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RESEARCH ARTICLE

Spatial distribution prediction and benefits assessment of green manure in the Pinggu District, Beijing, based on the CLUE-S model

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Abstract

Green manure use in China has declined rapidly since the 1980s with the extensive use of chemical fertilizers. The deterioration of field environments and the demand for green agricultural products have resulted in more attention to green manure. Human intervention and policy-oriented behaviors likely have large impacts on promoting green manure planting. However, little information is available regarding on where, at what rates, and in which ways (i.e., intercropping green manure in orchards or rotating green manure in cropland) to develop green manure and what benefits could be gained by incorporating green manure in fields at the county scale. This paper presents the conversion of land use and its effects at small region extent (CLUE-S) model, which is specifically developed for the simulation of land use changes originally, to predict spatial distribution of green manure in cropland and orchards in 2020 in Pinggu District located in Beijing, China. Four types of land use for planting or not planting green manure were classified and the future land use dynamics (mainly croplands and orchards) were considered in the prediction. Two scenarios were used to predict the spatial distribution of green manure based on data from 2011: The promotion of green manure planting in orchards (scenario 1) and the promotion of simultaneous green manure planting in orchards and croplands (scenario 2). The predictions were generally accurate based on the *receiver operating characteristic* (*ROC*) and *Kappa* indices, which validated the effectiveness of the CLUE-S model in the prediction. In addition, the spatial distribution of the green manure was acquired, which indicated that green manure mainly located in the orchards of the middle and southern regions of Dahuashan, the western and southern regions of Wangxinzhuang, the middle region of Shandongzhuang, the eastern region of Pinggu and the middle region of Xiagezhuang under scenario 1. Green manure planting under scenario 2 occurred in orchards in the middle region of Wangxinzhuang, and croplands in most regions of Daxingzhuang, southern Pinggu, northern Xiagezhuang and most of Mafang. The spatially explicit results allowed for the assessment of the benefits of these changes based on different economic and ecological indicators. The economic and ecological gains of scenarios 1 and 2 were 175 691 900 and

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143 000 300 CNY, respectively, which indicated that the first scenario was more beneficial for promoting the same area of green manure. These results can facilitate policies of promoting green manure and guide the extensive use of green manure in local agricultural production in suitable ways.

Keywords: CLUE-S model, green manure, spatial distribution, prediction, benefits assessment

1. Introduction

Green manure plays an important role in providing nutrients for crops, reducing dependence on chemical fertilizers, increasing crop yield, improving the ecological environment of agricultural fields, and reducing soil erosion and pollution (Becker *et al.* 1995; Thorup-Kristensen and van den Boogaard 1999; Robertson *et al.* 2000; Thorup-Kristensen *et al.* 2003; Germani and Plenchette 2004; Tejada *et al.* 2008a, b; Sharma *et al.* 2009; Miyazawa *et al.* 2010; Liebman *et al.* 2011; Pan *et al.* 2011; Bai *et al.* 2013; Samac *et al.* 2013; Zhao *et al.* 2013). China has a 3 000-year history of using green manure as a form of traditional organic manure (Yang *et al.* 2014). It is estimated that the planting area of green manure peaked at 10–15 million ha from the 1960s to 1980s because of a shortage of chemical fertilizers (Yang *et al.* 2012). Due to the current abundance of chemical fertilizers, which greatly contribute to yields and reduce labor needs, the planting area has been reduced to only 2–3 million ha. Since 2008, greater attention has been given to the benefits of green manure because of the soil and environmental degradation in fields from the overuse of chemical fertilizers and the growing demand for green food (i.e., food produced without pollution, overuse of chemical fertilizers or heavy metals) (Cao and Huang 2009). In the Pinggu District, the government began to systematically promote green manure, (i.e., February orchid (*Orychophragmus violaceus*) intercropping in orchards), and in 2011, the planting area reached 1 469 ha. In addition, this area increased to 3 469 ha in 2013. Despite the importance of green manure, limited information, i.e., suitable promotion locations, promotion rates, and promotion patterns (such as only promoting green manure in orchards or promoting green manure both in croplands and orchards) is available regarding how to predict future trends of promoting green manure at county level.

Currently, the topic of land use change is of worldwide interest. The simulation of land use dynamics using several models is widely used in land use planning research (Zuidema *et al.* 1994; Lambin 1997; Fisher and Sun 2001; Lambin *et al.* 2001; Kline *et al.* 2007; Schulp *et al.* 2008; Britz *et al.* 2011). Compared with other models, the conversion of land use and its effects at small region extent (CLUE-S) model is based on an empirical analysis of the spatial distribution of land use types, which takes into account geophysical and socio-economic properties (Verburg *et al.* 1999; Verburg *et al.* 2006, 2008; Verburg and Overmars, 2009; Luo *et al.* 2010). In addition, this model accounts for the competition among different land use types, simultaneously simulates different land uses, and produces a spatially explicit display of the simulation results.

