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Driving factors of green production behaviour among farmers of different scales: Evidence from North China

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Abstract: The agricultural production in China is gradually transitioning from extensive agriculture to green agriculture. In this context, identifying the driving factors and dimensions of farmers' green production behaviour can contribute to promoting sustainable agricultural development. Existing studies lack investigation into the identification of driving factors and dimensions of green production behaviour among farmers of different scales. This study examined 1 142 farm households from five major grain-producing provinces in the North China Plain in 2019. We employed probit-ISM (interpretive structural modelling) models to analyse the driving factors of green production behaviour among farmers of different scales and identify dimensional differences. The study concluded the following: *i*) Personal characteristics, household characteristics, operational characteristics, social network characteristics, organisational characteristics, and cognitive characteristics were factors driving green production behaviour among small-scale farmers. However, social network characteristics and organisational characteristics had insignificant effects on green production behaviour among large-scale farmers. *ii*) Personal characteristics, number of agricultural workers, scale of operation, degree of land fragmentation, and whether relatives and friends are civil servants were the deep-rooted factors driving farmers' green production behaviour. Part-time farming status, proportion of grain income, types of agricultural machinery, relationship with local farm machinery operators, and organisational characteristics were middle indirect factors. Cognitive characteristics represented the direct surface factors. This study can provide crucial information for government departments, which formulate differentiated policies to promote green production behaviour among farmers of different scales.

Keywords: farmers' green production behavior; interpretive structural modelling; large-scale farmers; probit model; small-scale farmers

Since the implementation of the household contract responsibility system with remuneration linked to output in rural China, significant achievements have been made in agricultural and rural development, leading to a remarkable improvement in the living standards of farmers (Mi et al. 2020). However, under the guidance of production-oriented policies, farmers have continued to engage in extensive agricultural production activities. The ecological and environmental problems caused by these practices have become increasingly prominent with economic development, posing severe challenges to the sustainable development of agriculture and rural areas in China, and causing serious damage to the production and living environment of farmers (Liu et al. 2020; Wu et al. 2021).

Taking pesticide and fertiliser application as an example, the amount of pesticide applied in China has increased from 154 600 tonnes in 1990 to 273 400 tonnes in 2020, accounting for over 10% of the world's total pesticide usage (FAO 2023). Since 2006, China has consist-

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ently been the largest producer and consumer of fertilisers in the world, with its fertiliser production accounting for over a quarter of the global total, and annual fertiliser consumption exceeding 30% (Guo and Wang 2021). The extensive agricultural production methods have brought significant negative externalities to China's ecological environment, making the green development of agriculture an urgent priority (Cao et al. 2020).

Agricultural green development relies on the promotion of green production behaviour among farmers. As the micro-operators of agricultural production, farmers shifting their production behaviour from extensive to green practices is crucial for driving agricultural green development (Li et al. 2020b). Therefore, investigating the driving factors and dimensions of farmers' green production behaviour is essential for studying agricultural green development. This exploration holds significant theoretical and practical significance.

Farmers' green production behaviour refers to 'a series of behaviours used in the pre-production, in-production, and post-production processes of agricultural activities that contribute to environmental protection and promote sustainable agricultural development' (Yang et al. 2020; Yu et al. 2021; Yu et al. 2022). Pre-production green production behaviour specifically includes the use of coated seeds (Li et al. 2022), green pesticides (Yan et al. 2023), soil testing-based fertilisation (Xu et al. 2022b), commercial organic fertiliser (Zhao et al. 2021), and agricultural film recycling (Luo et al. 2022). In-production green production behaviour specifically includes conservation agriculture and fallowing (Yu et al. 2022), integrated pest management (Yi et al. 2021), and straw return to the field (Wu et al. 2021). Post-production green production behaviour specifically includes transportation, storage, drying, processing, and sales (Mao et al. 2021; Gao et al. 2022).

Scholars have analysed and discussed the driving factors of farmers' green production behaviour from multiple perspectives. Some researchers argue that factors such as gender (Yang et al. 2024), age (Zhou et al. 2023), educational level (Yu et al. 2021), and physical health status (Yazdanpanah et al. 2022) within farmers' personal characteristics can drive their green production behaviour. Other scholars have found that family income (Qing et al. 2023), the proportion of non-agricultural income (Hou and Wang 2023), and e-commerce adoption rate (Li and Shen 2021) within household characteristics significantly drive farmers' green production behaviour. Scholars have also discovered that operational scale (Li et al. 2020a), farming conditions (Luo et al. 2022), degree of land fragmentation (Sui and Gao 2023), risk management (Wang et al. 2022), land transfer (Qi et al. 2021) within operational characteristics and farmers' awareness of green production technologies (Ataei et al. 2021) all play a driving role in farmers' green production behaviour.

Additionally, government policies (Pan et al. 2022; Wu et al. 2024), relevant publicity (Li et al. 2019), community governance (Niu et al. 2022), village regulations and contracts, quality certification (Du et al. 2023), social capital (Guo et al. 2022), outsourcing services (Yang et al. 2024), digital empowerment (Zhong et al. 2022), farmer cooperative education (Luo et al. 2022), livelihood capital (Ren et al. 2022), social cooperation (Niu et al. 2022), experience sharing (Zhang et al. 2018), and price expectations (Zhao et al. 2018) also drive farmers' green production behaviour.

Current research on the driving factors of farmers' green production behaviour has achieved certain milestones, which hold significant reference value for this study. However, existing research primarily focuses on specific types of green production behaviour, with research categories lacking sufficient detail. Moreover, the research predominantly examines the impact of individual driving factors on farmers' green production behaviour, yet these factors are not adequately specified. Furthermore, previous studies paid little attention to variations in driving factors across farmers of different scales, and the hierarchical relationship between these factors influencing farmers' green production behaviour remains insufficiently clarified.

Therefore, based on the research gap regarding insufficient specificity in categorising green production behaviour among households of different scales, as well as incomplete exploration of driving factors and their hierarchical relationships, this study extensively examines various green production behaviours across different scales of farmers. Underpinning the analysis with a detailed investigation of specific driving factors, the study further analyses their hierarchical relationships. This study provides valuable insights for scholars and experts engaged in agricultural green production, environmental conservation in agriculture, and agricultural climate change studies. Moreover, it offers directional guidance for agricultural authorities to formulate differentiated policies aimed at promoting green production practices among households of varying scales.

Driving factors of green production behavior among small-scale farmers

This study draws on relevant studies by Yu et al. (2021), Luo et al. (2022), Qiao et al. (2022), and Qing

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et al. (2023), combined with field survey data. Considering the current status of green production behaviour among farmers, factors influencing farmers' green production behaviour are categorised into several dimensions: personal characteristics (gender, age, education level, physical health status), household characteristics (number of agricultural workers, part-time farming status, proportion of grain income), operational characteristics (scale of operation, degree of land fragmentation, types of agricultural machinery), social network characteristics (whether relatives and friends are civil servants, relationship with local farm machinery operators), organisational characteristics (membership in cooperatives, collaboration with leading enterprises), and cognitive characteristics (perceptions of the importance of agricultural green production). The theoretical analysis examines how these driving factors impact farmers' green production behavior:

Personal characteristics. Generally, since men may exhibit a higher level of innovation and openness to new things compared to women, they are more likely to adopt green production behaviour (Adnan et al. 2018). Older farmers, due to their lower receptiveness to new ideas, tend to have a lower willingness to adopt green production behaviour (Adnan et al. 2019). Farmers with higher education levels possess better learning and acceptance capabilities for new concepts, leading to a stronger inclination toward adopting green production behaviour (Li et al. 2021). Additionally, healthier farmers, who have more energy and physical strength for agricultural production, have higher demands for agricultural green production, thereby showing a stronger motivation to adopt green production practices (Ataei et al. 2021). Therefore, this study posits the following research hypotheses:

$H_{1.1}$: Men are more likely than women to engage in agricultural green production.

$H_{1.2}$: Younger farmers are more likely than older farmers to participate in agricultural green production.

$H_{1.3}$: Farmers with higher education levels are more likely to engage in agricultural green production.

$H_{1.4}$: Healthier farmers are more likely to be involved in agricultural green production.

Household characteristics. Households with more agricultural labour are able to allocate more labour to agricultural production, have more time and energy to learn about green production practices, and are therefore more likely to adopt agricultural green production behaviour (Adnan et al. 2018). Part-time farmers, having access to a wider range of information channels, possess a deeper understanding of agricultural green production compared to full-time farmers, making them more likely to adopt such practices (Qi et al. 2021). Households with a higher proportion of income from grain are more dependent on agricultural production and are thus more likely to adopt agricultural green production behaviour to enhance the quality of their agricultural products (Li et al. 2021). Therefore, this study proposes the following research hypotheses:

$H_{2.1}$: Farmers with more agricultural labour available in their households are more likely to engage in agricultural green production.

