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Research article

How does land consolidation affect nongrain production? Evidence from county-level data in Jiangsu Province, China

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ABSTRACT

Using county-level panel data for Jiangsu Province from 2008 to 2018, this study adopted a fixed effect model to analyze the impact of land consolidation on crop planting structure, also considering the moderating effect of distance from the city center and the heterogeneous effect of various types of land consolidation. The results revealed that farmland consolidation and land reclamation had a negative impact on the proportion of grain crops (rice, wheat, and corn) cultivated, which declined by 0.0051 % (0.0069 %), 0.0055 % (0.0124 %), and 0.0101 % (0.0123 %) for every 1 % increase in investment, construction area, and newly added arable land from farmland consolidation (land reclamation), respectively, demonstrating that land consolidation has not prevented, or even encouraged nongrain production expansion. The production conditions of reclaimed arable land and land transfer practices following consolidation may be factors affecting these declines. Notably, the negative effect of land consolidation on crop planting structure weakens when the land is further away from the city center. To ensure food security, priority should be given to follow-up management after land consolidation and rational oversight and guidance following land transfer.

1. Introduction

Food security is a pressing global concern, and arable land that serves as a vital resource for producing grain is an essential prerequisite for food security [1,2]. The loss of high-quality arable land from rapid urbanization has raised considerable concerns regarding food security [3]. Based on current trajectories, previous research has demonstrated that by 2100, 51%–63 % of newly expanded urban land will be converted from arable land, and this phenomenon will primarily occur in China, India, sub-Saharan Africa, and Western Europe [4]. In addition, the internal utilization mode of arable land has undergone changes in nongrain production [5] that directly affect the amount of arable land for grain planting and endanger national food security.

As a potentially useful land management instrument [6,7], land consolidation has been implemented by various nations and districts to maintain food security and ensure sustainable production by increasing agricultural productivity [8–11]. Typically, agricultural productivity can be improved by increasing the cropping area or yield per unit area. Some studies have confirmed that land consolidation initiatives increase arable land area [12,13], and productivity improvement is primarily associated with expanded cropland area by adjusting scattered arable land, reclaiming damaged land and wasteland, and developing unused land [1,14]. Other studies have demonstrated that land consolidation has a significant influence on improving agricultural infrastructure and production

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conditions, enhancing the quality of arable land, and promoting the accessibility of mechanization [7,9,15,16]. Previous research has also revealed that land consolidation may be used as a strategy to coordinate and scale up the operation of arable land and encourage farmers to transition to more efficient use of modern agricultural inputs [6,17]. All of these improvements could help to increase the yield per unit area.

While implementing land consolidation projects helps to boost the stability or growth of crop production [1,18,19], it may also exert a significant impact on crop planting structure. Since farming conditions are highly related to the nongrain production decisions made by agricultural operators [20], better infrastructure and production conditions of arable land after consolidation can attract agricultural operators to use or rent the land for highly profitable cash crops, nurseries, floriculture, poultry, and agrotourism, transitioning to nongrain production [20–22], which poses a threat to food security [23]. However, studies that have already been conducted on the causes of nongrain production always focus on the low benefits of grain-growing, the transfer of rural population, the change of the spatial pattern of cropland resources, the change of food consumption structure, and the implementation of agricultural industrial policies such as the “one village, one product” strategy [24–26]. The impact of land consolidation on crop planting structure and the proportion of grain crops (rice, wheat, and corn) cultivated (i.e., nongrain production) has received limited research attention.

Further, the impact of land consolidation on nongrain production may differ depending on how far a county is from the city center. Cultivated land in the suburbs, especially those adjacent to urbanized areas is scarce and highly productive [27], and higher returns will induce agricultural operators to substitute cash crops for grain crops in these areas [28]. Meanwhile, higher proximity to socioeconomic centers offers more accessibility to resources and markets, which is also one of the decisive determinants for agricultural operators’ choice of cash crop plantations [29]. Additionally, the impact of land consolidation on nongrain production may vary with different types of land consolidation, dividing land consolidation into farmland consolidation, which works on agricultural land, increasing the area of cultivated land and improving cultivated land quality [30–32]; land reclamation, which regards construction-based and disaster-damaged land as its object, forming newly cultivated land by reclaiming [30,31,33]; land development, which regards unused land as its object, forming newly cultivated land by exploitation [30,31,34]. The moderating effect of distance between counties and city centers and the heterogeneous effect of different types of land consolidation, require further investigation but are currently being ignored.

Therefore, using the county-level data in Jiangsu Province in China from 2008 to 2018, this study endeavors to a) analyze the impact of land consolidation on crop planting structure, considering the moderating effect of distance from the city center, and b) examine the heterogeneous effect of land consolidation on crop planting structure based on farmland consolidation, land reclamation, and land development forms. This study can reveal how land consolidation affects nongrain production, and whether these effects are affected by the distance between counties and city centers and the various types of land consolidation. Further, the findings can provide guidance for developing follow-up management strategies for land consolidation to ensure food safety.

