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Agronomic technology to promote sustainable utilization of newly created farmland in the Chinese Loess Plateau

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Abstract

The new farmland created by land consolidation often faces the problems of poor soil structure and low productivity, which cause potential degradation risk. The Gully Land Consolidation Program (GLCP) significantly increased the quantity of farmland in the Chinese Loess Plateau (LP), but the research on a comprehensive method of simultaneously improving soil quality, agricultural profit, and utilization efficiency of newly created farmland (NCF) is relatively scant. This study explored an agronomic technology to improve soil quality, agricultural profit, and utilization efficiency NCF by the GLCP in the LP. Our field experiment was carried out in Yangjuangou catchment with seven soil treatments and planting *Brassica napus (B. napus)* on these soils: dry mixing Malan Loess and red clay at volumetric ratios of 1:0 (MR10), 5:1 (MR51), 2:1 (MR21), 1:1 (MR11), 1:2 (MR12), 1:5 (MR15), and 0:1 (MR01). The results showed that: the soil microstructure, physico-chemical properties, and productivity of NCF were significantly improved after soil reconstruction by dry mixing Malan Loess and red clay. More specifically, the MR51 boosted the root thickness and fresh weight of *B. napus* by 78.69% and 45.01% compared to that of red clay (MR01). Crop optimization by the *B. napus* helped to increase the agricultural profits of NCF. The proposed three portfolios of *B. napus*' silage, vegetable plus rapeseed, and vegetable plus silage enhanced the profits by 35.39%, 57.05%, and 66.93% in comparison with that of traditional crop planting, respectively. Therefore, industrial integration through effective, ecological and economic (3E) agriculture could advance sustainable utilization of NCF. Further, developing efficient agriculture, animal husbandry, agricultural products processing industry, and ecological tourism would enhance the multi-functional value of farmland. Our study suggests that targeted agronomic technology based on agricultural geographical engineering oriented to human-environment interaction can provide technical support for minimizing the degradation risk of NCF and generating more sustainable development in ecologically fragile areas.

KEYWORDS
Gully Land Consolidation Program, newly created farmland, soil reconstruction, crop optimization, agricultural geographical engineering

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1 | INTRODUCTION

Farmland degradation, exacerbated by rapid urbanization and industrialization, has become an issue of global ecological and social concern (Godfray et al., 2010; Liu et al., 2014; Smiraglia et al., 2016). Excessive urban expansion and the overuse of chemical fertilizer, lead to a noticeable drop in the quantity and quality of farmland. The reducing quantity and quality of farmland and its decreasing agricultural profitability result in a large amount of farmland abandonment (Li et al., 2022; Castro et al., 2020; Liu, 2018; Song & Pijanowski, 2014). These problems severely threaten food security, poverty alleviation, and rural revitalization (Foley et al., 2005; Liu & Li, 2017a), particularly in ecologically fragile areas (Cao et al., 2017). Various ecological restoration efforts have been made in the ecologically fragile areas (Cao et al., 2021; Li et al., 2021), albeit at the expense of lowering farmland amounts and degrading agriculture. However, farmers are still reluctant to cultivate degraded farmlands in the absence of adequate government subsidy and assistance, which aggravates farmland abandonment and agricultural yield decline (Gerber et al., 2009; Tallis et al., 2008).

Land consolidation has been widely used to increase the quantity and quality of farmland all over the world (Demetriou et al., 2012; Prosdocimi et al., 2016). China has implemented a series of land consolidation engineering to alleviate farmland shortages in ecologically fragile areas, such as gully land consolidation, sandy land engineering, and barren hilly land consolidation (Liu et al., 2014; Liu & Wang, 2019). Yet, recent studies have revealed that newly created farmland (NCF) in land consolidation engineering possesses poor physicochemical properties, which substantially reduces crop yields and agricultural profits (Li et al., 2022; Ma, Chen, Wang, et al., 2020; Song & Liu, 2017; Song & Pijanowski, 2014). As natural processes take their time in developing soil fertility and improving soil quality (Ma, Chen, Zhou, et al., 2020), extra production factors are invested to prevent the degradation of NCF.

Many approaches have been conducted to ameliorate the quality of NCF, for instance, using compound fertilizer, soil conditioner, natural rocks, and so forth. Compound fertilizer is widely used to improve NCF quality temporarily while causing side effects like soil contamination and hardening (Fu et al., 2019; Veloso et al., 2019). Various soil conditioners, such as synthetic soil polymers and organic solid wastes, are also applied to improve soil physicochemical qualities (Aksakal et al., 2012). But these conditioners are not necessarily cost-effective and may even contaminate soils. Adding natural rocks, such as red clay to sandy land or diatomite to saline land, to change soil particle composition serves as an effective way to improve farmland quality (Dessalew et al., 2017; Liu et al., 2018; Wang & Liu, 2020). Moreover, crop variety improvement, crop rotation, and cash crop planting are also proposed to help increase agricultural profit from NCF (Silvestri et al., 2017). However, these approaches almost failed as they overlook the coupling relationships among soil ecological suitability, crop physiological adaptability, and regional comparative advantage (Liu et al., 2018).