$H_{2.2}$: Part-time farmers are more likely to participate in agricultural green production.

$H_{2.3}$: Farmers from households with a higher proportion of income derived from grain are more likely to engage in agricultural green production.

Operational characteristics. Small-scale farmers with larger operational scales have higher demands for agricultural production, greater capacity to engage with new innovations, and therefore are more likely to participate in agricultural green production (Adnan et al. 2019). Farmers with higher levels of land fragmentation face larger costs in agricultural production and have lower risk tolerance for new practices, resulting in a lower willingness to adopt green production (Qi et al. 2021). Farmers who own a greater variety of agricultural machinery find it easier to utilise multiple machines to experiment with green production practices and are thus more likely to engage in agricultural green production (Sui and Gao 2023). Therefore, this study posits the following research hypotheses:

$H_{3.1}$: Small-scale farmers with larger operational scales are more likely to engage in agricultural green production.

$H_{3.2}$: Farmers with higher levels of land fragmentation are less likely to adopt green production behaviour.

$H_{3.3}$: Farmers who own a greater variety of agricultural machinery are more likely to participate in agricultural green production.

Social network characteristics. Currently, the Chinese government is actively promoting agricultural environmental protection policies in rural areas, with local officials continuously advocating for green production practices. As a result, households with relatives or friends who are government officials are more likely to be influenced by policy promotions, leading to a deeper understanding of agricultural green production and a stronger willingness to engage in such practices (Wu et al. 2021). However, familiarity with agricultural machinery operators has a different impact. Since most ordinary agricultural machinery operators

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in rural China only possess basic tillage and harvesting equipment and lack machinery for green production, households that are more familiar with these operators are more likely to rely directly on them for agricultural production, resulting in a lower willingness to adopt green production practices (Li et al. 2021). Therefore, this study proposes the following research hypotheses:

$H_{4.1}$: Farmers with relatives or friends who are government officials are more likely to engage in agricultural green production.

$H_{4.2}$: Farmers who are more familiar with agricultural machinery operators are less likely to participate in agricultural green production.

Organisational characteristics. Farmers who join cooperatives can more easily access green agricultural machinery provided by the cooperatives, making them more likely to engage in agricultural green production (Yu et al. 2020). Similarly, farmers who collaborate with leading enterprises can utilise advanced green agricultural equipment from these enterprises, which also increases their likelihood of participating in agricultural green production (Zhou et al. 2023). Therefore, this study posits the following research hypotheses:

$H_{5.1}$: Farmers who join cooperatives are more likely to engage in agricultural green production.

$H_{5.2}$: Farmers who collaborate with leading enterprises are more likely to participate in agricultural green production.

Cognitive characteristics. Farm households that perceive agricultural green production as important generally exhibit a stronger inclination towards adopting green agricultural practices compared to those who do not (Ataei et al. 2021). Therefore, this study proposes the following research hypothesis:

H_{6}: Farmers with a higher level of awareness regarding green production behaviour are more likely to engage in agricultural green production.

Figure 1 presents the driving factors for green production behaviour among small-scale farmers.

Identification of the driving factors of green production behaviour among small-scale farmers

Currently, researchers tend to categorise the hierarchical structure of driving factors into direct surface factors, middle indirect factors, and deep-rooted factors (Qiao et al. 2022). According to theory, deep-rooted factors impact middle indirect factors through certain pathways, and middle indirect factors further influence direct surface factors through specific pathways, thereby leading to farmers' green production behaviour. The theoretical analysis of the hierarchical structure of driving factors in this study is as follows:

Deep-rooted factors. These factors represent the determinants at the fundamental level of driving factors and are the primary drivers of farmers' green production behaviour. They are not influenced by other factors and are inherently determined by the natural attributes or endowments of the farmers and their families (Li et al. 2024).

Gender is a natural attribute determined at birth. Age is a qualitative variable determined based on natural circumstances. Education level is an unchangeable variable in the model. Physical health status is a natural attribute of a person. The number of agricultural workers is not influenced by the other factors. The scale of operation refers to the area of land operated by the family and is closely related to the number of family members (Li et al. 2024). The degree of land fragmentation is calculated based on the number of plots and cannot be influenced by other factors. Whether relatives and friends are civil servants is also a variable that cannot be influenced by the other variables. Therefore, the following hypothesis is proposed in this study:

H_{7}: Gender, age, education level, physical health status, number of agricultural workers, the scale of operation, degree of land fragmentation, and whether relatives and friends are civil servants are deep-rooted factors influencing farmers' green production behaviour.

Middle indirect factors. These factors are intermediary influences on farmers' green production behaviour, driven by deep-rooted factors that subsequently impact direct surface factors, thereby fostering green production behaviour (Qiao et al. 2022).

Part-time farming status is influenced by deep-rooted factors. For instance, men are more likely to seek work outside the home. The proportion of grain income is also influenced by deep-rooted factors. For example, the greater the number of agricultural workers, the higher the proportion of grain income. Types of agricultural machinery are influenced by deep-rooted factors. For example, households with higher degrees of land fragmentation tend to own fewer types of agricultural machinery. Relationship with local farm machinery operators is influenced by deep-rooted factors. Households with higher degrees of land fragmentation are more likely to seek help from farm machinery operators (Li et al. 2023). Membership in cooperatives is influenced by deep-rooted factors. Older farmers feeling less capable of farming are more likely to convert their land into cooperative shares. Collaboration with leading enterprises is influenced by deep-rooted factors.

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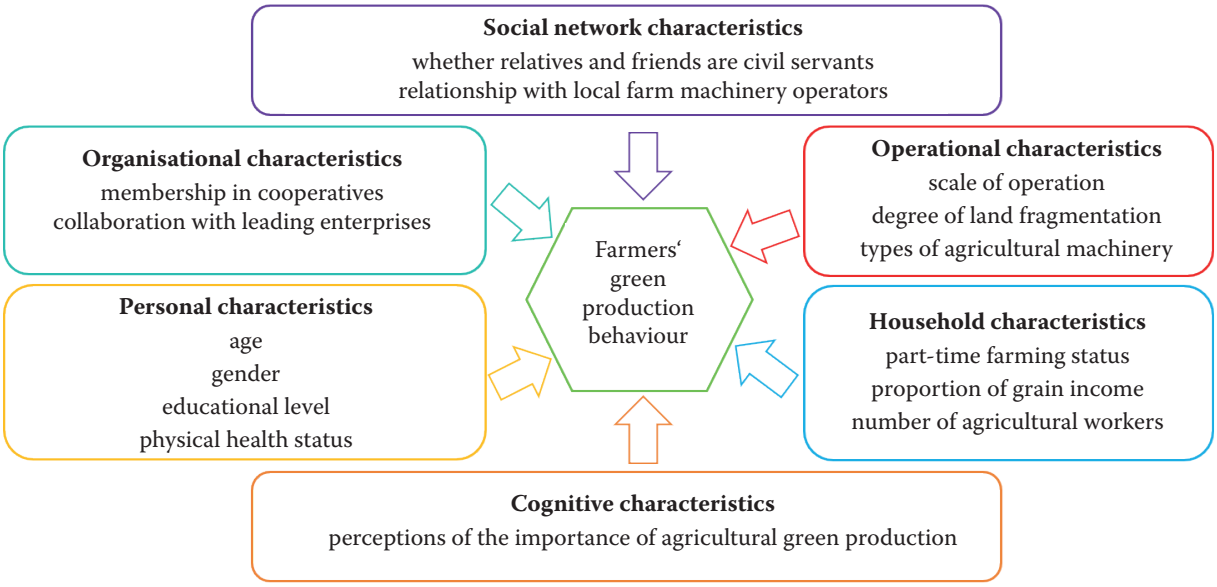

Figure 1. Driving factors of green production behaviour among small-scale farmers

Source: Authors' own elaboration

Farm households with larger land holdings are more likely to collaborate with leading enterprises. Therefore, this study proposes the following research hypothesis:

H_8: Part-time farming status, proportion of grain income, types of agricultural machinery, relationship with local farm machinery operators, membership in cooperatives, and collaboration with leading enterprises serve as middle indirect factors influencing farmers' green production behaviour.

Direct surface factors. Such factors represent direct factors that drive farmers' engagement in green production activities, influenced by middle indirect factors (Li et al. 2023).