Similar to the land use type classification system, 4 types of land use for planting or not planting green manure were classified in the present study. The geophysical and socio-economic driving factors that influence type conversion at a resolution of 100 m were considered. An interpolation model was used to calculate the quantitative changes in the 4 types. Next, CLUE-S was used to translate these changes into a spatial distribution of 4 types in the Pinggu District in 2020 by using 2011 as a baseline and the economic and ecological benefits of promoting green manure were analyzed. Briefly, this paper addressed the following objectives: (i) How to rationally predict the spatial distribution of the promotion of green manure planting in 2020 by the CLUE-S model on a county scale; (ii) How to calculate the area of promotion of green manure planting given the dynamic changes in croplands and orchards over time; and (iii) how to assess the economic and ecological benefits of incorporating or rotating green manure to determine which scenario provides greater benefits.

2. Results and disscussion

2.1. Prediction accuracy

The logit regression results were examined using the *receiver operating characteristic* (*ROC*) indices (Pontius and Schneider 2001). An *ROC* greater than 0.7 suggests strong correlations and a strong ability to explain the conversion between different types using the selected driving factors. Similar to land use type classification, 4 types of land use for planting or not planting green manure were classified in this paper: the promotion of green manure planting (T1), croplands without the promotion of green manure planting (T2), orchards without the promotion of green manure planting (T3) and other lands (T4). The *ROC*s for T1 to T4 were 0.933, 0.847, 0.896 and 0.726, respectively. The *ROC* of T4 was relatively low, which can be attributed to the complex components of this type, including forest, water, and built-up types of land use. The reasons underlying changes in T4 were generally complicated and unclear, and such changes cannot be accurately determined by simply adjusting the driving factors or other parameters. The resulting regression coefficients for the driving factors were used in subsequent experiments.

The accuracy of predicting whole types can be evaluated by using *Kappa* indices (Gobin *et al.* 2002). The predicted map for 2013 was compared with the actual map using ENVI 4.8. The *Kappa* index was 0.91, which suggested the model effectively captured future trends. The excellent *Kappa* indices can be ascribed to the small changes in driving factors over the 3 years.

2.2. Prediction of the spatial distribution of green manure in 2020

The spatial distribution of all types for the two predicted scenarios was presented in Fig. 1. Under scenario 1, the promotion of green manure planting in orchards mainly occured in the middle and southern regions of Dahuashan, the western and southern regions of Wangxinzhuang, the middle region of Shandongzhuang, the eastern region of Pinggu and the middle of Xiagezhuang (Fig. 1-A). Under scenario 2, the promotion of green manure planting mainly occurred in the middle region of Wangxinzhuang, and croplands located in most regions of Daxingzhuang, southern Pinggu, northern Xiagezhuang and most of Mafang (Fig. 1-B). The promotion of green manure only applied to orchards to meet the demands of T1 was assumed to occur under scenario 1. The *total probability* (*TPROP*) was assumed to provide an accurate description of the spatial distribution of all types under the actual geophysical and socio-economic conditions in the study area. The conversion was observed in grid cells with higher *TPROP* values. Thus, *TPROP* was used to determine which grids had the potential to increase the percentage cover of the different types. The demand for grid cells with T1 cover was considerably higher than the actual cover in 2011, which experienced an increase in iteration. The evaluation of soil-related attributes, such as soil organic matter, significantly contributed greatly to the conversion based on an analysis of the contribution of the driving factors. Lower *TPROP* values mainly resulted from lower levels of driving factors, such as higher elevations and lacking soil nutrients, which restricted the expansion of green manure in orchards in Liujiadian, Zhenluoying and Huangsongyu. Due to flat terrain and fertile soil, the conversion from T3 to T1 mainly occurred in southern Dahuashan, western Wangxinzhuang and in the middle of Shandongzhuang. Similar conditions were observed in Mafang due to the flat terrain, fertile soil and high fruit production. No spatial distribution of green manure was found in Machangying and Donggaocun, which were hampered by low levels of driving factors. In general, the area of orchards in southern Pinggu was smaller than that in northern Pinggu. Therefore, the southern region of Pinggu had a lower potential for an increase in the percentage cover of T1.