The Loess Plateau (LP) is one of the world's most vulnerable eco-regions, plagued by serious soil erosion, and limited livelihood resources (Fu et al., 2017; Li et al., 2021). Since 1999, the Grain-for-Green Program (GGP) has greatly increased the vegetation coverage to improve the regional ecology and environment (Cao et al., 2018; Lü et al., 2012). However, the rapid reduction of farmland with the large-scale effort in converting slope farmland to plant vegetation threatens farmers' livelihoods (Chen et al., 2015; Li et al., 2019). According to statistics, 4.83 millon ha of farmland have been converted to vegetation, which had obviously exceeded the original limitation of 2.52 million ha (Lü et al., 2012). To reconcile the relationship between ecological protection and farmers' livelihood, the LP's Yan'an City has implemented the Gully Land Consolidation Program (GLCP) since 2013, through which around 33,700 ha of farmland had been created (Liu & Li, 2017b; Liu & Wang, 2019; Zhang et al., 2021). Furthermore, Yan'an City adopted several methods to increase the fertility and reduce the abandonment and degradation rate of NCF. For example, biochar and organic fertilizers and an organic amendment called *He Kang* (a soil amendment of plant nutrient type) were used to improve soil fertility and control secondary saline-alkali degradation (Chang et al., 2021; Han et al., 2021; Yang et al., 2020). Increased crop yields were achieved by selecting suitable crops and optimizing planting technology for common crops such as potato and canola (USA) -*Brassica napus (B. napus)* (Chen et al., 2021; Liu et al., 2017). However, these methods just work in a short term and merely focus on one single goal of improving soil quality or raising economic benefits, thus making it difficult to solve the problem of inefficient utilization. Hence, there is an increasingly urgent need to explore an effective agronomic technology to improve soil quality while increasing the agricultural profit of NCF.

This study aims to propose a comprehensive agronomic technology to sustainable utilization of NCF based on field experiment in the Yangjuangou catchment. The specific objectives were as follows: (i) to evaluate the soil quality improvement effect of soil restructuration technology based on soil particles complementarity; (ii) to assess the agricultural profits enhancement of planting structure optimization method that takes crop's physiological adaptability and regional comparative advantage into account; and (iii) to explore utilization model of NCF according to regional topographic characteristics, resources endowment, and industrial basis. The main findings of this study can help to support agricultural geographical engineering technology and promote the coordinated relationship in a coupled human-environment interaction system for the LP.

2 | MATERIALS AND METHODS

2.1 | Site description

The field experiment was conducted at the Research Station for Gully Land Consolidation and Sustainable Land-use on the Loess Plateau (36°41′48.31″N, 109°31′17.91″E). The station is located in Yangjuangou catchment, the central region of the LP in Yan'an City, northern Shaanxi Province, and has an elevation between 989 and 1250 m (Figure 1). The area is a typical catchment in the loess hilly-gully region, which is

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8.50 km from the new town of Yan'an City and covers an area of 4.10 km^2. This catchment is characterized by the semiarid continental climate with an annual sunshine duration of 2563 hr, an annual mean temperature of 9.50°C, and annual mean precipitation of 550 mm occurring mainly between July and September (Wang et al., 2017). This area implemented the GLCP in 2014, creating about 27.84 ha of new farmlands. The main soil type of NCF is Huangmian Soil developed from loess parent materials. The primary agricultural model of this catchment is traditional rain-fed maize planting after the GLCP.

2.2 | Experimental design

This study summarized the reasons for inefficient utilization and degradation risk of NCF after the GLCP (Figure 2). The soil of NCF is mainly dominated by red clay removed from the depth of the surrounding slopes (Ma, Chen, Zhou, et al., 2020). The red clay is compact and cohesive due to the high clay and low sand content, which caused the poor microstructure of NCF (Ma, Chen, Wang, et al., 2020). The uncultivated soil generally has lower concentrations of organic matter, nitrogen, phosphorus, and nutrients, which results in the weak fertility of NCF (Li et al., 2017). Roller compaction with heavy machinery results in structure deterioration of NCF during the process of farmland reclamation (Fu et al., 2019). Hence, the poor quality and lower maturity of NCF means it could be easily degraded (Feng & Li, 2021). Meanwhile, farmers continue their traditional crop planting with an extensive management mode after the GLCP, which exacerbates the degradation of NCF with higher sensitivity to tillage practices. Traditional crops with poor stress resistance have a lower yield on the NCF and in turn, cause lower agricultural profits (Liu