2. Materials and methods

2.1. Study area

Previous research has shown that urbanization has caused much higher rates of arable land loss in China’s more developed eastern

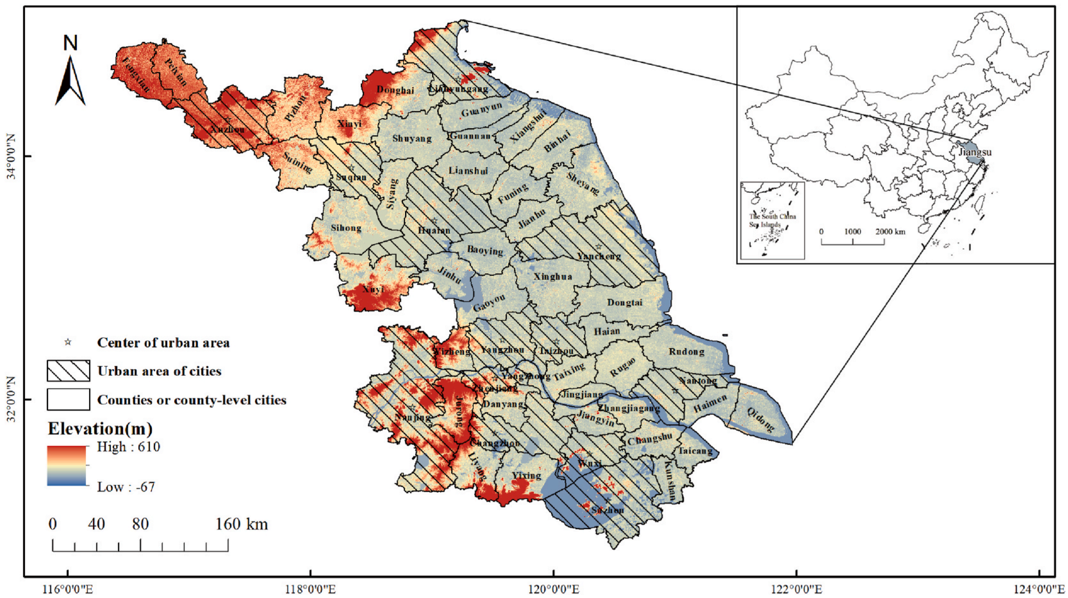

Fig. 1. Study area and county and county-level city distribution.

area, and areas with better economic conditions consistently present a higher proportion of nongrain arable land [35]. We chose Jiangsu Province as the study area for this reason. Jiangsu Province is located on China's east coast (116°21′-121°56′ east longitude and 30°45′-35°08′ in the north latitude). Jiangsu boasts advantageous natural resource endowments, flat terrain, vertical and horizontal rivers, and favorable transit locations. The province is known as "the land of fish and rice," in reference to having the largest japonica rice-producing area in South China and being a major producer of premium low-protein wheat. In addition, corn, peanuts, colza, coarse cereals, beans, Chinese herbal medicines, and horticultural vegetables are widely planted in Jiangsu. Based on 2018 administrative divisions, Jiangsu Province includes 41 counties or county-level cities and 13 urban areas of cities. Due to the limited crop planting area in urban areas of cities, we exclude these areas from the study area. Finally, the study area includes 41 counties or county-level cities (Fig. 1).

2.2. Data

This study uses panel data for the chosen 41 counties or county-level cities in Jiangsu Province from 2008 to 2018. The Second National Land Survey was started in July 2007 and the Third National Land Resource Survey was conducted in 2018–2019. To maintain the data consistency, the land consolidation data used are from 2008 to 2018 based on the Second National Land Survey.

Data on crop planting structure (i.e., the proportion of cultivated grain crop area in the total sown area of farm crops), the number of agricultural laborers, agricultural machinery power, chemical fertilizer usage, major agricultural machinery, and per capita GDP are obtained from the Jiangsu Statistical Yearbook (2009–2019). The climatic variables of temperature, precipitation, and sunshine were obtained from the China Meteorological Data Service Center (https://data.cma.cn/). Jiangsu Province has 69 monitoring stations for meteorological data, and this study included data from each monitoring station, applying inverse distance weighting interpolation and extracting the climatic variables of the counties or county-level cities based on boundaries. We measure land consolidation based on investment in land consolidation, land consolidation construction area, and newly added arable land from land consolidation, obtaining these data from the Land Development and Consolidation Center of Jiangsu Province. This study determines the distance variables based on geometrical center distances between the counties or county-level cities and the nearest cities using the Path Distance tool in ArcGIS 10.3.

2.3. Econometric model

This study measures land consolidation based on investment in land consolidation (*investment*), construction area of land consolidation (*area*), and newly added arable land from land consolidation (*cropland*) applying the following fixed effect (FE) models:

$$structure_{it} = \alpha_1 investment_{it} + \beta_1 investment_{it} * distance_{it} + \delta_1 Z_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

$$structure_{it} = \alpha_2 area_{it} + \beta_2 area_{it} * distance_{it} + \delta_2 Z_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (2)$$

$$structure_{it} = \alpha_3 cropland_{it} + \beta_3 cropland_{it} * distance_{it} + \delta_3 Z_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (3)$$

where subscript i denotes region, and subscript t denotes year. The dependent variable *structure* denotes the proportion of cultivated grain crop area in the total sown area of farm crops to indicate crop planting structure. Interaction items include the moderating effects of *distance*, which is a dummy variable measured by the geometrical center distance between the counties or county-level cities and the nearest cities. We used the Natural Breaks method in ArcGIS 10.3 to classify distances, obtaining four distinct distance classes. Z is a

Table 1
Variable definitions and descriptive statistics.