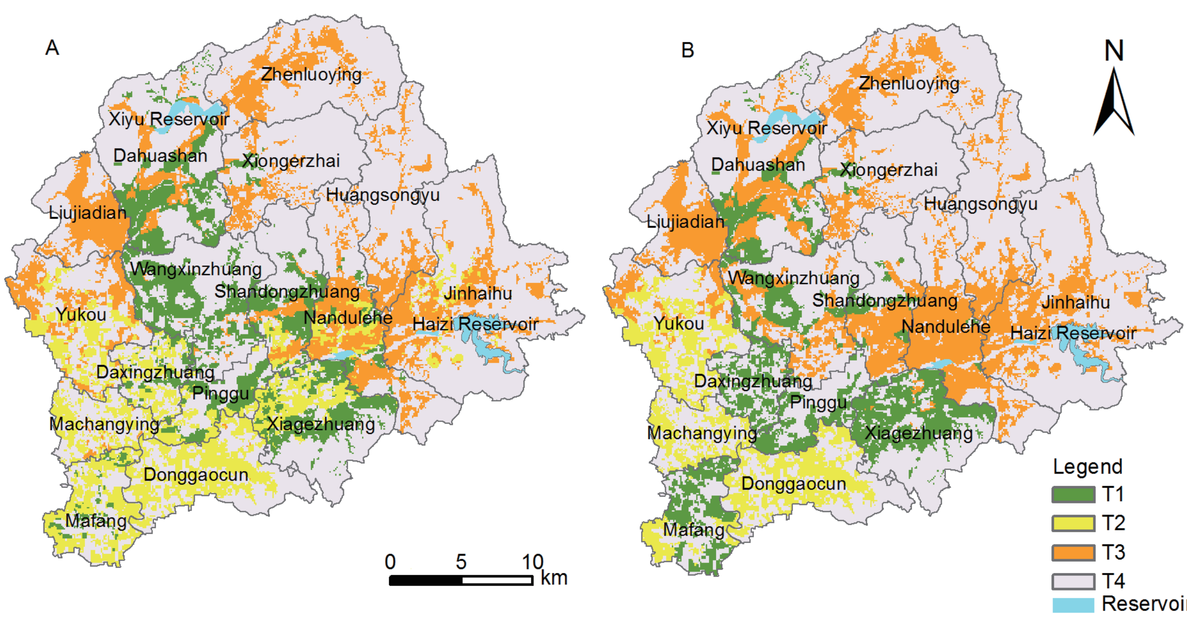

Fig. 1 Prediction of the spatial distribution of 4 types of land use for planting or not planting green manure under different scenarios in 2020. A, scenario 1. B, scenario 2. T1, the promotion of green manure planting; T2, croplands without the promotion of green manure planting; T3, orchards without the promotion of green manure planting; T4, other lands. The same as below.

In scenario 2, the promotion of green manure to cropland and orchards was assumed to occur simultaneously. The demand for T1 was the same as that in scenario 1. Compared with scenario 1, the demand for T2 was lower and the demand for T3 was higher (Table 1). Assuming green manure development followed the trend shown in the non-spatial module, some croplands and orchards without green manure would be converted to T1. When comparing the simulated scenario for 2020 with the actual map of 2011, the conversion of T1 from other types would primarily occur in Daxingzhuang, Xiagezhuang and Mafang. In general, the grids that were easily converted to T1 had slightly more fertile soil, somewhat higher crop and fruit yields, and lower elevations.

Based on the features in scenario 1, green manure intercropping was used in orchards. The specific spatial distribution of intercropping was shown in Fig. 2-A. However, Fig. 2-A cannot be used to discriminate between a green manure rotation and intercropping of T1 in scenario 2 because the green manure was only intercropped in orchards from 2011 to 2013 and no spatial distribution was obtained for green manure rotations with main crops in 2011. However, the rotation should appear under scenario 2 based on the scenario characteristics. The CLUE-S model cannot generate a new rotation system during subsequent simulations because the type in the model must be consistent before and after a model run. Thus the CLUE-S model was unable to distinguish the spatial distribution of rotations and intercropping in scenario 2. However, to account for the economic and ecological benefits of green manure, the spatial distributions of T1 in Fig. 1-B can be overlapped with the cropland and orchards shown in the land use planning map of the Pinggu District in 2020 to distinguish the two systems. The rotations were mainly concentrated south of

Table 1 Demand for 4 types of land use for planting or not planting green manure in 2011 and two scenarios (ha)[1)]

Comparisons among 2011 and two scenarios[2)]	Demand for T1	Demand for T2	Demand for T3	Demand for T4
The year of 2011	1 469	13 037	20 634	59 340
Scenario 1	10 469	11 597	15 234	57 180
Scenario 2	10 469	7 097	19 734	57 180

[1)] T1, the promotion of green manure planting; T2, croplands without the promotion of green manure planting; T3, orchards without the promotion of green manure planting; T4, other lands.
[2)] Scenario 1, the promotion of green manure planting in orchards; scenario 2, the promotion of simultaneous green manure planting in orchards and croplands.
The same as below.