The part-time farming status can influence cognitive abilities, as households with a better part-time farming status are more exposed to external knowledge and have greater access to green production knowledge. The proportion of grain income also affects cognition: households with a higher proportion of grain income may be more inclined to acquire additional agricultural production knowledge (Guo et al. 2021). Households with more diverse types of agricultural machinery are generally large-scale family operations with more liquid assets, and these households may be more inclined to acquire more knowledge about green management practices in agriculture. Due to the fact that many farm machinery operators currently possess only conventional agricultural machinery rather than green machinery, they can typically offer only standard agricultural services to farmers instead of offering green services. Furthermore, farmers who are familiar with local farm machinery operators have developed a path-dependent relationship in their agricultural production processes, relying solely on these operators for their services. As a result, they lack the motivation to actively seek green services from other service organizations. Consequently, farmers who are more familiar with local farm machinery operators may exhibit a lower level of awareness regarding agricultural green production practices. (Xu et al. 2022b). Households that are members of cooperatives are likely to have higher cognitive abilities related to green production due to knowledge dissemination within cooperatives. Similarly, households collaborating with leading enterprises are typically local grain growers with enhanced cognitive abilities related to green production. Therefore, this study posits the following research hypothesis:

H_9: Cognitive characteristics are a direct surface factor influencing household green production behaviour.

Figure 2 identifies the dimensions of drivers for green production behaviour among small-scale farmers.

Driving factors of green production behaviour among large-scale farmers

Building upon the research on small-scale farmers, this study, based on the work of Li and Shen (2021), Li et al. (2021), Wu et al. (2021, 2024), and Yu et al. (2021), we selected personal characteristics, household characteristics, operational characteristics, social network

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characteristics, organisational characteristics, and cognitive characteristics as the factors driving the green production behaviour of large-scale farmers.

Personal characteristics. Male farmers generally have higher risk tolerance and are more likely to adopt green production behaviour; younger farmers are more adept at embracing new innovations and are therefore more likely to adopt green production behaviour (Yu et al. 2021); farmers with higher educational levels are more receptive to green production behaviour and are consequently more likely to adopt them; and healthier farmers, having more physical capacity to experiment with new practices, are also more likely to engage in green production behaviour (Li et al. 2021). Therefore, this study posits the following research hypotheses:

$H_{10.1}$: Male large-scale farmers are more likely than female large-scale farmers to engage in agricultural green production practices.

$H_{10.2}$: Younger large-scale farmers are more likely than older large-scale farmers to engage in agricultural green production.

$H_{10.3}$: Large-scale farmers with higher education levels are more likely to engage in agricultural green production than those with lower education levels.

$H_{10.4}$: Large-scale farmers who are healthier are more likely to engage in agricultural green production than those who are less healthy.

Household characteristics. In general, large-scale farmers with a higher number of agricultural labourers have greater demands for agricultural production and are more likely to adopt green production behaviour (Li et al. 2021). Part-time large-scale farmers, with their broader experience, are more knowledgeable about green production and are more likely to implement these behaviours. Additionally, large-scale farmers who have a higher proportion of income from grain are more focused on agricultural production and are more likely to adopt green production behaviour (Li and Shen 2021). Therefore, this study proposes the following research hypotheses:

$H_{11.1}$: Large-scale farmers with more agricultural labourers are more likely to engage in agricultural green production.

$H_{11.2}$: Part-time large-scale farmers are more likely to engage in agricultural green production.

$H_{11.3}$: Large-scale farmers with a higher proportion of income from grain are more likely to engage in agricultural green production.

Operational characteristics. Large-scale farmers with a larger operational scale can benefit from economies of scale, reducing the costs associated with adopting new technologies, and are therefore more likely to implement green production behaviour (Li and Shen 2021). Conversely, large-scale farmers with more fragmented land are unable to achieve economies of scale in agricultural production, which increases the costs of adopting new technologies, making them less likely to adopt green production behaviour (Wu et al. 2021). Additionally, large-scale farmers with a greater variety of agricultural machinery may already possess green machinery compatible with green production technologies, increasing the likelihood of adopting such behaviour. Therefore, this study posits the following research hypotheses:

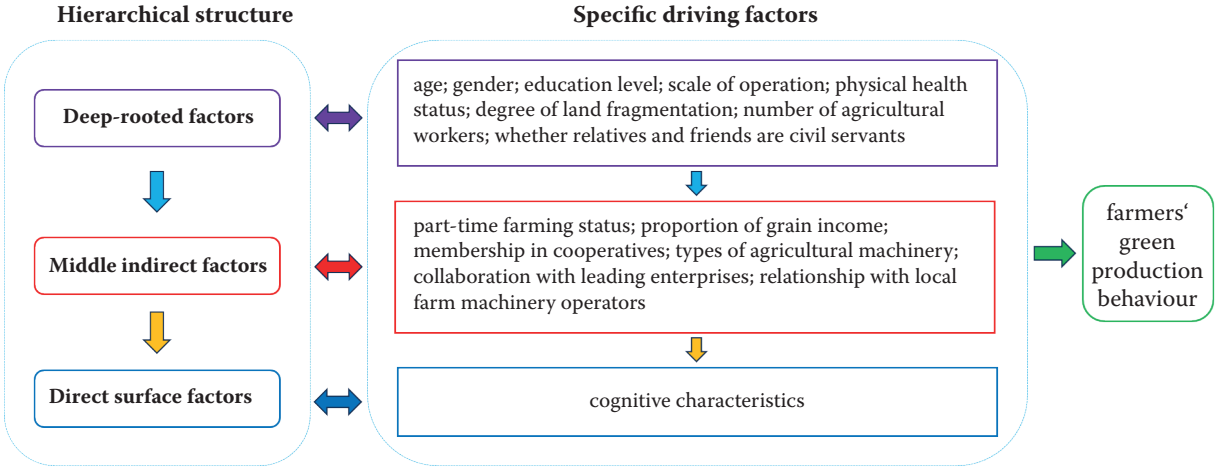

Figure 2. Identification of the driving factors of green production behaviour among small-scale farmers

Source: Authors' own elaboration

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$H_{12.1}$: Large-scale farmers with a larger operational scale are more likely to engage in agricultural green production.

$H_{12.2}$: Large-scale farmers with a higher degree of land fragmentation are more likely to refrain from engaging in agricultural green production.

$H_{12.3}$: Large-scale farmers with a greater variety of agricultural machinery are more likely to participate in agricultural green production.

Social network characteristics. In terms of social network characteristics, there are differences between large-scale farmers and small-scale farmers. Due to their extensive networks, large-scale farmers are likely to have a level of awareness about agricultural green production that is comparable to or exceeds that of public officials, thus experiencing a lower degree of influence from public official campaigns (Wu et al. 2021). Additionally, large-scale farmers may already possess agricultural machinery for ploughing, planting, and harvesting services, which results in a reduced impact from local agricultural machinery operators (Yu et al. 2021). Therefore, this study proposes the following research hypotheses:

$H_{13.1}$: The occupation of relatives or friends as public officials does not have a significant driving effect on large-scale farmers engaging in agricultural green production.

$H_{13.2}$: Familiarity with local agricultural machinery operators does not have a significant driving effect on large-scale farmers engaging in agricultural green production.

Organisational characteristics. In terms of farmer organisational characteristics, there are significant differences between large-scale and small-scale farmers. Compared to small-scale farmers, large-scale farmers generally possess greater financial resources and a more diverse range of agricultural machinery. Some large-scale farmers even establish cooperatives or leading agricultural enterprises themselves. Due to their larger capacity for engaging in agricultural green production, they are less influenced by cooperatives or leading enterprises (Wu et al. 2024). Therefore, this study posits the following research hypotheses:

$H_{14.1}$: Joining a cooperative does not have a significant impact on the green production behaviour of large-scale farmers.

$H_{14.2}$: Collaboration with leading agricultural enterprises does not have a significant impact on their green production behaviour.

Cognitive characteristics. Similar to small-scale farmers, large-scale farmers with a higher level of awareness regarding agricultural green production show greater interest and motivation in engaging in green production behaviour (Wu et al. 2021). Therefore, this study proposes the following research hypothesis:

H_{15}: Large-scale farmers with a higher level of awareness regarding agricultural green production are more likely to engage in green production behaviour.

Figure 3 presents the driving factors for green production behaviour among large-scale farmers.

