss of revenue in agriculture. Baryannis et al. (2019) revealed that applying AI technology (artificial intelligence), Data Analytics (data analysis) to risk management will help to give early warning (72 hours before the storm passes), thereby, all levels, sectors, people farmers will have timely response measures, limit risks caused by climate change, and produce more efficient and sustainable agriculture.

Digital transformation helps the agricultural industry to improve productivity, quality and efficiency of production and consumption of agricultural products (Hien and Chi, 2023). The application of IoT technology, big data (big data), and biotechnology has helped to analyse data about the environment, soil types, plants, and plant growth stages. Based on the provided data, the producer will make appropriate decisions (fertilising, watering, spraying pesticides, harvesting …), thereby, reducing costs, reducing pollution water and land resources, protecting biodiversity (Baryannis et al., 2019). Mamai et al. (2020) suggested that the application of information technology and digitisation in operation and management will help make decisions faster and more accurately thanks to a timely and transparent reporting system, increasing management effectiveness and efficiency. For agribusiness enterprises, digital technology also helps increase operational efficiency, cut operating costs, and reach more customers. As a result, the operational efficiency and competitiveness of enterprises are enhanced (Jamaludin, 2021). Therefore, digital transformation in agriculture is defined as creating environment, agricultural digital ecology as the foundation, creating institutions, promoting the transformation from traditional agriculture to smart-green agriculture. Therefore, we hypothesise that:

H2 Digitalisation enhances the relationship between smart green production willingness and environment protection.

Based on these previous studies, this paper proposes the theoretical framework depicted in Figure 1.

Figure 1 The proposed framework



3 Methodology

3.1 Study area

In Vietnam, the green agricultural model is increasingly interested by farmers. In many localities, many models have been and are in the process of converting green and ecological agriculture to the trend of the world market as well as helping to reduce the impact of climate change. In September 2022, the Ministry of Agriculture and Rural Development approved the action plan for the implementation of the National Green Growth Strategy for the 2021–2030 periods, aiming to develop agriculture towards an ecological, circular, low carbon emission in order to improve quality growth, added value, competitiveness and sustainable development. Accordingly, to develop agriculture towards ecological, organic, circular, low carbon emission in order to improve growth quality, added value, competitiveness and sustainable development; reduce agricultural and rural environmental pollution, towards a carbon-neutral economy by 2050.

Agriculture plays an extremely important role in Vietnam's economy and society. Agriculture includes crop production, animal husbandry, fisheries and forestry. Tropical climate, fertile soil, abundant water resources and rich biodiversity are important conditions so that after 40 years of 'Doi Moi' economic reform, Vietnam's agricultural industry has developed. In the direction of diversified trade, meeting domestic and international needs. Currently, the government is promoting a comprehensive restructuring program of the agricultural sector in the context that Vietnam's agriculture is facing the crossroads of both opportunity and challenge.

3.2 Measurement scale

Deforestation has four items and captured from Austin et al. (2019). Three items of mechanical power are captured from the study of Singh and Mittal (1992). Renewable organic resources have three items and adapted from Reddy and Yang (2005) and Padam et al. (2014). Four items of organic fertiliser are captured from the research of Jia et al. (2020), Chi (2022), Abdel-Raouf et al. (2018). Digitalisation has five components from the study of Gray and Rumpe (2015) and Mondejar et al. (2021). Smart-green production willingness using four items from the research of Mondejar et al. (2021) and Chi (2022). Finally, environment protection employing three items was adapted from Tantayanubutr and Panjakajornsak (2017) and Chi (2022).

3.3 Data analysis

Farmer household was the sample unit and convenience sampling is the technique in this study. A probabilistic method was used to determine the sample size required to allow valid inferences about the population.

In terms of sample size, in case of lacking accurate data, previous studies apply a similar non-probability method a (Chen and Tsai, 2007). According to Hair et al. (2014), a satisfactory analysis using the structural equation modelling (SEM) requires a sample size of at least 300. A probability method is used to identify the sample size necessary to enable valid inferences about the population. We follow Horng et al. (2012) to calculate the required samples using a 95% confidence interval and ±0.05 sampling error. According to Vietnamese General Statistics Office, there are 16.881 farmer households (GSO, 2021), the formulation is as follows:

$$\text{Sample size} = \frac{N}{N\left(\frac{2d}{Z\frac{\propto}{2}}\right)^2 + 1} = \frac{16,881}{16,881 = \left(\frac{2 * 0.05}{1.96}\right)^2 + 1} = 384$$

Therefore, this study distributed the questionnaire to 600 farmer households to get at least 400 responses. Farmers were selected in the South of Vietnam to distribute questionnaires because of two reasons. Firstly, the region with the highest per capita income in 2021 is the Southeast region (5,794,000 VND/person/month) and the lowest is the Northern Midlands and Mountains (2,837 VND/person/month) (GSO, 2021). Hence, customers tend to accept the higher quality of agricultural products which push farmers having strong motivations for innovate their production. Secondly, the South has a larger agricultural area than the North of Vietnam and has a diverse range of agricultural, forestry and fishery products such as Can Tho, Ca Mau, Long An, An Giang, Binh

Phuoc, Quy Nhon, Vinh Long, Tra Vinh, Tay Nguyen. Therefore, we focused our survey on the southern region of Vietnam.