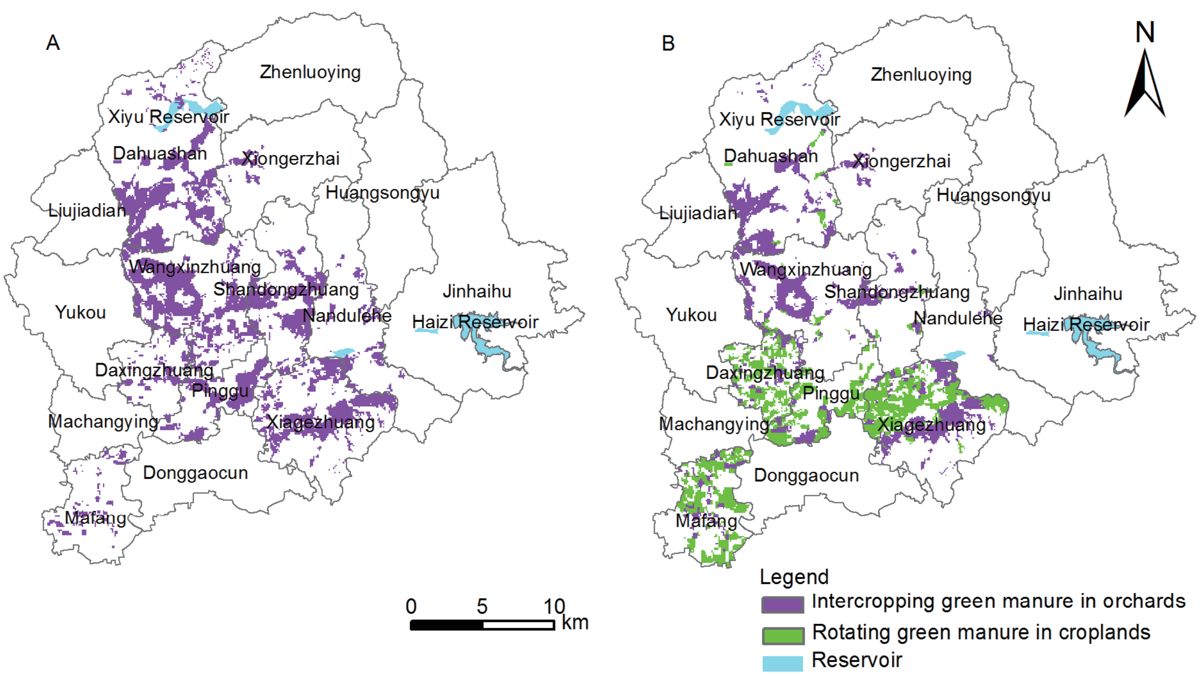

Fig. 2 Spatial distribution of intercropping green manure and rotating green manure under different scenarios in 2020. A, scenario 1. B, scenario 2.

the study area and intercropping was concentrated in the northern region of the study area (Fig. 2-B).

2.3. Assessment of economic and ecological benefits

The actual predicted areas of the 4 types of land use for planting or not planting green manure under different scenarios in 2020 conducted by the CLUE-S model are presented in Table 2. The area of intercropped green manure was 10 457 ha, with economic gains of 136 510 900 CNY under scenario 1. Under scenario 2, the area of intercropped green manure was 5 246 ha, with economic gains of 35 335 400 CNY, and the area of green manure rotations was 5 211 ha, with economic gains of 68 483 900 CNY based on equations in Materials and methods part. Thus, the total economic benefit was 103 819 300 CNY under scenario 2. The gains were higher in scenario 1, which can be ascribed to a greater increase in fruit yield per ha (0.750 t ha^{-1}) that was higher than that of the crop yield (0.553 t ha^{-1}). In addition, the unit-price of fruit (8 000 CNY t^{-1}) was greater than that of the crops (2 140 CNY t^{-1}). When promoting the same area of green manure, the ecological benefits were similar under the two scenarios (i.e., approximately 39 181 000 CNY). The respective total gains were 175 691 900 and 143 000 300 CNY under scenario 1 and scenario 2. Thus, under the assumption of promoting the same area of green manure for the purpose of economic and eco-income benefits, scenario 1 was more suitable.

3. Conclusion

In this study, the CLUE-S model was used to predict the spatial distribution of the promotion of green manure planting in the Pinggu District of Beijing, China. Besides, this study considered land use dynamics, mainly croplands and orchards, in the Pinggu District while calculating the demand for whole types. The predictions identified the core areas that were suitable for promoting green manure.

Based on the assessment of economic and ecological benefits, the gains of scenarios 1 and 2 were 175 691 900 and 143 000 300 CNY, respectively. Thus, under the assumption that the same area was planted in green manure for the purpose of economic and eco-income benefits, scenario 1 was more suitable.

The CLUE-S model is widely used to simulate land use type conversions. In this paper, the CLUE-S model was used to predict the spatial distribution of green manure based on the core ideas of land use type conversion and spatial allocation. In this study, vegetable land, which was included in cropland, accounted for 1.6% of the total study area. The inclusion of vegetable land in cropland may impact the prediction accuracy. This impact could be removed from croplands to improve the prediction accuracy. In addition, the parameters of the CLUE-S model (for example, *ELAS*) were derived from expert knowledge and the observed behavior in recent years. Parameters needed for assessing the ecological benefits of February orchid can be obtained in related field experiments. Further studies should be conducted to predict the trends of promoting green manure planting based on dynamic predictions of the spatial distribution of croplands and orchards rather than only taking the quantitative change of cropland and orchards into consideration.