Variables		Description	Mean	SD	Min	Max
Dependent variable	*structure*	The proportion of cultivated grain crop area in the total sown area of farm crops (%)	0.72	0.12	0.35	0.92
Independent variables	*investment*	Investment in land consolidation (CNY10,000)	13,592.67	35,741.45	0.00	543,714.40
	area	Construction area of land consolidation (ha)	1236.82	1674.49	0.00	10,111.40
	cropland	Newly added arable land from land consolidation (ha)	310.66	274.07	0.00	1737.10
Dummy variables	*distance* 1	Class1: 29.56–42.93 km	0.07	0.26	0.00	1.00
	distance 2	Class2: 42.94–57.47 km	0.41	0.49	0.00	1.00
	distance 3	Class3: 57.48–71.17 km	0.37	0.48	0.00	1.00
	distance 4	Class4: 71.18–115.79 km	0.15	0.35	0.00	1.00
Control variables	*labor*	Number of laborers in agriculture, forestry, animal husbandry, and fishery industries (10,000 persons)	12.98	7.36	1.60	34.23
	machinery	Major agricultural machinery (10,000 kW)	71.85	39.74	11.96	214.30
	GDP	Per capita GDP (CNY)	57,316.99	38,117.45	8147.70	218,984.10
	temperature	Annual mean temperature (°C)	15.84	1.15	13.68	25.48
	rainfall	Annual precipitation (cm)	108.93	28.42	55.58	221.83
	sunlight	Annual hours of sunlight (day)	82.69	5.19	70.29	98.02

Note: Variables for investment and per capita GDP are actual values deflated by consumer price indices, with the year 2008 serving as the base period.

control variable including variables for different kinds of agricultural inputs, level of economic development, and climatic factors. μ_i and γ_t are unit and time FEs, respectively, and ε_{it} is the usual error term. Table 1 presents the definitions and descriptive statistics of the study's variables, and we applied the Stata 15.1 software package to analyze the data examining mean, standard deviation, min, and max.

3. Results

3.1. Changes in land consolidation and grain crop cultivation

3.1.1. Temporal change and spatial distribution of land consolidation

In this study, the temporal change and spatial distribution of land consolidation projects conducted in 41 counties or county-level cities in Jiangsu Province between 2008 and 2018 are analyzed from temporal and spatial perspectives.

The temporal change of land consolidation is illustrated in Fig. 2, representing data totaled by counties or county-level cities for each year. *Investment* decreased slightly between 2008 and 2009, but rapidly climbed from 2009 to 2017, reaching CNY 18,196.62 million before declining to CNY 12,346.79 million in 2018. Furthermore, *area* presents considerable fluctuation, increasing and decreasing between 2008 and 2016, and remaining at about 73,900 in 2017 and 2018. *cropland* lowered slightly from 2008 to 2009, increased to an average of 12,000 ha from 2010 to 2014, rapidly expanded to 19,295.32 ha in 2017, then decreased to 12,496.19 ha in 2018. Fig. 2 also demonstrates that farmland consolidation had the largest construction area of land consolidation, while land reclamation had the largest investment in land consolidation and the largest area of newly added arable land from land consolidation.

The spatial distribution of land consolidation is illustrated in Fig. 3, presenting data totaled by year for each county or county-level city. For farmland consolidation in 2008–2018, *investment* was higher in Liyang, Yizheng, and Dongtai, *area* was larger in Haian, Dongtai, and Funing, and *cropland* was more expansive in Liyang and Sheyang, as shown in (a), (b), and (c) of Fig. 3. For land reclamation in 2008–2018, *investment* was higher in Haian, Jurong, and Kunshan, while *area* and *cropland* were larger in Baoying, Sihong, and Xinghua, as shown in (d), (e), and (f) of Fig. 3. For land development in 2008–2018, *investment* and *area* were higher in Dongtai, Yixing, and Shuyang, while *cropland* was broader in Dongtai, Shuyang, and Fengxian, as shown in (g), (h), and (i) of Fig. 3.

3.1.2. Temporal changes in grain crop cultivation

Fig. 4 summarizes temporal changes in the area of cultivated grain crops, grain crop yields, and the proportion of cultivated grain crops in the total sown area of farm crops from 2008 to 2018. As shown in Fig. 4, area of grain crop cultivation (*sown area*) and grain crop yields (*yield*) were roughly stable from 2008 to 2018. Grain crop cultivation increased from 91.16 thousand hectares in 2008 to 94.41 thousand hectares in 2018, while grain crop yields increased from 592.02 thousand tons in 2008 to 651.59 thousand tons in 2018. Additionally, a shifting pattern occurred in the proportion of cultivated grain crop area in the total sown area of farm crops (*structure*) from 2008 to 2018. The proportion of cultivated grain crops decreased from 72.78 % in 2008 to 71.84 % in 2015 and then increased to 73.06 % in 2018.

3.2. Results of the econometric model

3.2.1. Overall model results

We apply the modified Wald test for heteroskedasticity, Pesaran's test of cross-sectional independence, and the Wooldridge test for autocorrelation to the panel data following the benchmark regression. The results in Table 2 indicate the presence of heteroskedasticity in the models. Therefore, this study uses robust standard errors, presenting the results of the impact of land consolidation, including *investment*, *area*, and *cropland* in Table 3. The Stata 15.1 software package produced all the econometric analyses.