Identification of the driving factors of green production behaviour among large-scale farmers

Similar to small-scale farmers, and following the framework proposed by Qiao et al. (2022), the driving factors behind the green production behaviour of large-scale farmers can be categorised into three hi-

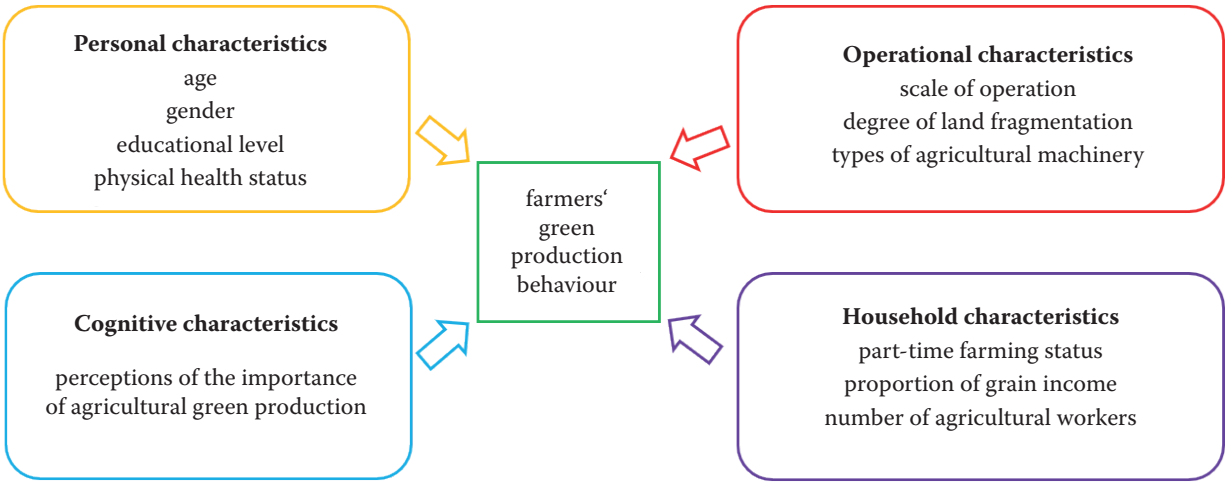

Figure 3. Driving factors of green production behaviour among large-scale farmers

Source: Authors' own elaboration

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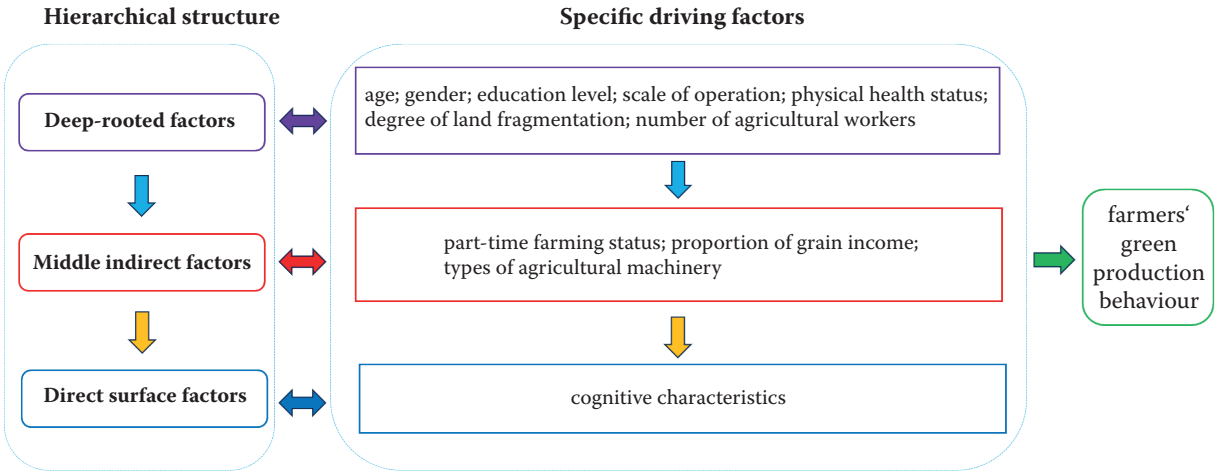

Figure 4. Identification of the driving factors of green production behaviour among large-scale farmers

Source: Authors' own elaboration

erarchical levels: deep-rooted factors, middle indirect factors, and direct surface factors.

Deep-rooted factors. Based on the above analysis, it is evident that large-scale farmers are not significantly influenced by whether their relatives or friends are civil servants (Wu et al. 2021). Therefore, integrating the hierarchical structure of the driving factors for small-scale farmers' green production behaviour, this study posits the following research hypothesis:

H_{16}: Age, gender, education level, the scale of operation, physical health status, degree of land fragmentation, and the number of agricultural workers are considered deep-rooted factors driving the green production behaviour of large-scale farmers.

Middle indirect factors. Based on the above analysis, it is apparent that large-scale farmers are not significantly influenced by local agricultural machinery operators, membership in cooperatives, or partnerships with leading enterprises (Wu et al. 2024). Therefore, this study proposes the following research hypothesis:

H_{17}: Part-time farming status, the proportion of grain income, and types of agricultural machinery are considered middle indirect factors driving the green production behaviour of large-scale farmers.

Direct surface factors. The analysis above indicates that, similar to small-scale farmers, large-scale farmers are also significantly influenced by cognitive characteristics (Wu et al. 2021). Therefore, integrating the hierarchical structure of driving factors for small-scale farmers' green production behaviour, this study posits the following research hypothesis:

H_{18}: Cognitive characteristics are considered direct surface factors driving the green production behaviour of large-scale farmers.

Figure 4 identifies the dimensions of drivers for green production behaviour among large-scale farmers.

MATERIAL AND METHODS

Conceptual definition

Farmers' green production behaviour. In this study, we comprehensively considered all stages of farmers' agricultural production and extensively surveyed four specific green production behaviours: coated seeds, soil testing-based fertilisation, deep tillage, and integrated pest management. Based on the existing research (Sui and Gao 2023), this study defined farmers' green production behaviour as follows: If a farmer adopts any one of the four green production behaviours (coated seeds, soil testing-based fertilisation, deep tillage, or integrated pest management) they are considered to have adopted green production behaviour.

Classification of farmers by scale. Through field surveys and literature review, we identified significant heterogeneity in green production behaviour among farmers of various scales, prompting the need for distinct studies on this topic. The categorisation of farmer scale primarily distinguishes between small-scale farmers and large-scale farmers, yet scholars dispute the specific criteria for this differentiation (Wu et al. 2021). This paper draws on relevant studies, adopting the 0.0067 km² standard to classify farmers: catego-

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rising those with less than 0.0067 km² as small-scale farmers and those with 0.0067 km² or more as large-scale farmers.

Models

Probit model. This paper selects grain-growing farmers as the research subjects, with the dependent variable being whether farmers adopt agricultural green production behaviour, which is a binary decision problem. Therefore, this paper employs the probit regression model to analyse various driving factors (Zhao et al. 2021). In the survey data, $Y = 0$ represents not adopting agricultural green production behaviour, and $Y = 1$ represents adopting agricultural green production behaviour. The paper constructed a binary probit analysis model for the adoption of green production behaviour by farmers to clarify the impact of different driving factors on farmers' green production behaviour. The specific form of the model is as shown in Equation (1):

$$\begin{aligned}\text{Prob}\,(Y = 1|x_1, x_2, \ldots, x_k) &= \\ &= 1 - \Phi\,[-(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k)] \\ &= \Phi\,(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k)\end{aligned} \quad (1)$$

where: prob(–) – probability of farmers adopting agricultural green production behaviour; Y – dependent variable, indicating whether farmers adopt agricultural green production behavior; $\Phi(-)$ – standard normal cumulative distribution function; β_0 – intercept term; $x_1, x_2, \ldots, x_k$ – independent variables; $\beta_1, \beta_2, \ldots, \beta_k$ – coefficients of the independent variables.

ISM model. Interpretive structural modelling (ISM) is commonly used as a tool to analyse complex economic and social issues (Xu et al. 2022a). It is primarily used to determine the hierarchical relationships among various factors. By utilising matrices and corresponding computational methods, the model analyses the interrelationships and hierarchical structure among these driving factors (Guo et al. 2021). This process ultimately identifies deep-rooted factors, middle indirect factors, and direct surface factors. The results are then illustrated using appropriate diagrams. Specifically, the operational steps of the ISM model were as follows:

First, we determined the adjacency matrix R between factors. Assuming there are k significant driving factors, where S_0 represents the specific situation of farmers' adoption of green production behaviour, and S_i (S_j) represents the *i(j)* significant driving factor, the elements of the adjacency matrix R were defined by Equation (2):

$$r_{ij} = \begin{cases} 1\ (S_i \text{ has relationship with } S_j) \\ 0\ (S_i \text{ hasn't relationship with } S_j) \end{cases} \quad (2)$$

$(i, j = 0, 1, \ldots, k)$

Next, we determined the accessibility matrix M between factors, which was calculated using Equation (3):

$$\begin{aligned}M = (R + I)^{\lambda+1} = (R + I)^{\lambda} \neq (R + I)^{\lambda-1} \\ \neq \ldots \neq (R + I)^2 \neq (R + I)\end{aligned} \quad (3)$$

where: I – identity matrix, where $2 \leq \lambda \leq k$, and matrix exponentiation is performed using Boolean algebra.