4. Materials and methods

4.1. Study area

The Pinggu District (40°01´44´´–40°22´39´´N, 116°55´20´´–117°24´09´´E) is located in the northeastern region of Beijing, China, and the terrain of the study area slopes from northeast to southeast (Fig. 3). The region is surrounded by mountains on the eastern, southern and northern sides, and the middle of the region consists of plains. Pinggu contains 16 towns and covers an area of 948.35 km^2, of which one-third is flat and two-thirds are mountainous. The typical mountainous and flat topography affects the distribution of regional climate and soil, which are highly suitable for agriculture. The main land use type in Pinggu is agricultural land, and the areas of orchards and croplands account for 26.26 and 13.01% of the total land area, respectively. Fruit sales and crop production are major components of the local economy.

The February orchid (*Orychophragmus violaceus*) is one of the main types of green manure that can be rotated in croplands or intercropped in orchards in the study area. The government began systematically promoting the growth of February orchids in orchards in autumn 2010 over an area of 1 469 ha. Consequently, the cumulative area of green manure increased to 3 469 ha in 2013. The February orchid is a biennial plant that is sown in the autumn and can survive the winter. February orchids grow rapidly, cover the ground after turning green, and produce inflorescence in April. Therefore, the 2011 spatial distribution was more reliable for February orchid.

Table 2 Predicted areas of 4 types of land use for planting or not planting green manure under different scenarios in 2020 (ha)

Scenario	Predicted areas of T1	Predicted areas of T2	Predicted areas of T3	Predicted areas of T4
1	10 457	11 682	15 195	57 416
2	10 457	7 156	19 688	57 519

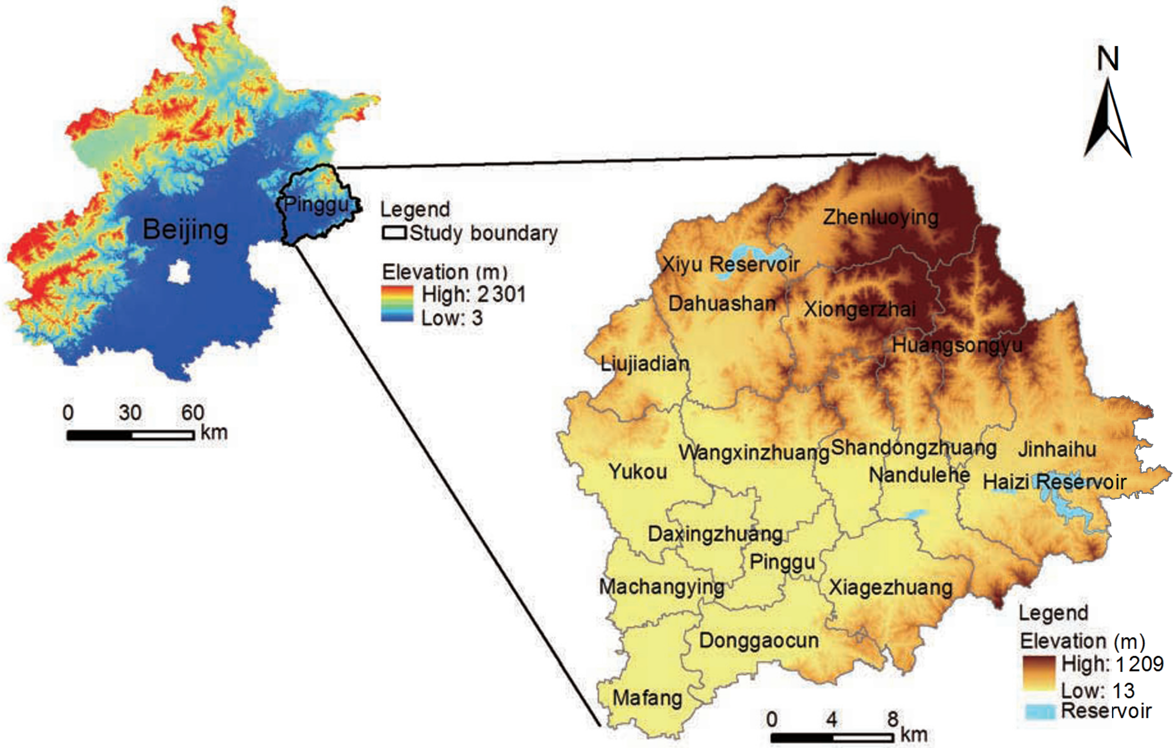

Fig. 3 The site and elevation map of the study area.

The Pinggu District is located in the northern region of the North China Plain. Although wheat-maize double-cropping systems originally played a crucial role in agricultural production, this type of system hindered sustainable agricultural development because of water shortage. Recently, planting one crop per year has been replaced with planting two crops. Spring maize is sown in April and harvested in September. In addition, February orchid is planted in autumn in fallow croplands to improve the ecological environment and reduce soil erosion. So the area of spring maize is approximately equal to the cropland area. If green manure planting is promoted by rotating with spring maize, the spatial distribution of croplands could be used instead of spring maize for the prediction in this paper.