Table 1 Measurement scale

Construct	*Code*	*Item*	*Source*
Deforestation (DEF)	DEF1	Clear forest for logging roads	Austin et al. (2019)
	DEF2	Clear forest for farmland	
	DEF3	Urban expansion such as roads and housing development	
	DEF4	Natural disasters such as shoreline erosion, volcanic activity and landslides	
Mechanical power (MEC)	MEC1	We use of tools, implements and machines for agricultural land development	Singh and Mittal (1992)
	MEC2	We use of tools, implements and machines for crop production	
	MEC3	We use of tools, implements and machines for harvesting, preparation for storage	
Renewable organic resources (REN)	REN1	We use organic waste to make fertiliser	Reddy and Yang (2005) and Padam et al. (2014)
	REN2	We use renewable organic resource to protect weeds and pests	
	REN3	We have turned agricultural by product into renewable organic resources	
Organic fertiliser (FER)	FER1	We use fertiliser from animal waste	Jia et al. (2020), Chi (2022) and Abdel-Raouf et al. (2018)
	FER2	We use organic fertiliser in nurturing plants	
	FER3	We do not use chemicals to kill weeds and pests in the production process	
	FER4	We make our own organic fertiliser from animal waste	
Digitalisation (DIG)	DIG1	Internet of things	Gray and Rumpe (2015) and Mondejar et al. (2021)
	DIG2	Artificial intelligence	
	DIG3	Smart technologies	
	DIG4	Smart mobility	
	DIG5	Big data	
Smart-green agricultural production willingness (WIL)	WIL1	We are willing to adopt technology for predicting the real-time information on soil nutrient	Mondejar et al. (2021) and Chi (2022)
	WIL2	We are willing to adopt clean process in production	
	WIL3	We recover the end-of-life goods and recycling	
	WIL4	We use low energy consumption such as water, electricity, and gas during production	
Environment protection (ENV)	ENV1	Ecological monitoring	Tantayanubutr and Panjakajornsak (2017) and Chi (2022)
	ENV2	Resource efficiency	
	ENV3	Environment control	

Six collectors were recruited to deliver the survey to farmers in five places from March to June 2022. Father, after each participant completed questionnaire, they received a small financial incentive from the research project through the online bank transfer. This study follows proper ethical procedure, by ensuring that all the answers of participants will be kept confidential. In addition, all the questionnaires will be anonymous. After launching survey, we collected 330 valid answers. Table 2 presents the respondents' information. The percentage of male was higher than female (57% versus 43%). The majority of farm managers were under 50 years old and had above five year-experience.

Table 2 Respondents' information

Information		*Percentage (%)*
Gender of farmer	Female	43
	Male	57
Age of farm manager	18–30	16
	31–40	39
	41–50	34
	Above 50	11
Education	Less than high school	46
	University	43
	Post university	11
Farming experience	Under five years	18
	5–10 years	34
	10–20 years	40
	Above 20 years	8

To obtain the validity and reliability, this study employed 'confirmatory factor analysis' – CFA. To test the moderating role of digitalisation on the proposed relationships, we complied the suggestion of Kenny and Judd (1984), Baron and Kenny (1986) and Sauer and Dick (1993) to test the interaction among the proposed factors and the moderating role of digitalisation.

4 Findings

This study investigates the effects of five factors (deforestation, mechanical power, Renewable organic resources, Organic fertiliser, Digitalisation in which digitalisation plays the moderator) on smart green agriculture willingness and the interaction among digitalisation, smart green willingness and environment protection. Therefore, we need to employ CFA for seven constructs as suggestion of Hair et al. (2010). Hair et al. (2010) suggested that CFA tests the discriminant and convergent values of the factors. CFA assesses the quality of observed variables, confirms the factor structures. The observed variables included in the CFA analysis are to determine which factor the observed variable belongs to, and the function of the CFA is now to assess whether the data of the observed variable in that scale are consistent with other variables in the same scale.