The F-test results in Table 3 are all statistically significant at least at a 5 % level, indicating that the overall models are significant. The findings demonstrate that coefficients of *investment*, *area*, and *cropland* are −0.0120, −0.0144, and −0.0128, respectively, which are coefficients statistically significant at least at a 5 % level, demonstrating that land consolidation had a negative influence on crop planting structure. More specifically, for every 1 % rise in the *investment*, *area*, and *cropland*, the respective proportion of cultivated

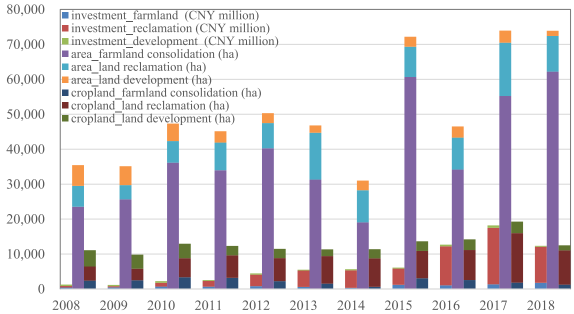

Fig. 2. Temporal change in land consolidation.

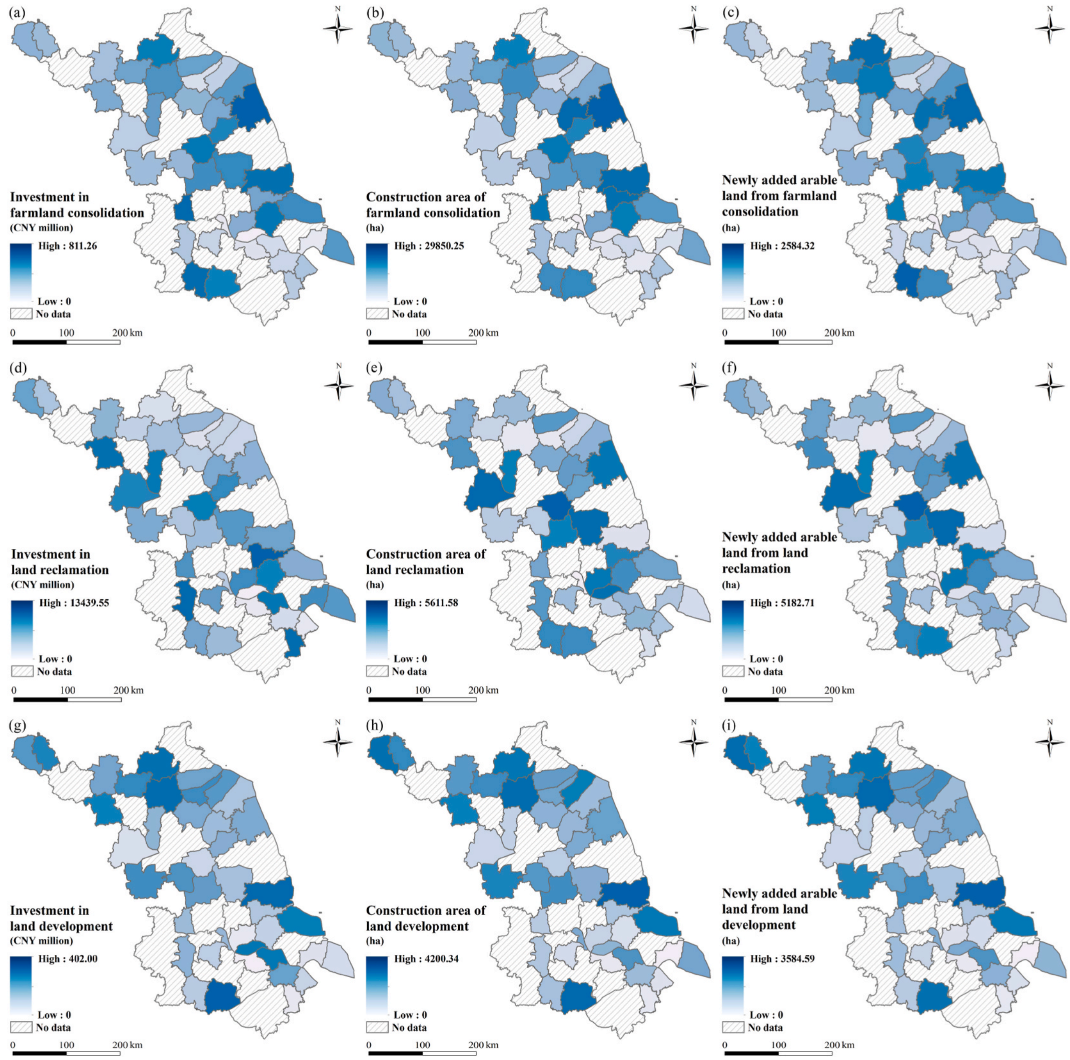

Fig. 3. Spatial distribution of land consolidation: (a)Investment in farmland consolidation; (b)Construction area of farmland consolidation; (c) Newly added arable land from farmland consolidation; (d)Investment in land reclamation; (e)Construction area of land reclamation; (f)Newly added arable land from land reclamation; (g)Investment in land development; (h)Construction area of land development; (i)Newly added arable land from land development.