4.2. Data and processing

The 2011 to 2013 spatial distribution of promoting green manure planting in the study area was obtained from the Beijing Soil and Fertilizer Station. Landsat thematic mapper (Landsat TM) image data (acquired 2011–2013; resolution: 25 m) were processed using geometric correction, band overlapping and image enhancement. Land use information, such as where the cropland, orchard or rural residential sites were located, was extracted from the data using ENVI 4.8 with human-computer interactive operations. Elevation and slope data were acquired from digital evaluation model. Soil-related attributes, such as soil organic matter, total nitrogen, available phosphorus and available potassium, were derived from a 1:5 million soil map, and distance to the nearest road, railroad, river and main town were calculated using ArcGIS 10.0 to describe transport accessibility. All of these data, excluding the spatial distribution of promotion of green manure planting and the Landsat TM images, were obtained from the Beijing Digital Soil System. The socio-economic variables, such as population density, agricultural population density, fruit yield and crop yield data, were obtained from the Statistical Date of Pinggu District, Beijing, for 2012 (http://www.pg.bjstats.gov.cn/tjsj/ndsj/index1.htm; http://www.pg.bjstats.gov.cn/tjsj/ndsj/index2.htm). All GIS data were converted to an equal-area projection and gridded using a basic grid size of 100 m×100 m (0.01 km^2). The same approach was followed for the socio-economic variables.

4.3. Methods of prediction of spatial distribution of green manure

Classification of 2011 types of land use for planting or not planting green manure Similar to land use type classification, 4 types of land use for planting or not planting green manure were classified in this paper: the promotion of green manure planting (T1), croplands without the promotion of green manure planting (T2), orchards without the

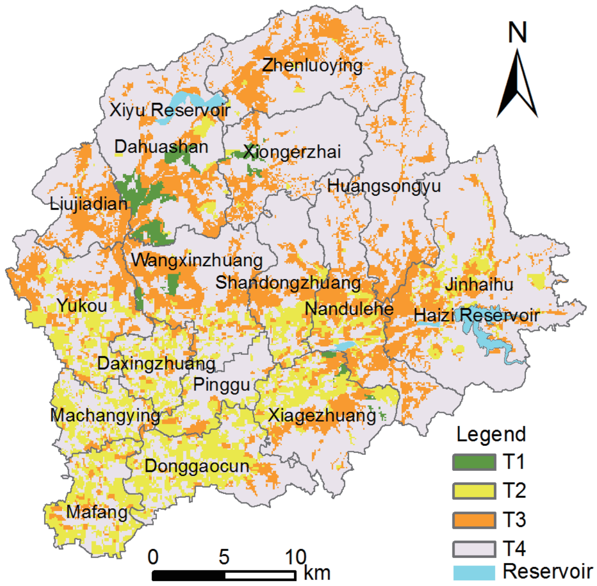

Fig. 4 Spatial distribution of 4 types of land use for planting or not planting green manure of the study area in 2011.

promotion of green manure planting (T3) and other lands (T4). The T4 classification referred to all land use types (e.g., forest, built-up areas, water) except croplands and orchards. Competition among different types determines what changes will ultimately occur. T1 was mainly spatially distributed in Dahuashan, Wangxinzhuang and Xiongerzhai (Fig. 4). The 4 types covered areas of 1 469, 13 037, 20 634, and 59 340 ha, respectively.

Selection of spatial and temporal scales The CLUE-S model is a grid-based model, and the spatial scale refers to the spatial resolution (i.e., the raster cell size). In this study, the resolution was initialized at 300 m and then decreased stepwise (50 m $step^{-1}$) for comparative purposes. Optimal simulation results were obtained at a resolution of 100 m. The actual 2011 map was analyzed using the CLUE-S model to predict the 2013 map, and the prediction was verified for accuracy. Next, the actual 2013 map was analyzed to predict the scenarios for 2020.

Non-spatial module The CLUE-S model is sub-divided into two distinct modules, namely, a non-spatial module and a spatial module (Verburg *et al.* 2009). The non-spatial module calculates changes in area for the 4 types of land use for planting or not planting green manure. Considering green manure rotations in cropland or intercropping in orchards, this module must account for the dynamic quantitative changes in croplands and orchards within a given year. The demand for cropland and orchards was derived from the general plan for land-use in Pinggu District (2006–2020) (http://pg.bjgtj.gov.cn/art/2012/12/5/art_563_70845.html), and the demand for the promotion of green manure planting in croplands and orchards under different scenarios was obtained from the relative promotion plans for green manure planting provided by the Beijing Soil and Fertilizer Station. The government aims to promote 1 000 ha of green manure every year. The specific demand for T2 and T3 can be represented as follows:

$$S_{T2i}=a_i-b_i \quad (1)$$

Where, S_{T2i} is the demand for T2 in year i, a_i represents the demand for cropland in year i, and b_i represents the demand for green manure rotation with a main crop (i.e., spring maize) in year i. The value of a_i for 2012 to 2020 was obtained using interpolation based on the general plan for land-use in Pinggu District (2006–2020).

$$S_{T3i}=c_i-d_i \quad (2)$$

Where, S_{T3i} is the demand for T3 in year i, c_i represents the demand for orchards in year i, and d_i represents the demand for intercropping green manure with fruit trees in year i. The value of c_i for 2012 to 2020 was obtained through interpolation based on General Plan for Land-use in Pinggu District (2006–2020).