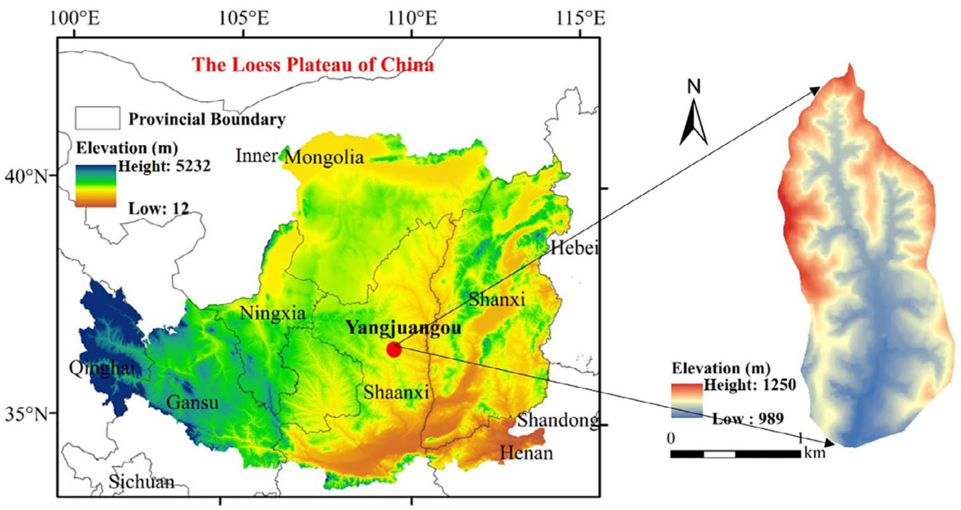

FIGURE 1 Location of the LP and Yangjuangou catchment. Coloured areas and red spot in left Figure indicates the location of the LP and Yangjuangou catchment. The right map shows the topography of the Yangjuangou catchment [Colour figure can be viewed at wileyonlinelibrary.com]

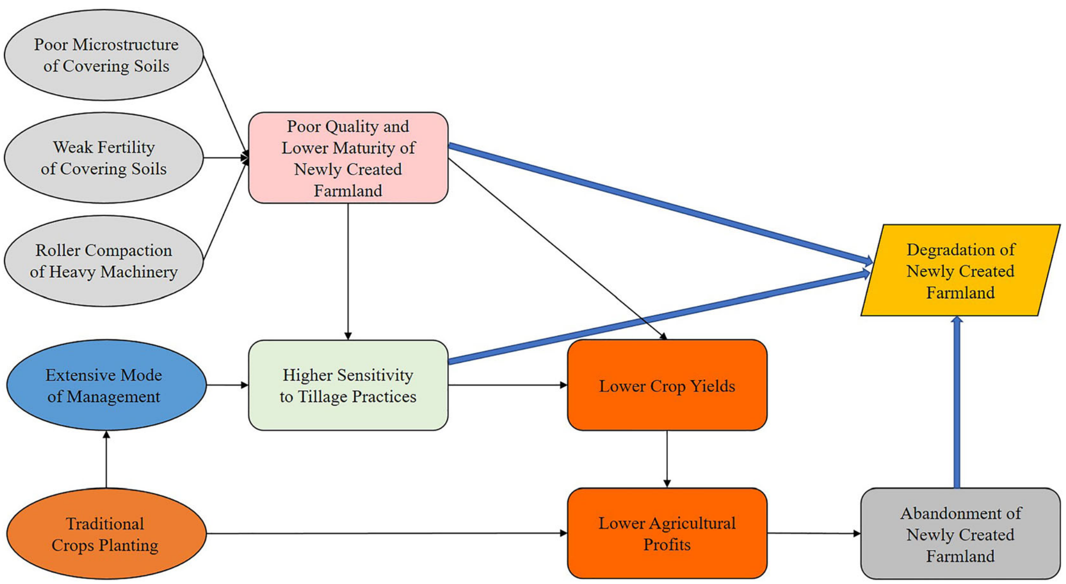

FIGURE 2 The causes of inefficient utilization and degradation risk of newly created farmland (NCF) after the GLCP [Colour figure can be viewed at wileyonlinelibrary.com]

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et al., 2017). Farmers as '*Homo economicus*' usually abandon the NCF, which further renders farmland degradation over the years (Li et al., 2019; Li et al., 2022). In view of the above problems, this study proposed reconstructing soil microstructure to improve farmland quality and optimizing planting structure to boost agricultural profits according to the agricultural geographical engineering, and the effect was evaluated by the field experiment. Specifically, Malan Loess with higher sand content was added to the red clay for reconstructing the soil microstructure based on the soil particles complementarity; *B. napus* with better stress resistance and less input demands was selected to optimize the planting scheme.