Then we determined the hierarchical structure and logical relationships of each driving factor. From Equation (4), it can be observed that the accessibility matrix was divided into the reachable set $P(S_i)$ and the antecedent set $Q(S_i)$, both representing the set of all driving factors reachable from the factor S_i in the accessibility matrix, where m_{ij} and m_{ji} represent factors in the accessibility matrix. Equation (5) was used to determine the highest level (L_1) and its included driving factors and then sequentially determine other levels. The specific operation involved removing the rows and columns containing the highest-level factors from the accessibility matrix M to form the accessibility matrix M_1, and repeating the steps of Equation (4) and Equation (5) to obtain the factors in the second level, and so on, until all levels were identified.

$$P(S_i) = \{S_j|m_{ij} = 1\},\ Q(S_i) = \{S_j|m_{ij} = 1\} \quad (4)$$

$$L_1 = \{S_i|P(S_i) \cap Q(S_i) = P(S_i);\ i = 0, 1, \ldots, k\} \quad (5)$$

Finally, we determined the hierarchical structure of each driving factor and connected the factors between adjacent levels with directed arrows to obtain the hierarchical structure of driving factors for green production behaviour among farmers.

Data and variables

Study area. The study area of this research was the North China Plain, known for the highest grain production in China. Among the provinces included in this study were Henan, Shandong, Jiangsu, Anhui,

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and Hebei, all of which rank prominently in national grain production.

Data sources. The survey employed a combination of multi-stage stratified sampling and random sampling methods. It was conducted through face-to-face interviews, with the questionnaires being filled out by the researchers themselves. After removing invalid questionnaires (those with missing key information, logical errors, or variable deficiencies), a total of 1 142 valid questionnaires were collected, resulting in a questionnaire validity rate of 95.17%.

Dependent variable. The dependent variable in this study was the adoption of green production behaviour. As described earlier, the definition of farmers' green production behaviour in this study was 'if the surveyed households adopt any one of the four green farming practices, namely coated seed, soil testing-based fertilisation, deep tillage, and integrated pest management,

Table 1. Variable description and basic information

Variable names	Variable description and assignment	Mean	SD
Dependent variable			
Adoption of green production behaviour	engagement in green production in 2019: yes = 1; no = 0	0.306	0.461
Independent variable			
Personal characteristics			
Gender	household head gender: male = 1; female = 0	0.890	0.313
Age	age of the household head (years)	55.596	4.926
Education level	educational level of the household head: primary school and below = 1; junior high school = 2; high school and technical secondary school = 3; college and above = 4	1.857	0.700
Physical health status	self-rated physical health status of the household head: poor = 1; fair = 2; good = 3	2.771	0.549
Household characteristics			
Number of agricultural workers	number of agricultural labourers in the household (people)	2.810	0.946
Part-time farming status	whether family members engaged in off-farm work or business in the past year: yes = 1; no = 0	0.691	0.462
Proportion of grain income	Proportion of grain income to total household income: [0%, 10%) = 1; [10%, 20%) = 2; [20%, 30%) = 3; [30%, 50%) = 4; 50% and above = 5	2.772	1.198
Operational characteristics			
Scale of operation	operational area of farmland for the household (km^2)	0.010	0.014
Degree of land fragmentation	number of land plots	5.570	1.310
Types of agricultural machinery	number of types of agricultural machinery owned by the household	2.131	1.865
Social network characteristics			
Whether relatives and friends are civil servants	whether your relatives or friends are civil servants: yes = 1; no = 0	0.086	0.280
Relationship with local farm machinery operators	is your household familiar with local agricultural machinery operators: yes = 1; no = 0	0.264	0.441
Organizational characteristics			
Membership in cooperatives	have you joined a cooperative: yes = 1; no = 0	0.256	0.436
Collaboration with leading enterprises	are you cooperating with a leading enterprise: yes = 1; no = 0	0.084	0.278
Cognitive characteristic			
Perception of the importance of agricultural green production	not important = 1; moderate = 2; quite important = 3	2.818	0.515

Source: Authors' own processing

https://doi.org/10.17221/188/2024-AGRICECON

they are considered to have adopted green production behaviour'.

Independent variables. As described above, the independent variables in this study included personal characteristics (gender, age, education level, physical health status), household characteristics (number of agricultural workers, part-time farming status, proportion of grain income), operational characteristics (scale of operation, degree of land fragmentation, types of agricultural machinery), social network characteristics (whether relatives and friends are civil servants, relationship with local farm machinery operators), organisational characteristics (membership in cooperatives, collaboration with leading enterprises), and cognitive characteristic (perception of the importance of agricultural green production).

Table 1 provides the variable description and basic information of this study.

RESULTS

Driving factors and dimensions of green production behaviour among small-scale farmers

Driving factors of small-scale farmers. The probit regression model for analysing the driving factors of green production behaviour among small-scale farmers was conducted using Stata 15.0 software, and the specific computational results are shown in Table 2. The Wald test statistic was 117.91, which passed the significance test at the 1% level, indicating a good overall fit of the model.

Specifically, gender had a significant positive impact on green production behaviour among small-scale farmers, as male farmers tend to be more adventurous compared to female farmers. Age was negatively correlated with green production behaviour among small-scale farmers, as younger farmers had weaker path dependency on traditional extensive agricultural production methods. Education level was positively correlated with green production behaviour among small-scale farmers, as those with higher levels of education tended to be more receptive to green production practices. Physical health status was positively correlated with green production behaviour among small-scale farmers, as farmers with better physical health were more energetic in engaging in agricultural green production activities. The number of agricultural workers was positively correlated with green production behaviour among small-scale farmers, as households with more agricultural workers were more capable of managing agricultural activities compared to those with fewer workers. Part-time farming status was positively correlated with green production behaviour among small-scale farmers, as farmers engaged in part-time work or business activities were generally more able to quickly understand the basics of agricultural green production. The proportion of grain income was positively correlated with green production behaviour among small-scale farmers, as households with a higher proportion of grain income tended to prioritise agricultural production.

Table 2. Probit analysis of driving factors of green production behaviour among small-scale farmers

Variable name	Coefficient	Robust SE	*Z*-value
Gender	0.397*	0.209	1.900
Age	–0.022*	0.012	–1.833
Education level	0.178*	0.100	1.780
Physical health status	0.212*	0.123	1.724
Number of agricultural workers	0.148**	0.062	2.387
Part-time farming status	0.314**	0.127	2.472
Proportion of grain income	0.107*	0.062	1.726
Scale of operation	0.154***	0.033	4.667
Degree of land fragmentation	–0.911**	0.425	–2.144
Types of agricultural machinery	0.055*	0.033	1.667
Whether relatives and friends are civil servants	0.648**	0.265	2.445
Acquaintance with local farm machinery operators	–0.333**	0.140	–2.379
Membership in cooperatives	0.589***	0.172	3.424
Collaboration with leading enterprises	0.599**	0.276	2.170
Perception of the importance of agricultural green production	0.258**	0.127	2.031
Constant term	–2.880***	0.857	–3.361
Sample size		573.000	
Log pseudolikelihood		–275.010	
Wald χ^2 (15)		117.910***	
Probability > χ^2		0.000	
Pseudo R^2		0.173	

*, **, *** statistical significance at the 10%, 5%, and 1% levels, respectively, in the *t*-test for mean differences

Source: Authors' own processing.

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The scale of the operation was positively correlated with green production behaviour among small-scale farmers, as larger-scale farmers were relatively more able to achieve economies of scale in agricultural green production. The degree of land fragmentation was negatively correlated with green production behaviour among small-scale farmers, as higher degrees of land fragmentation implied higher marginal costs for farmers engaging in agricultural green production. The types of agricultural machinery were positively correlated with green production behaviour among small-scale farmers, as households with more types of agricultural machinery were more likely to possess green agricultural machinery themselves. Whether relatives and friends were civil servants was positively correlated with green production behaviour among small-scale farmers, as households with relatives and friends who were civil servants were more likely to be recommended to engage in agricultural green production by these civil servant connections. Acquaintance with local farm machinery operators was negatively correlated with green production behaviour among small-scale farmers, as households less familiar with agricultural machinery operators were less likely to prioritise seeking help from them in the mechanical operations of agricultural production.

Membership in cooperatives was positively correlated with green production behaviour among small-scale farmers, as joining a cooperative allowed farmers to access the green services provided to members by the cooperative. Collaboration with leading enterprises was positively correlated with green production behaviour among small-scale farmers, as farmers collaborating with leading enterprises can benefit from the green production machinery provided by these enterprises. Farmers' cognitive characteristic was positively correlated with green production behaviour among small-scale farmers, as those who perceived agricultural green production as more important tended to have a stronger understanding of agricultural green production.