Under scenario 1, the demand for T1 is d_i for only promoting green manure planting in orchards. $S_{P1i}=d_i=1\,000$, $b_i=0$, $S_{T2i}=a_i$

Under scenario 2, the demand for T1 is b_i plus d_i. $S_{T1i}=b_i+d_i=1\,000$, $b_i=500$, $d_i=500$

The demand for T4 is defined as:

$$S_{T4i}=S_{Total}-S_{T1i}-S_{T2i}-S_{T3i} \quad (3)$$

Where, S_{T4i} is the demand for T4 in year i and S_{Total} represents the total area of the study area, which is equal to the size of the Pinggu District.

The demand for all types under different scenarios is shown in Table 1.

Spatial module The spatial module consists of a spatially explicit allocation procedure. The spatial distributions of the 4 types of land use for planting or not planting green manure are quantified using a binomial logit model with the percentages of the types as the dependent variables and the geomorphological, transport accessible, soil-related and socioeconomic driving factors as independent variables.

In this study, 15 driving factors were included based on their availability, stability, and relevance and the suitability of the data, elevation (X_1), slope (X_2), distance to the nearest road (X_3), distance to the nearest railway (X_4), distance to the nearest river (X_5), distance to the nearest rural resident site (X_6), distance to the nearest the main town (X_7), soil organic matter (X_8), total nitrogen (X_9), available phosphorus (X_{10}), available potassium (X_{11}), population density (X_{12}), agricultural population density (X_{13}), fruit yield (X_{14}) and crop yield (X_{15}). Specifically, X_1 and X_2 were used to describe the terrain conditions, and X_3, X_4, X_5, X_6 and X_7 were used to describe the transport accessibility. The above geophysical factors are essential for difficult terrain conditions with limited access to the promotion of green manure planting. Furthermore, X_8, X_9, X_{10} and X_{11} were indicators of soil chemistry properties. For example, green manures are preferred for plants in low fertility soils rather than high fertility soils because green manure can increase crop yield. X_{12}, X_{13}, X_{14} and X_{15} were the key socio-economic factors that influence promotion in the county. The probabilities of the conversion of location characteristics were defined by using the following logit model:

$$\ln(\frac{P_i}{1-P_i})=\beta_0+\beta_1X_{1,i}+\beta_2X_{2,i}+...+\beta_nX_{n,i} \quad (4)$$

Where, P_i is the probability that a grid cell in location i contains a particular type and the $X_{n,i}$ represent the driving factors. The coefficient (β) was estimated using a logit regression with the actual type as the dependent variable and the i values ranging from 1 to 4, for T1 through T4, respectively.

Conversion between different types determines what changes will eventually take place. The specific conversion settings of the 4 types affect the temporal dynamics of the prediction, which are composed of two parameters (i.e., the conversion elasticity (*ELAS*) and transition matrix). The first parameter, which ranges from 0 (easy conversion) to 1 (irreversible change), is determined based on expert knowledge and observed behavior in recent years. In this study, the *ELAS* values were 1, 0.5, 0.1 and 0.6 for scenario 1 and 1, 0.1, 0.1 and 0.6 for scenario 2. The second parameter, i.e., the transition matrix, has values of 0 (irreversible transition) or 1 (easy conversion) and indicates what conversions are possible for each type. In this study, all of the values in the transition matrix were 1, which suggested that all patterns could easily be converted.

The CLUE-S model operates at discrete time steps and uses conversion rules to predict the demand for all patterns and the most likely changes in different types based on eq. 4. For each grid *i,* the total probability ($TPROP_{i,u}$) was calculated for each type according to the following formula:

$$TPROP_{i,u}=P_{i,u}+ELAS_u+ITER_u \quad (5)$$

Where, $TPROP_{i,u}$ is the suitability of location i for a type u, $ELAS_u$ is the conversion elasticity for type u and $ITER_u$ is an iteration variable that is specific to type u and indicative of the relative competitive strength of type u.

The specific explicit approach to modeling changes for the different types, which allows us to evaluate the possible consequences. For example, the effect of promoting green manure planting on economic and ecological benefits was determined by comparing the increased benefits of green manure promotion with the benefits obtained without using green manure. Indicators such as the reduction in chemical fertilizer use and the reduction in nutrient loss were adopted as measures to assess economic and ecological benefits. Parameters were obtained from a series of experiments that were conducted by Beijing Soil and Fertilizer Station and Jiangxi Academy of Agricultural Sciences.