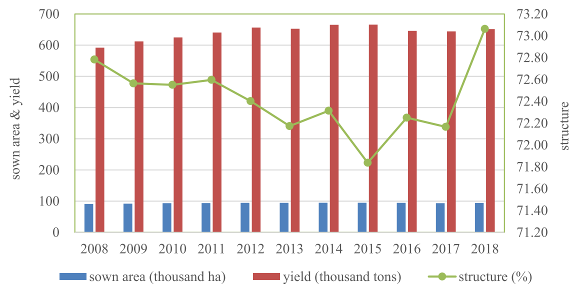

Fig. 4. Temporal changes in grain crop cultivation.

grain crops decreased by 0.0120 %, 0.0144 %, and 0.0128 %.

The interaction items of land consolidation and distance are introduced into the models to examine whether the impact of land consolidation on crop planting structure varies with the distance between counties or county-level cities and city centers. Table 3

Table 2
Tests for heteroskedasticity, cross-sectional independence, and autocorrelation.

	Equation (1)	Equation (2)	Equation (3)
Modified Wald test for heteroskedasticity(χ^2)	14,937.200	14,554.200	16,911.870
	(0.0000)	(0.0000)	(0.0000)
Pesaran's test of cross-sectional independence	−1.1600	−0.9500	−0.9210
	(0.2462)	(0.3422)	(0.3568)
Wooldridge test for autocorrelation (F)	2.5390	2.4310	2.5730
	(0.1189)	(0.1268)	(0.1166)

Note: p-values are in parentheses.

Table 3
The impact of land consolidation on crop planting structure.

Equation (1)		Equation (2)		Equation (3)	
*ln*investment	−0.0120**	*ln*area	−0.0144***	*ln*cropland	−0.0128***
	(0.0051)		(0.0031)		(0.0024)
*ln*investment*$distance_2$	0.0107*	*ln*area*$distance_2$	0.0142***	*ln*cropland*$distance_2$	0.0129***
	(0.0056)		(0.0039)		(0.0040)
*ln*investment*$distance_3$	0.0143**	*ln*area*$distance_3$	0.0162***	*ln*cropland*$distance_3$	0.0144***
	(0.0056)		(0.0036)		(0.0033)
*ln*investment*$distance_4$	0.0140**	*ln*areat*$distance_4$	0.0167***	*ln*cropland*$distance_4$	0.0140***
	(0.0061)		(0.0043)		(0.0044)
*ln*labor	0.0886*	*ln*labor	0.0933*	*ln*labor	0.0922*
	(0.0498)		(0.0500)		(0.0518)
*ln*machinery	0.0654	*ln*machinery	0.0691	*ln*machinery	0.0652
	(0.0521)		(0.0520)		(0.0519)
*ln*GDP	−0.0273	*ln*GDP	−0.0281	*ln*GDP	−0.0257
	(0.0287)		(0.0304)		(0.0300)
temperature	0.0081**	temperature	0.0080*	temperature	0.0080*
	(0.0039)		(0.0041)		(0.0043)
rainfall	0.0002*	rainfall	0.0002	rainfall	0.0002*
	(0.0001)		(0.0001)		(0.0001)
sunlight	0.0005	sunlight	0.0004	sunlight	0.0006
	(0.0010)		(0.0010)		(0.0010)
constant	0.3418	constant	0.3297	constant	0.3110
	(0.2590)		(0.2697)		(0.2773)
Year FE	yes	Year FE	yes	Year FE	yes
Observations	451	Observations	451	Observations	451
R^2	0.114	R^2	0.112	R^2	0.102
F-test	2.161**	F-test	12.31***	F-test	31.99***

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at 1 %, 5 %, and 10 % levels, respectively.

reveals that all interaction items are positive and statistically significant at least at a 10 % level, indicating that the distance from the city center had a positive moderating effect on the negative impact of land consolidation on crop planting structure. Compared with regions that are closer to the city center, the negative impact of land consolidation on crop planting structure in those situated farther from the city center was weakened.

Table 4
The impact of farmland consolidation on crop planting structure.

Equation (1)		Equation (2)		Equation (3)	
*ln*investment	−0.0051**	*ln*area	−0.0055**	*ln*cropland	−0.0101**
	(0.0023)		(0.0024)		(0.0042)
*ln*investment*$distance_2$	0.0048**	*ln*area*$distance_2$	0.0053**	*ln*cropland*$distance_2$	0.0101**
	(0.0020)		(0.0021)		(0.0038)
*ln*investment*$distance_3$	0.0055**	*ln*area*$distance_3$	0.0059**	*ln*cropland*$distance_3$	0.0111***
	(0.0021)		(0.0022)		(0.0040)
*ln*investment*$distance_4$	0.0084***	*ln*areat*$distance_4$	0.0087***	*ln*cropland*$distance_4$	0.0136***
	(0.0025)		(0.0028)		(0.0044)
Control variables	yes	Control variables	yes	Control variables	yes
Year FE	yes	Year FE	yes	Year FE	yes
Observations	451	Observations	451	Observations	451
R^2	0.114	R^2	0.110	R^2	0.105
F-test	3.971***	F-test	4.222***	F-test	22.710***

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at 1 %, 5 %, and 10 % levels, respectively.