Dimension identification of small-scale farmers. According to the probit model analysis above, the significant driving factors of green production behaviour among small-scale farmers included gender, age, education level, physical health status, number of agricultural workers, part-time farming status, the proportion of grain income, the scale of operation, degree of land fragmentation, types of agricultural machinery, whether relatives and friends are civil servants, acquaintance with local farm machinery operators, membership in cooperatives, collaboration with leading enterprises, and perception of the importance of agricultural green production, totalling 15 variables. These variables are denoted as S_i *(i=1, 2, …, 15)*, while agricultural green production behaviour is represented with S_0.

Based on theoretical analysis and expert consultation, the logical relationships between these factors were determined as shown in Figure 5, where *V* indicates that the row factor had a direct or indirect influence on the column factor, *A* indicates that the column factor had a direct or indirect influence on the row factor, and 0 indicates that there was no mutual influence between the row and column factors. The adjacency matrix of the calculated driving factors is shown in Figure 6. The accessibility matrix was calculated from the adjacency matrix, as shown in Figure 7.

Through analysis and calculation, the top-level element set $L_1=\{S_0\}$ was obtained. Subsequently, the second, third, and fourth-level element sets were derived as follows: $L_2=\{S_{15}\}$, $L_3=\{S_6, S_7, S_{10}, S_{12}, S_{13}, S_{14}\}$, $L_4=\{S_1, S_2, S_3, S_4, S_5, S_8, S_9, S_{11}\}$. Based on L_1, L_2, L_3, and L_4, the rows and columns were rearranged to obtain the skeleton matrix, as shown in Figure 8.

Finally, based on the hierarchical structure of the driving factors, the ISM of green production behaviour of small-scale farmers was obtained, as shown in Figure 9. From the figure, it can be observed that the conclusions drawn from the ISM model aligned with the theoretical analysis presented earlier. The cognitive characteristic of farmers was the direct surface factor driving green production behaviour among small-scale farmers. Part-time farming status, the proportion of grain income, types of agricultural machinery, acquaintance with local farm machinery operators, membership in cooperatives, and collaboration with leading enterprises serve as middle indirect factors driving green production behaviour. Gender, age, education level, physical health status, number of agricultural workers, the scale of operation, degree of land fragmentation, and whether relatives and friends are civil servants represent the deep-rooted factors driving green production behaviour among small-scale farmers.

Driving factors and dimensions of green production behaviour among large-scale farmers

Driving factors of large-scale farmers. The probit regression model was used to analyse the driving fac-

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A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	S_0
V	0	0	V	0	0	0	0	0	V	V	0	V	0	S_1	
V	0	0	V	0	0	0	0	0	V	V	V	V	S_2		
V	V	V	0	0	0	0	0	V	V	V	0	S_3			
0	0	0	0	0	V	0	0	V	V	V	S_4				
0	0	0	V	0	V	V	V	V	A	S_5					
V	0	0	V	0	V	0	A	V	S_6						
V	A	A	V	0	V	0	A	S_7							
0	V	V	V	0	V	0	S_8								
0	0	0	V	0	V	S_9									
V	V	V	V	0	S_{10}										
V	V	V	0	S_{11}											
V	A	A	S_{12}												
V	V	S_{13}													
V	S_{14}														
S_{15}															

Figure 5. The logical relationship between driving factors of small-scale farmers

A – column factor had a direct or indirect influence on the row factor; V – row factor had a direct or indirect influence on the column factor

Source: Authors' own processing

$$R' = \begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&1&0&1&1&0&0&0&0&0&1&0&0&1\\
1&0&0&1&1&1&1&0&0&0&0&0&1&0&0&1\\
1&1&1&0&0&1&1&1&0&0&0&0&0&1&1&1\\
1&0&1&0&0&1&1&1&0&0&1&0&0&0&0&0\\
1&1&1&1&1&0&1&1&1&1&1&0&1&0&0&0\\
1&1&1&1&1&1&0&1&0&0&1&0&1&0&0&1\\
1&0&0&1&1&1&1&0&1&0&1&0&1&1&1&1\\
1&0&0&0&0&1&1&1&0&0&1&0&1&1&1&0\\
1&0&0&0&0&1&0&0&0&0&1&0&1&0&0&0\\
1&0&0&0&1&1&1&1&1&1&0&0&1&1&1&1\\
1&0&0&0&0&0&0&0&0&0&0&0&0&1&1&1\\
1&1&1&0&0&1&1&1&1&1&1&0&0&1&1&1\\
1&0&0&1&0&0&0&1&1&0&1&1&1&0&1&1\\
1&0&0&1&0&0&0&1&1&0&1&1&1&1&0&1\\
1&1&1&1&0&0&1&1&0&0&1&1&1&1&1&0
\end{bmatrix}$$

Figure 6. Adjacency matrix of small-scale farmers

R – adjacency matrix

Source: Authors' own processing

$$M' = \begin{bmatrix}
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&1&0&1&0&1&1&0&0&0&0&0&1&0&0&1\\
1&0&1&1&1&1&1&0&0&0&0&0&1&0&0&1\\
1&0&0&1&0&1&1&1&0&0&0&0&0&1&1&1\\
1&0&0&0&1&1&1&1&0&0&1&0&0&0&0&0\\
1&0&0&0&0&1&0&1&1&1&1&0&1&0&0&0\\
1&0&0&0&0&1&1&1&0&0&1&0&1&0&0&1\\
1&0&0&0&0&0&0&1&0&0&1&0&1&0&0&0\\
1&0&0&0&0&0&0&1&1&0&1&0&1&1&1&0\\
1&0&0&0&0&0&0&0&1&1&1&0&1&0&0&0\\
1&0&0&0&0&0&0&0&0&0&1&0&1&1&1&0\\
1&0&0&0&0&0&0&0&0&0&0&1&0&1&1&1\\
1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0\\
1&0&0&0&0&0&0&0&0&0&0&0&0&1&1&1\\
1&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1\\
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1
\end{bmatrix}$$

Figure 7. Accessibility matrix of small-scale farmers

M – accessibility matrix

Source: Authors' own processing

https://doi.org/10.17221/188/2024-AGRICECON

N' =

	S_0	S_{15}	S_{14}	S_{13}	S_{12}	S_{10}	S_7	S_6	S_{11}	S_9	S_8	S_5	S_4	S_3	S_2	S_1
S_0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{15}	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{14}	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{13}	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
S_{12}	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S_{10}	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
S_7	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
S_6	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
S_{11}	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
S_9	1	0	1	0	1	0	1	0	0	1	0	0	0	0	0	0
S_8	1	0	1	0	0	1	0	1	0	0	1	0	0	0	0	0
S_5	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0
S_4	1	1	0	1	0	0	0	1	0	0	0	0	1	0	0	0
S_3	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
S_2	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0
S_1	1	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1

Figure 8. Skeleton matrix of small-scale farmers

N – skeleton matrix

Source: Authors' own processing

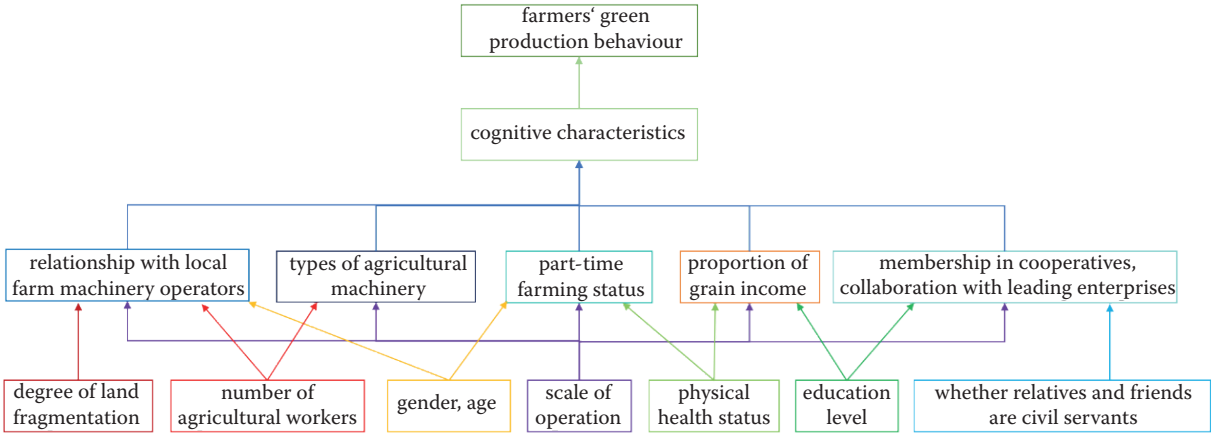

Figure 9. The hierarchical structure of driving factors of green production behaviour among small-scale farmers

Source: Authors' own elaboration

tors of green production behaviour among large-scale farmers using Stata 15.0 software, and the specific computational results are shown in Table 3. As indicated in the table, the Wald test statistic was 138.99, passing the significance test at the 1% level, suggesting a good overall model fit.