4.4. Methods of assessing the economic and ecological benefits of green manure

February orchid can be rotated with crops or intercropped in orchards. Thus, the economic benefits of two methods will vary with differences in the physical characteristics of the main crops and fruit trees. The economic benefits of green manure rotations in cropland can be represented as follows:

$$T_1=(e\times p_e+f\times p_f+r_N\times p_N+r_P\times p_P+r_K\times p_K-x)\times S_1 \quad (6)$$

Where, T_1 is the economic benefit of a rotation; e represents the increased crop yield per ha produced by green manure rotations (here, 0.553 t ha^{-1}); p_e is the unit-price of maize (here, 2 140 CNY t^{-1}); f represents the value of the fresh and dry weight of green manure per ha (here, 4.080 t ha^{-1}); p_f is the unit-price of the fresh and dry weight of green manure (here, 1600 CNY t^{-1}); r_N represents the reduction in the amount of nitrogen fertilizer used (here, 0.024 t ha^{-1}); p_N is the unit-price of nitrogen fertilizer (here, 1650 CNY t^{-1}); r_P represents the reduction in the amount of phosphate fertilizer used (here, 0.007 t ha^{-1}); p_P is the unit-price of phosphate fertilizer (here, 2500 CNY t^{-1}); r_K represents the reduction in the amount of potash fertilizer used (here, 0.024 t ha^{-1}); p_K is the unit-price of potash fertilizer (here, 2600 CNY t^{-1}); x is the cost of green manure rotations in the year of application, including the cost of seed and labor (here, 1050 CNY ha^{-1}); and S_1 is the rotation area of green manure and spring maize.

The economic benefits of intercropping green manure in orchards can be represented as follows:

$$T_2=(g\times p_g+h\times p_h+r_N\times p_N+r_P\times p_P+r_K\times p_K-y)\times S_2 \quad (7)$$

Where, T_2 is the economic benefit of intercropping; g represents the increased fruit yield per ha caused by intercropping green manure (here, 0.750 t ha^{-1}); p_g is the unit-price of fruit (here, 8000 CNY t^{-1}); h represents the fresh and dry weight value of green manure per ha (here, 4.800 t ha^{-1}); p_h is the unit-price of the fresh and dry weight of green manure (here, 1600 CNY t^{-1}); r_N represents the reduction in the amount of nitrogen fertilizer used (here, 0.024 t ha^{-1}); p_N is the unit-price of nitrogen fertilizer (here, 1650 CNY t^{-1}); r_P represents the reduction in the amount of phosphate fertilizer used (here, 0.007 t ha^{-1}); p_P is the unit-price of phosphate fertilizer (here, 2500 CNY t^{-1}); r_K represents the reduction in the amount of potash fertilizer (here, 0.024 t ha^{-1}); p_K is the unit-price of potash fertilizer (here, 2600 CNY t^{-1}); y is the cost of incorporating green manure in the year of application, including the cost of seed and labor (here, 740 CNY ha^{-1}); and S_2 is the green manure intercropped area in orchards.

The ecological benefit of green manure application in cropland and orchards can be represented as follows:

$$T_3=(i\times p_i+j\times p_j+k\times p_k+l\times p_l+m\times p_m+n\times p_m)\times S_3\times k \quad (8)$$

Where, T_3 is the ecological benefit of developing green manure; i represents the increased soil organic matter (SOM) per ha caused by planting green manure (here, 4.50 t ha^{-1}); p_i is the unit-price of SOM (here, 400 CNY t^{-1}); j represents the decrease in the N loss per ha (here, 0.59 kg ha^{-1}); p_j is the unit-price of N (here, 3.50 CNY kg^{-1}); k represents the decrease in the P loss per ha (here, 0.06 kg ha^{-1}); P_k is the unit-price of P (here, 5.00 CNY kg^{-1}); l represents the increase in water conserved (here, 123.00 t ha^{-1}); p_l is the unit-price of reservoir water (here, 1.36 CNY t^{-1}); m represents the amount of carbon dioxide absorbed by green manure per ha (here, 4.89 t ha^{-1}); p_m is the unit-price of forestation (here, 2 600 CNY t^{-1}); n represents the amount of accumulated oxygen per ha (here, 3.57 t ha^{-1}); p_n is the unit-price of oxygen (here, 326.90 CNY t^{-1}); and S_3 is the area of developed green manure. In this paper, the ecological benefits of February orchid were calculated based on the ecological benefits of milk vetch (*Astragalus sinicus* L.) growing in a paddy. The ecological benefits for the two scenarios were the same for the same area of green manure. The ecological benefits of February orchid can be multiplied by the adjustment factor k (here, 0.85) to roughly estimate that in the study area.

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