In addition, the impact of land consolidation on crop planting structure is estimated again without control variables for robustness checks, and the results presented in Appendix A are consistent with those presented in Table 3. Meanwhile, the variable *distance* has also been handled as a continuous variable for robustness checks, and the results presented in Appendix B are consistent with those presented in Table 3.

3.2.2. Heterogeneity analysis

As noted previously, land consolidation includes farmland consolidation, land reclamation, and land development. The results regarding the impact of these forms of land consolidation on crop planting structure are presented in Tables 4–6. The F-test results are all statistically significant at a 1 % level, indicating that the overall models are significant.

As shown in Tables 4 and 5, farmland consolidation and land reclamation had similar effects on crop planting structure. Table 4 shows that the coefficients of *investment*, *area*, and *cropland* are statistically significant at a 5 % level, demonstrating that crop planting structure was negatively impacted by farmland consolidation. To be precise, the proportion of the cultivated grain crop area in the total sown area of farm crops declined by 0.0051 %, 0.0055 %, and 0.0101 % for every 1 % increase *investment*, *area*, and *cropland* from farmland consolidation, respectively. Similarly, land reclamation had a negative impact on crop planting structure, and the proportion of the cultivated grain crop area in the total sown area of farm crops decreased by 0.0069 %, 0.0124 %, and 0.0123 % for every 1 % increase in *investment*, *area*, and *cropland* from land reclamation, respectively.

The positive and statistically significant coefficients of the interaction items indicate that the distance from the city center had a positive moderating effect on the negative impact of farmland consolidation on crop planting structure. This demonstrates that the negative effects of farmland consolidation on crop planting structure in counties or county-level cities that are farther from the city center were less pronounced than those that are closer to the city center. The distance from the city center also had a positive moderating effect on the negative impact of land reclamation on crop planting structure.

Unlike the coefficients of farmland consolidation and land reclamation, Table 6 shows that the impact of land development on crop planting structure is positive, although statistically insignificant. The interaction items are negative, some of which are statistically significant at a 10 % level, indicating that distance from the city center had a negative moderating effect on the positive impact of land development on crop planting structure.

4. Discussion

4.1. Effects of land consolidation on crop planting structure

The results demonstrate that farmland consolidation and land reclamation had a negative effect on the proportion of cultivated grain crops, indicating a rising trend of nongrain production. Although the impact of land development on the proportion of cultivated grain crops is positive, it was not statistically significant. The results indicated that the initial intention of land consolidation has been contradicted by the results.

An essential explanation for the decreased proportion of cultivated grain crops is the objective improvement in farming conditions and farmers' subjective motivation following land consolidation. The decreased proportion of grain crops cultivated was determined to have been strongly influenced by farming conditions. Farmland consolidation improves existing arable land involving measures such as land leveling, soil improvement, development of irrigation and drainage systems, and construction or reconstruction of field roads [7]. Land reclamation converts vacant/idle construction land and disaster-damaged land into arable land [36], and the land that needs to be reclaimed is usually mixed with operating farmland, and is always consolidated alongside existing arable land to establish a concentrated contiguous area. After land consolidation, smaller, irregular-shaped, and scattered parcels become larger, normally shaped, and contiguous parcels. In addition, agricultural infrastructure and production conditions are also improved [1,37]. Nongrain production is more likely to occur in concentrated and continuous arable land, and nongrain crops (i.e., nursery plantations) are more

Table 5
The impact of land reclamation on crop planting structure.

Equation (1)		Equation (2)		Equation (3)	
*ln*investment	−0.0069***	*ln*area	−0.0124***	*ln*cropland	−0.0123***
	(0.0019)		(0.0023)		(0.0025)
*ln*investment*distance$_2$	0.0052**	*ln*area*distance$_2$	0.0112***	*ln*cropland*distance$_2$	0.0106***
	(0.0025)		(0.0034)		(0.0036)
*ln*investment*distance$_3$	0.0088***	*ln*area*distance$_3$	0.0153***	*ln*cropland*distance$_3$	0.0151***
	(0.0023)		(0.0026)		(0.0027)
*ln*investment*distance$_4$	0.0095***	*ln*areat*distance$_4$	0.0164***	*ln*cropland*distance$_4$	0.0166***
	(0.0030)		(0.0045)		(0.0048)
Control variables	yes	Control variables	yes	Control variables	yes
Year FE	yes	Year FE	yes	Year FE	yes
Observations	451	Observations	451	Observations	451
R^2	0.128	R^2	0.124	R^2	0.124
F-test	2.490***	F-test	8.935***	F-test	7.242***

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at 1 %, 5 %, and 10 % levels, respectively.

Table 6
The impact of land development on crop planting structure.