Factors such as gender, age, education level, physical health status, number of agricultural workers, part-time farming status, the proportion of grain income, the scale of operation, degree of land fragmentation, types of agricultural machinery, and the cognitive characteristic all had a significant impact on the green production behaviour of large-scale farmers.

It is important to note that whether relatives and friends were civil servants, acquaintance with local farm machinery operators, membership in cooperatives, and collaboration with leading enterprises did not have a significant impact on the green production behaviour of large-scale farmers. This is because large-scale farmers generally had their own agricultural production habits and mindset, making them less susceptible to the influence of social networks or organisational characteristics compared to small-scale farmers.

Dimension identification of large-scale farmers. According to the probit model analysis above, there were 11 variables that drove the green production behaviour of large-scale farmers, including gender,

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Table 3. Probit analysis of driving factors of green production behaviour among large-scale farmers

Variable names	Coefficient	Robust SE	*Z*-value
Gender	1.405***	0.377	3.727
Age	–0.055***	0.014	–3.929
Education level	0.373***	0.105	3.552
Physical health status	0.752***	0.170	4.424
Number of agricultural workers	0.196***	0.066	2.970
Part-time farming status	0.260*	0.151	1.722
Proportion of grain income	0.277***	0.066	4.197
Scale of operation	0.015***	0.004	3.750
Degree of land fragmentation	–1.153***	0.448	–2.574
Types of agricultural machinery	0.089***	0.033	2.697
Whether relatives and friends are civil servants	0.362	0.239	1.515
Acquaintance with local farm machinery operators	–0.076	0.161	–0.472
Membership in cooperatives	0.224	0.157	1.427
Collaboration with leading enterprises	0.349	0.220	1.586
Perception of the importance of agricultural green production	0.699**	0.286	2.444
Constant term	–5.406***	1.375	–3.932
Sample size		569.000	
Log pseudolikelihood		–274.560	
Wald χ^2 (15)		138.990***	
Probability > χ^2		0.000	
Pseudo R^2		0.251	

*, **, *** statistical significance at the 10%, 5%, and 1% levels, respectively, in the *t*-test for mean differences
Source: Authors' own processing

A	A	A	A	A	A	A	A	A	A	A	S_0
V	0	0	0	0	V	V	0	V	0	S_1	
V	0	0	0	0	V	V	V	V	S_2		
V	0	0	0	V	V	V	0	S_3			
0	V	0	0	V	V	V	S_4				
0	V	V	V	V	A	S_5					
V	V	0	A	V	S_6						
V	V	0	A	S_7							
0	V	A	S_8								
0	V	S_9									
V	S_{10}										
S_{11}											

Figure 10. The logical relationship between driving factors of large-scale farmers

V – row factor had a direct or indirect influence on the column factor; A – column factor had a direct or indirect influence on the row factor
Source: Authors' own processing

https://doi.org/10.17221/188/2024-AGRICECON

R" =

0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	1	0	1	1	0	0	0	0	1
1	0	0	1	1	1	1	0	0	0	0	1
1	1	1	0	0	1	1	1	0	0	0	1
1	0	1	0	0	1	1	1	0	0	1	0
1	1	1	1	1	0	1	1	1	1	1	0
1	1	1	1	1	1	0	1	1	0	1	1
1	0	0	1	1	1	1	0	1	0	1	1
1	0	0	0	0	1	1	1	0	1	1	0
1	0	0	0	0	1	0	0	1	0	1	0
1	0	0	0	0	1	1	1	1	1	1	0
1	1	1	1	0	0	1	1	0	0	1	0

Figure 11. Adjacency matrix of large-scale farmers

R – adjacency matrix
Source: Authors' own processing

M" =

1	0	0	0	0	0	0	0	0	0	0	0
1	1	0	1	0	1	1	0	0	0	0	0
1	0	1	1	1	1	1	0	0	0	0	0
1	0	0	1	0	1	1	1	0	0	0	0
1	0	0	1	1	1	1	1	0	0	1	0
1	0	0	0	0	1	0	1	1	1	1	0
1	0	0	0	0	0	1	1	0	0	1	0
1	0	0	0	0	0	0	1	0	0	1	0
1	0	0	0	0	0	0	1	1	0	1	0
1	0	0	0	0	0	0	0	0	1	1	0
1	0	0	0	0	0	0	0	0	0	1	0
1	0	0	0	0	0	0	0	0	0	0	1

Figure 12. Accessibility matrix of large-scale farmers

M – accessibility matrix
Source: Authors' own processing

age, education level, physical health status, number of agricultural workers, part-time farming status, proportion of grain income, scale of operation, degree of land fragmentation, types of agricultural machinery, and cognitive characteristics. These variables were denoted as S_i *(i=1, 2, ..., 11)*, while agricultural green production behaviour was denoted as S_0. The logical relationships between these factors are shown in Figure 10. The adjacency matrix of the calculated driving factors is shown in Figure 11. The accessibility matrix was calculated from the adjacency matrix, as shown in Figure 12.

Through analysis and calculation, the top-level element set $L_1 = \{S_0\}$ was obtained. Subsequently, the second, third, and fourth-level element sets were derived as follows: $L_2 = \{S_{11}\}$, $L_3 = \{S_6, S_7, S_{10}\}$, $L_4 = \{S_1, S_2, S_3, S_4, S_5, S_8, S_9\}$. Based on L_1, L_2, L_3, and L_4, the rows and columns were rearranged to obtain the skeleton matrix as shown in Figure 13.

Finally, based on the hierarchical structure of the driving factors, the ISM of green production behaviour of large-scale farmers was obtained as shown in Figure 14. From the figure, it can be observed that the conclusions drawn from the ISM model aligned with the theoretical analysis presented earlier. The cognitive characteristic of farmers was the direct surface factor driving green production behaviour among large-scale farmers. Part-time farming status, the proportion of grain income, and types of agricultural machinery served as middle indirect factors driving green production behaviour. Gender, age, education level, physical health status, number of agricultural workers, the scale of operation, and degree of land fragmentation represent the deep-rooted factors driving green production behaviour among large-scale farmers.

N" =

	S_0	S_{11}	S_{10}	S_7	S_6	S_9	S_8	S_5	S_4	S_3	S_2	S_1
S_0	1	0	0	0	0	0	0	0	0	0	0	0
S_{11}	1	1	0	0	0	0	0	0	0	0	0	0
S_{10}	1	1	1	0	0	0	0	0	0	0	0	0
S_7	1	1	0	1	0	0	0	0	0	0	0	0
S_6	1	1	0	0	1	0	0	0	0	0	0	0
S_9	1	1	0	0	0	1	0	0	0	0	0	0
S_8	1	1	1	1	1	0	1	0	0	0	0	0
S_5	1	1	0	0	0	0	0	1	0	0	0	0
S_4	1	1	0	0	0	0	0	0	1	0	0	0
S_3	1	1	1	1	1	0	0	0	0	1	0	0
S_2	1	1	1	1	1	0	0	0	0	0	1	0
S_1	1	1	0	0	0	0	0	0	0	0	0	1

Figure 13. Skeleton matrix of large-scale farmers

N – skeleton matrix
Source: Authors' own processing

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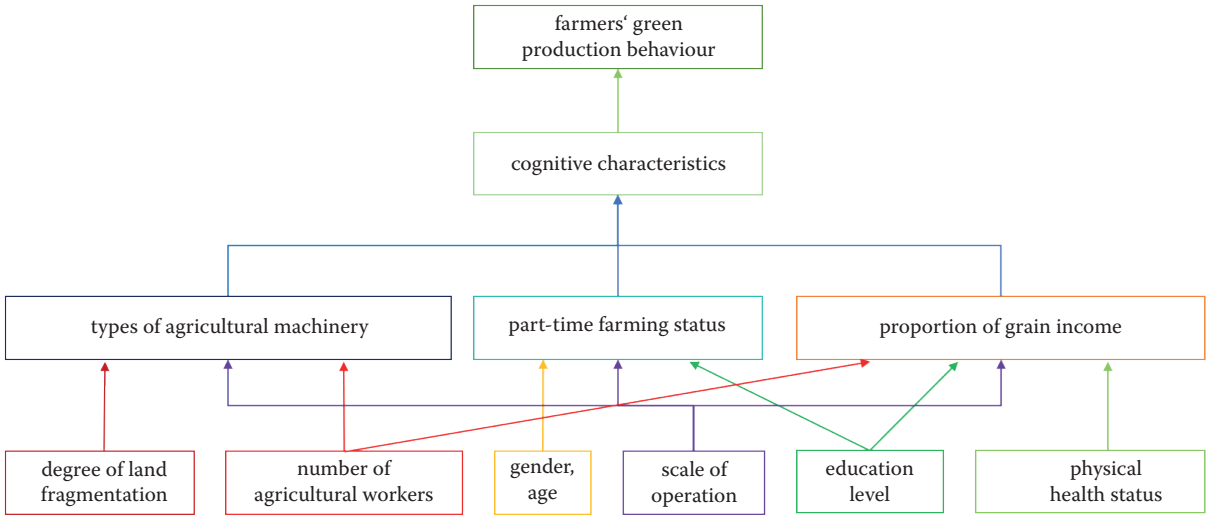

Figure 14. The hierarchical structure of driving factors of green production behaviour among large-scale farmers

Source: Authors' own processing

DISCUSSION

Theoretical contributions. First, this study encompassed agricultural green production behaviours related to both pre-production and in-production stages. Specifically, it included the use of coated seeds in the pre-production phase, deep tillage during the in-production cultivation process, soil testing based fertilisation in the fertilisation phase, and integrated pest management in the field management stage. This scope enriches the theoretical understanding of agricultural green production behaviour.