Table 3 Reliability and validity test of the scale

Measurement items	*Standardised factor loading*	*Cronbach's α*	*AVE*	*CR*
Deforestation (DEF)				
DEF1	0.770	0.855	0.568	0.841
DEF2	0.699			
DEF3	0.782			
DEF4	0.763			
Mechanical power (MEC)				
MEC1	0.822	0.823	0.614	0.826
MEC2	0.799			
MEC3	0.728			
Renewable organic resources (REN)				
REN1	0.801	0.853	0.591	0.812
REN2	0.788			
REN3	0.716			
Organic fertiliser (FER)				
FER1	0.709	0.788	0.575	0.843
FER2	0.769			
FER3	0.727			
FER4	0.823			
Digitalisation (DIG)				
DIG1	0.663	0.806	0.561	0.864
DIG2	0.777			
DIG3	0.798			
DIG4	0.689			
DIG5	0.807			
Smart green agriculture production (WIL)				
WIL1	0.716	0.875	0.617	0.866
WIL2	0.792			
WIL3	0.827			
WIL4	0.804			
Environment protection (ENV)				
ENV1	0.779	0.892	0.587	0.809
ENV2	0.735			
ENV3	0.783			

The reliability and validity of the scale were tested with the multivariate statistical analysis software SPSS22.0. The results are shown in Table 3. The Cronbach's a value of this study is greater than the critical value of 0.7 and the combined reliability (CR) is greater than 0.75, indicating that the scale has good reliability. The construct validity of the initial scale was tested using confirmatory factor analysis. The standardised load coefficient of latent variables corresponding to each item is greater than 0.5, and the average variance extraction (AVE) of all latent variables is basically above 0.5. These findings indicate that the convergence validity is good.

Table 4 Results of testing the first part

Partial relationships	*Model 1*			*Model 2*		
	β	*P value*	*t*	*β*	*P value*	*t*
Dependent variable: smart-green production willingness						
Deforestation	0.023	0.047	2.594			
Mechanical power	0.198	0.030	2.608			
Renewable organic resource	0.321	***	4.478			
Organic fertiliser	0.337	***	4.843			
	F = 47.53, R2 = 0.317, $p < 0.001$					
Digitalisation				0.507	***	11.155
				F = 114.51, R2 = 0.451, $p < 0.001$		
Dependent variable: environment protection						
Smart-green production willingness	0.408	0.000				

Note: ***$p < 0.001$.

Table 5 Results of the interaction testing

Moderating effect	*Hypothesis*	*β*	*P value*	*t*
Dependent variable: smart-green production willingness				
Digitalisation × Deforestation	H1a	0.337	***	3.132
Digitalisation × Mechanical power	H1b	0.304	***	2.992
Digitalisation × Renewable organic resource	H1c	0.201	0.025	2.671
Digitalisation × Organic fertiliser	H1d	0.119	0.056	1.560
Dependent variable: environment protection				
Digitalisation × Smart-green production	H2	0.527	***	5.673
F = 65.727, R2 = 0.599, p < 0.001				

In the next step, this study conducted the hierarchical regression to test the interaction between digitalisation and proposed relationships (deforestation → smart-green production willingness, mechanical power → smart-green production willingness, renewable organic resource → smart-green production willingness, organic fertiliser → smart-green production willingness, and smart-green production willingness → environment protection). Firstly, we tested each factors having direct influence on smart-green production willingness and environment protection without interactions. Table 2 showed deforestation, renewable organic resource, organic fertiliser and mechanical power have directly positive effects on smart-green production willingness. Meanwhile, digitalisation also has positive impact on smart-green production and farmers' willingness toward smart-green agriculture has positive influence on environment protection.

Secondly, this study conducted the analysis of interaction terms between deforestation, mechanical power, renewable organic resource, and organic fertiliser on smart-green production willingness.

Table 5 stated that moderating impacts of digitalisation on deforestation, mechanical power and renewable organic resource, smart-green production have positively significant, except for the link between organic fertiliser and smart-green production willingness. This addressed that digitalisation has non-influence on the association between organic fertiliser and smart-green production.

Thirdly, we tested the mediating effect of digitalisation when digitalisation was assumed to have mediating role in the proposed relationships. For doing that, we conducted the structural equalling model (SEM) by using SPSS AMOS 22.0. Table 6 showed that the model does not reach the fit with Chi-square/df = 5.543, RMSEA = 0.0601, CFI = 0.451, TLI = 0.301 and IFI = 0.403. This model fit was under the requirement of above 0.9 according to suggestion of Hair et al. (2010). Therefore, digitalisation did not play the mediating role because it is a pure moderating factor.

Table 6 Results of SEM testing

Effects	β	*p*
Deforestation → Digitalisation	0.255	0.008
Mechanical power → Digitalisation	0.251	0.007
Renewable organic resources → Digitalisation	0.106	0.052
Organic fertiliser → Digitalisation	0.178	0.048
Digitalisation → Smart-green production willingness in agriculture	0.216	0.003
Chi-square/df = 5.543, RMSEA = 0.0601, CFI = 0.451, TLI = 0.301 and IFI = 0.403		

Consequently, the results showed that hypothesis H1a, H1b, H1c and H2 are accepted, except for H1d.