Equation (1)		Equation (2)		Equation (3)	
*ln*investment	0.0004	*ln*area	0.0020	*ln*cropland	0.0019
	(0.0021)		(0.0024)		(0.0024)
*ln*investment*$distance_2$	−0.0020	*ln*area*$distance_2$	−0.0043	*ln*cropland*$distance_2$	−0.0044
	(0.0023)		(0.0027)		(0.0027)
*ln*investment*$distance_3$	−0.0029	*ln*area*$distance_3$	−0.0055	*ln*cropland*$distance_3$	−0.0054
	(0.0025)		(0.0033)		(0.0033)
*ln*investment*$distance_4$	−0.0031	*ln*areat*$distance_4$	−0.0056*	*ln*cropland*$distance_4$	−0.0054*
	0.0004		(0.0031)		(0.0031)
Control variables	yes	Control variables	yes	Control variables	yes
Year FE	yes	Year FE	yes	Year FE	yes
Observations	451	Observations	451	Observations	451
R^2	0.114	R^2	0.113	R^2	0.112
F-test	2.504***	F-test	2.716***	F-test	2.651***

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at 1 %, 5 %, and 10 % levels, respectively.

likely to be cultivated in former paddy soil because it is flat and fertile, which makes it possible to obtain better returns with fewer inputs [20]. Furthermore, the direct driving force of nongrain production is related to the relatively low benefits of grain production [24,25]. According to the National Cost–Benefit Compilation of Agricultural Products in China, the net profit of grain crop (rice, wheat, and corn) production has declined from CNY 2795.85 per hectare in 2008 to CNY −1283.85 per hectare in 2018. Since grain crops have much lower profitability than nongrain production [23], in pursuit of maximum revenue, rational farmers may have low enthusiasm for planting grain crops and may be inclined toward nongrain production on consolidated land. Additionally, a neighborhood effect would occur when concentrated and continuous arable land belongs to various households. Farmers are more likely to select the same high-yield nongrain crops as their neighbors based on the higher returns obtained by nongrain production pioneers and for easier communication regarding market-related information [23,38].

Another notable factor influencing the decreased proportion of cultivated grain crops may be related to the practices of arable land transfer and intended use after land consolidation. Transaction costs caused by land fragmentation and small land parcels, as well as the low quality of farmland and underdeveloped production facilities are barriers to land transfer [25]. Land consolidation could expediently improve land fragmentation [39–41], as well as improve farmland infrastructure, enhance land quality, and facilitate large-scale operations [11,34,42], which reduces transaction costs for arable land transfer and can even raise the price of arable land transfer [41,43], incentivizing farmers to transfer arable land [44]. However, land transfer may result in the substitution of cash crops for grain crops [21,22]. It is unsustainable to rent land for grain production due to the low revenue related to grain production, rising leasing prices, and improved conditions for agricultural production. As a result, nongrain production is prominent in the land that is transferred [25]. Research has shown that farm households can boost output by around 0.21 % by shifting 1 % of the cultivated grain area to nongrain-sown area, and better production conditions such as wells and underground channels facilitated high-value vegetable cultivation, which requires more precise water supply than grain crops [45]. Furthermore, when early adopters of nongrain production receive significant economic benefits, they will be more motivated and better able to rent more arable land to expand their production and influence the crop choices of their neighbors [20].

4.2. Regional heterogeneity in the effects of land consolidation on crop planting structure

This study demonstrates that counties or county-level cities that are distant from the city center experienced a less negative impact of land consolidation on the proportion of grain crops cultivated than those that are closer to the city center. A potential rationale for this is that cultivated land adjacent to urbanized areas is scarce and highly productive, and scarce land should be used to yield higher returns [27]. Meanwhile, nongrain crops such as vegetables always have higher storage and transportation requirements than grain crops [46]. Moreover, some nongrain crops (i.e., grape vineyards), have considerable ecological and ornamental value. Farmers prefer to plant these nongrain crops close to city centers for higher returns, easy transportation and to obtain benefits beyond the product itself.

In addition, achieving the goals of local economic development and increasing farmers' income is vital for local governments. Nongrain production has the potential to generate greater economic benefits and support regional economic growth considerably. In addition, the benefits generated by protecting arable land can be unconditionally shared by regions that prioritize economic development. This results in some local governments being more likely to support economic development while ignoring or even approving some nongrain production practices, particularly in areas close to the city center [20].

4.3. Cropland management on grain crop cultivation

4.3.1. Promote land consolidation to boost agricultural productivity more effectively

The initial aim of land consolidation is to reduce fragmentation, increase cultivated area, and promote agricultural productivity [14]. Priority should be given to oversight and regulation of newly added arable land after land consolidation to ensure its appropriate use; and to maintain stability in total grain acreage, in particular. In addition, adequate supervision is also crucial to prevent the phenomenon of newly added arable land being abandoned again [13]. Furthermore, improving the productivity of cropland is essential for ensuring food security. Consequently, when consolidating land, a higher strategic focus should be targeted toward enhancing the quality of arable land rather than solely pursuing a rise in its quantity [1]. It is crucial to continuously advance the transformation of medium and low yield fields, establish high-quality farmland, and improve the agricultural infrastructure and farming environment, among other relevant approaches to enhance grain production capacity. Additionally, land consolidation projects must receive ongoing regulatory oversight, which is equally crucial and can be easily ignored.