Second, this study used survey data from farmers in China's major grain-producing regions, selecting 15 variables from six key characteristics (personal, family, operational, organisational, social network, and cognitive characteristics of farmers) for driving factors analysis. Based on this, the ISM model was employed to deconstruct the hierarchical relationships among driving factors, clarifying the logical relationships between the drivers of farmers' green production behaviour. This approach extended existing theoretical research.

Third, this study conducted a comparative analysis of the differences in driving factors between small-scale and large-scale farmers' green production behaviour in China's major grain-producing regions. It clarifies the distinct driving factors influencing green production behaviour for small-scale versus large-scale farmers, thus contributing theoretically to the existing body of research.

Comparison with similar studies. Comparing the results of this study with existing studies, we found the following similarities and differences: Firstly, this study found that the main driving factors of green production behaviour among small-scale farmers included social network characteristics, the cognitive characteristic, and age, among others. This is similar to the findings of Yang et al. (2020), Gao et al. (2022), and Zhou et al. (2023). This similarity may be attributed to the relatively low level of green production among small-scale farmers, making them more susceptible to influence from relatives, friends, and local agricultural machinery owners in engaging in agricultural green production. Additionally, other studies suggest that factors such as mechanical outsourcing services (Qing et al. 2023), risk perception (Li et al. 2022), and agricultural extension services (Yan et al. 2023) significantly impact the green production behaviour of small-scale farmers. This could be because mechanical outsourcing services and agricultural extension services are part of the social network characteristics of farmers, while risk perception is a type of cognitive characteristic of farmers. Both social network characteristics and cognitive characteristics of farmers have a significant impact on the green production behaviour of small-scale farmers.

Secondly, this study suggests that the scale of operation is a primary factor influencing the green production behaviour of large-scale farmers. This is similar to the findings of Wu et al. (2021), which may be attributed to the further expansion of operational scale by large-scale farmers leading to economies of scale.

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Engaging in green production on this basis can achieve decreasing marginal costs. Furthermore, other research indicates that factors such as land transfer quality (Li and Shen 2021) significantly impact the green production behaviour of large-scale farmers. This could be due to the fact that land transfer quality partially reflects the degree of land fragmentation and soil fertility, which are one of the operational characteristics. The operational characteristics have a significant impact on the green production behaviour of large-scale farmers.

Finally, this study suggests that age and education level, organisational characteristics, and cognitive characteristic are the deep-rooted, middle indirect, and direct surface factors driving farmers' green production behaviour, respectively. This is in line with the findings of Qiao et al. (2022), which may be due to the fact that characteristics such as age are not influenced by other factors but can influence organisational characteristics, which in turn affect farmers' cognitive characteristic. However, Qiao et al. (2022) argue that the degree of land fragmentation is a middle indirect factor driving farmers' green production behaviour, while this study considers the degree of land fragmentation to be a deep-rooted factor driving farmers' green production behaviour. This may be because this study focuses on the North China Plain, while Qiao et al. (2022) focuses on Hainan Province. The North China Plain is characterised by open terrain and predominantly plain land, where the degree of land fragmentation largely determines the probability of farmers engaging in green production, making it a deep-rooted factor. In contrast, Hainan Province is mainly hilly, and land fragmentation is already a significant issue in hilly areas, but its impact is not as pronounced as in plain areas, making it a middle indirect factor.

Research limitations and future research directions. Although this study empirically examined and hierarchically deconstructed the driving factors of green production behaviour among small-scale and large-scale farmers in five major grain-producing provinces of North China, it still has certain limitations. As the 1 142 surveyed farmers were all located in the North China Plain, where wheat cultivation predominates, the research lacks an analysis of rice farmers in southern China and corn farmers in northeastern China. However, farmers cultivating different crops may exhibit variations in the driving factors behind their green production behaviour, which represents a limitation of the current study in terms of its research subjects.

Therefore, future research could further explore the driving factors of green production behaviour among rice farmers in southern China and corn farmers in northeastern China, and compare the differences in the driving factors of green production behaviour among farmers cultivating different crops, such as wheat, corn, and rice.

CONCLUSION

This study, through empirical analysis of survey data from 1 142 farmers in the North China Plain, confirmed the validity of the hypotheses in the theoretical analysis and yielded the following research conclusions:

Firstly, there were significant differences in the driving factors of green production behaviour between small-scale and large-scale farmers. Specifically, personal characteristics, household characteristics, operational characteristics, social network characteristics, organisational characteristics, and cognitive characteristic were all factors driving green production behaviour among small-scale farmers. However, the impact of social network characteristics and organisational characteristics on green production behaviour among large-scale farmers was not significant. This is because large-scale farmers had a stronger ability to engage in green production behaviour themselves and were less susceptible to specific factors in social networks and organisational characteristics compared to small-scale farmers.

Secondly, gender, age, education level, physical health status, number of agricultural workers, scale of operation, degree of land fragmentation, whether relatives and friends are civil servants, formed the deep-rooted factors driving farmers' green production behaviour; while part-time farming status, proportion of grain income, types of agricultural machinery, acquaintance with local farm machinery operators, membership in cooperatives, and collaboration with leading enterprises constituted middle indirect factors driving farmers' green production behaviour. Farmers' cognitive characteristic represented the direct surface factors driving farmers' green production behaviour. This is because deep-rooted factors such as gender are not influenced by other factors, while middle indirect factors such as part-time farming status are influenced by deep-rooted factors and subsequently affect farmers' cognitive characteristic, which in turn drive the occurrence of farmers' green production behaviour.

Recommendations. Based on the research conclusions, the following policy recommendations are proposed. Firstly, agricultural departments should develop

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differentiated policies to guide farmers of various scales towards engaging in green production tailored to local conditions. For small-scale farmers, the organisational and social network characteristics of farmers significantly influence their adoption of green production practices. Therefore, grassroots public officials should intensify efforts to promote the benefits of green production. Additionally, township governments and village committees should gradually encourage the use of green production machinery among local farm machinery operators. Village collective organisations should also play a role by connecting small-scale farmers with local cooperatives and leading enterprises, guiding them to join cooperatives or collaborate with leading enterprises. This would leverage the financial and scale advantages of cooperatives and leading enterprises to provide green production services to small-scale farmers, thereby enhancing their level of green production. For large-scale farmers, it is necessary to enhance their willingness to participate in green production by guiding them to establish new agricultural entities such as cooperatives, grassroots supply and marketing cooperatives, leading agricultural enterprises, and family farms. Additionally, providing subsidies for the purchase of green agricultural production machinery can promote improvements in their level of green production.

Secondly, it is essential to enhance supporting measures based on the hierarchical structure of driving factors to promote agricultural green production. First, the reform of urban-rural household registration systems should be effectively advanced to eliminate restrictions imposed by the household registration system, thereby addressing difficulties faced by farmers in education and healthcare, and improving their educational levels and health conditions. On this basis, young male migrant workers should be encouraged to return to their hometowns and engage actively in agricultural production, thus increasing the agricultural labor force within families. Second, subsidies for grain-producing farmers should be increased to raise their income levels and provide greater support for purchasing agricultural machinery, thereby promoting the variety and quantity of machinery used. Third, farmers should be guided to transfer land or purchase agricultural socialised services, concentrating dispersed land and allocating it to service organisations for unified management, which will enhance operational scale and reduce land fragmentation. Finally, agricultural technical service organisations and grassroots agricultural promotion departments should intensify training and publicity efforts to improve farmers' understanding and capability in green production, thereby effectively raising their awareness of agricultural green behaviour.

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