5 Discussion

5.1 Theoretical implications

This study finds that digitalisation has pushed the development of smart-green agricultural production and increased the environment protection. The study's findings have several implications to green agricultural production and green behaviour research.

Firstly, this study highlights the importance of digitalisation on developing smart-green agricultural production through the interaction with deforestation. These finding is in line with the suggestion of Bager et al. (2021) and Rifin et al. (2020), which showed the trade agreement and IT adoption are the key drivers of forestation. It can be concluded that since a developing country (Vietnam) has policies in combating deforestation in ten years ago and has international agreement to prevent exploitation and illegal trade in forest products (Trieu et al., 2020), farmers do not have more desire to be illegal actors in exploit the forest products.

Secondly, this study also implies that digitalisation pushes the development of smart-green agricultural production through the interaction with renewable organic resource. These findings support the research of Liao et al. (2022) and Chang (2022). They suggested the impact of digitalisation on smart-green production at zero emissions and the removal of harmful chemical preparation. This is particular true for an emerging economy, like Vietnam. The more information technology is applied in agricultural production, the more ecological environment is protected by reducing the use of toxic fertiliser or pesticides and reducing the gas emissions.

Thirdly, the study's finding showed the promoting of digitalisation in the link between mechanical power and smart-green production willingness. Daun et al. (2022) also support this finding, by which digital transformation of the agricultural sector includes basic activities such as applying modern technology in farming, linking value chains and changing management methods. Application of new technical technologies and mechanical power in farming support environment protection.

Next, the interaction between digitalisation and organic fertiliser was found not to be related with smart-green production willingness. This finding may be somewhat different with Liu and Wu (2022). They supposed using organic fertiliser has helped people create clean products, which do not pollute the environment and limit the use of pesticides and chemical preparations.

Finally, this study confirms that digitalisation increasing smart-green production willingness in agriculture production will help environment protection. Balogun et al. (2020), Praveen and Sharma (2020) and Chi (2022) also supported this finding. They all suggested information technology application promotes farmers' households in transforming traditional agriculture to smart-green agriculture and protecting natural environment.

5.2 Practical implications

This study has managerial implications in agriculture production. Firstly, this study addresses the role of government policies in agricultural production to encourage and attract investment in the technology industry serving agriculture. The Ministry of Agriculture and Rural Development will continue to direct the implementation of models of good agricultural practices, organic agriculture, and circular agriculture. At the same time, coordinate with ministries, branches and localities to organise training courses for cooperatives and farmer households to apply organic, circular and ecological agriculture. In the immediate future, the Ministry of Agriculture and Rural Development assigns the National Centre for Agricultural Extension, the Science and Technology Program to serve the construction of new rural areas, and functional units to develop programs to integrate into production plans, and transferring science and technology related to organic agriculture and circular agriculture to production households, farms, cooperative groups, cooperatives and businesses. Secondly, it is necessary to build a link between farmers, domestic and foreign research institutes, universities, companies and enterprises to deploy, demonstrate, test and put into production and apply the achievements of the science and technology 4.0 in agriculture production. Thirdly, it is necessary to promote the manufacturing industry of agricultural machinery and equipment. Encourage investment in machinery and equipment in agricultural production on the basis of production reorganisation and effective implementation of demand-stimulating policies for agricultural mechanisation; creating favourable conditions for FDI enterprises to invest and manufacture machines for agricultural production in Vietnam.

6 Conclusions and limitations

This study is the first discovery in agricultural and green marketing research to shed light on the apparel impacts of those factors in environment protection in a transition economy. However, it also has some limitations. First, this research is based on the premise that digitalisation can drive smart-green agriculture production and environment protection, but some studies have found that there is a deviation between digitalisation and environment protection. Hence, future research can explore the incentive effect of digitalisation on other industries. Second, this study may disclose the problem of confounding in data analysis. The future research may compare the pure linear model with the one completed with the interaction terms (moderating effects). Thirdly, this research just focuses on four factors (deforestation, mechanical power, renewable organic resource, and organic fertiliser) while several variables are not included in the model. The future research needs to investigate the impact of legal regulations, government incentives, political decisions on the innovative agricultural production. Finally, our research is limited to the context of Vietnamese farm households. The findings may not be generalisable for other farmers from other emerging economies. We, therefore, encourage additional studies using data collected in countries other than Vietnam.

Acknowledgements

This research is sponsored by Foreign Trade University under Research Program number FTURP02-2023-14.

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