4.3.2. Regulate land transfer practices following land consolidation

It is also crucial to improve the efficiency of grain cultivation and grain production capacity to promote economies of scale and ensure food security. Economies of scale can be achieved by land consolidation or land transfer [44]. Land consolidation can decrease the number of plots, increase the average size of plots, and reform the shape of irregular plots, which promotes large-scale operations [47,48]. Large-scale and intensive agriculture is also dependent on concentrated and continuous operations that can be achieved through land transfer. As previously noted, land consolidation may incentivize farmers to transfer arable land. It is essential to encourage family farms, agricultural cooperatives, and leading enterprises in rural areas to grow grain crops and rent individual farmers' land for collective cultivation to prevent possible substitutions of cash crops for grain crops that may be caused by arable land transfer. That is, land operation rights should be encouraged to flow toward key professional households, family farms, agricultural cooperatives, and leading enterprises that are responsible for the scale operation of the land following consolidation [6,16]. Furthermore, land contracts could clearly dictate the requirements for arable land use and crop types to ensure food security [20]. Additionally, for emerging consolidated farmland agricultural operations to realize the scale for grain crops, it is also worthwhile to consider the approach of "transfer land and then implement the land consolidation project" [16].

4.3.3. Consider regional heterogeneity in cropland management

The impact of land consolidation on the proportion of grain crops cultivated is heterogeneous due to different areas being located at various distances from city centers. Therefore, following the implementation of land consolidation, regulatory cropland management oversight regarding grain crop cultivation should consider geographical differentiation. Cropland in counties or county-level cities that are close to cities should implement restrictions on nongrain production to ensure a stable grain supply. Specifically, farmers should be actively encouraged to choose grain crops that are more scale-efficient and make it easier to replace manpower with machinery based on the development of the farming environment and the mechanization circumstances after land consolidation. Additionally, farmers' nongrain production practices must be strategically directed to ensure the long-term increase and stability of grain production. Forms of nongrain production that do not harm the tillage layer could be moderately developed [20], and the quality of arable land can be improved by implementing reasonable crop rotation and efficient soil nutrition techniques. Integrated crop–livestock systems that entail raising a variety of crops and livestock in a mixed farming system should also be considered [49,50]; for instance, rice–fish and rice–duck [51,52] coculture patterns. By applying such innovations, farmers will obtain higher revenue, and the surrounding countryside will also achieve greater aesthetic and ecological value.

5. Conclusion

Using county-level data in Jiangsu Province in China from 2008 to 2018, this study analyzed the impact of land consolidation on crop planting structure, considering the moderating effect of distance from the city center and the heterogeneous effects of various types of land consolidation. The results demonstrated that land consolidation, particularly farmland consolidation and land reclamation, has had a negative influence on the proportion of grain crops cultivated, demonstrating a trend toward nongrain production. Moreover, compared with regions that are closer to city centers, the negative impact of land consolidation on the proportion of grain crops cultivated has been weaker in regions that are farther from city centers. The objective improvement of farming conditions, subjective profit-seeking behavior, and arable land transfer practices following land consolidation may provide significant explanations for this phenomenon.

To regulate attempts to use cropland for nongrain production and ensure food security, priority should be given to the follow-up supervision of newly added arable land and the ongoing maintenance of land consolidation projects. Farmers should also be guided and encouraged to select grain crops that are more scale-efficient and for which it is easier to replace manpower with machinery under the improved farming conditions of land consolidation. Additionally, transferred arable land after land consolidation should be actively guided toward professional key households, family farms, agricultural cooperatives, and leading enterprises that are responsible for scale and intensive operation.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Yanyuan Zhang: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Conceptualization. **Zhixiang Liang:** Writing – review & editing, Writing – original draft, Software, Methodology. **Linyan Wang:** Writing – original draft,

Software, Methodology. **Wei Zou:** Supervision, Funding acquisition, Conceptualization. **Min Xia:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

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Appendix A

Appendix A
The impact of land consolidation on crop planting structure without control variables

Equation (1)		Equation (2)		Equation (3)	
lninvestment	−0.0136**	lnarea	−0.0119***	lncropland	−0.0138***
	(0.0054)		(0.0028)		(0.0025)
lninvestment*distance$_2$	(0.0000)	lnarea*distance$_2$	0.0114***	lncropland*distance$_2$	0.0137**
	0.0123*		(0.0042)		(0.0052)
lninvestment*distance$_3$	(0.0061)	lnarea*distance$_3$	0.0145***	lncropland*distance$_3$	0.0156***
	0.0154**		(0.0035)		(0.0035)
lninvestment*distance$_4$	(0.0057)	lnareat*distance$_4$	0.0150***	lncropland*distance$_4$	0.0157***
	0.0161**		(0.0044)		(0.0044)
Control variables	no	Control variables	no	Control variables	no
Year FE	yes	Year FE	yes	Year FE	yes
Observations	451	Observations	451	Observations	451
R^2	0.038	R^2	0.030	R^2	0.023
F test	1.733*	F test	4.097***	F test	4.251***

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at 1 %, 5 %, and 10 % levels, respectively.

Appendix B
The impact of land consolidation on crop planting structure with continuous distance

Equation (1)		Equation (2)		Equation (3)	
lninvestment	−0.0724***	lnarea	−0.1040***	lncropland	−0.1089***
	(0.0234)		(0.0388)		(0.0396)
lninvestment*distance	0.0066***	lnarea*distance	0.0095***	lncropland*distance	0.0100***
	(0.0021)		(0.0035)		(0.0036)
Control variables	yes	Control variables	yes	Control variables	yes
Year FE	yes	Year FE	yes	Year FE	yes
Observations	451	Observations	451	Observations	451
R^2	0.113	R^2	0.109	R^2	0.109
F test	2.767***	F test	2.651***	F test	2.665***

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at 1 %, 5 %, and 10 % levels, respectively.

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