The field experiment was conducted with seven treatments and three replications in a randomized complete block design in 2017. Each plot was set with an area of 5 m $\times$ 15 m, separated by a barrier with a width of 0.50 m. Seven treatments were tested based on the different volumetric ratios of dry mixing Malan Loess and red clay: 1:0 (MR10), 5:1 (MR51), 2:1 (MR21), 1:1 (MR11), 1:2 (MR12), 1:5 (MR15), and 0:1 (MR01). The specific procedures of soil reconstruction were that: (a) stripped the original soils of 0–30 cm in the newly created farmland; (b) took the predetermined amount of Malan Loess and red clay, and crushed them into particles with a size less than 3 cm; (c) fully mixed two soils at different volumetric ratios, and laid them on the field (thickness: 30 cm); (d) evenly spread compound fertilizer (300 kg ha^{-1}) and farmyard manure (sheep manure, 30000 kg ha^{-1}) as base artificial fertilization and tilled fields by the rotary cultivator. The *B. napus* (crop variety Huayouza 62) was sown/broadcast onto soil with a suitable moisture condition on April 15, 2017. The sowing depth was 2–3 cm; the row space was 30–40 cm; the seeding rate was 4.5 kg ha^{-1}. Other field managements were carried out following the local agricultural schedule, including thinning out seedlings, top dressing, watering, cultivation, weed, and pest control. To compare the profits of different *B. napus* products, the crop was harvested at the initial flowering stage and mature stage, respectively.

2.3 | Soil sampling and analysis

A total of 21 soil samples were collected from the tillage layer (0–30 cm) during the harvesting stage of *B. napus* in October, 2017. Each sample was composited from five individual sampling points within the experimental plots of each treatment along with an "S" pattern by using a 5-cm diameter stainless steel corer. Each soil sample was mixed evenly and passed through an 8-mm nylon sieve to remove animal residues, roots, and gravel. Approximately 1 kg of soil reserved was placed into polyethylene bags. Soil physic-chemical properties were measured after air-drying in the laboratory.

Soil particle size distribution (PSD) was determined by a laser particle size analyzer (Malvern Mastersizer 2000, measuring range: 0.02–2000 μm), and the classification was in line with international grading standards. Soil microstructure was observed and photographed with a scanning electron microscope (SEM, Tescan-5136SM) after depositing a gold film (thickness: 10–20 nm) on the samples' surface by ion spluttering (Hitachi E-1010) (Ma, Chen, Wang, et al., 2020). The soil mineral elements were determined with an energy dispersive spectrometer (EDS, Inca X-Max 80), and the result was used to calculate the silicon:aluminum ratio indicating the degree of soil maturation. Soil porosity was measured by visually interpreting SEM photos using the software NANO MEASURER (version: 1.2).

Soil pH was measured in suspension (the ratio of soil and water 1:2.5) with an automatic acid-based titrator (INESADZB-718). Soil cation exchange capacity (CEC) was determined using flame photometry after treating samples with, NaOAc solution and then NH_4OAc solution (Lu, 2000). Soil organic matter (SOM) was measured by hot oxidation with sulfuric acid and potassium dichromate (Yeomans & Bremner, 1988). Available potassium (HNO_3-K) was determined by flame photometry after extracting samples in NHO_3 at the solution/solid ratio of 20:1 for 0.5 hr (Ma, Chen, Wang, et al., 2020). Available phosphorus ($NaHCO_3$-P) was determined by the Olsen measured method after soil treatment with $NaHCO_3$ at the ratio of solution/solid of 20:1 for 0.5 hr. Available nitrogen (NaOH-N) was transformed to NH_3 by NaOH and $FeSO_4$ powder at 40°C for 24 hr, and then absorbed with H_3BO_3 and titrated with H_2SO_4 (Lu, 2000).

2.4 | *B. napus* growth and agricultural profit

The root thickness, height, and fresh weight of *B. napus* were measured at the initial flowering stage to compare the growth of *B. napus* among different treatments. The *B. napus* was hand-harvested from five random quadrats (1 m $\times$ 1 m) within each plot along an "S" pattern; and the root thickness, height, and fresh weight of *B. napus* were determined by a vernier caliper, tape, and the weighing method respectively. The *B. napus* growth of each treatment was obtained by calculating the average value of the quadrats in corresponding plots. The remaining *B. napus* was hand-harvested at the mature stage to determine the yield of rapeseed and its straw.

The *B. napus* is an important oil and excellent forage crop, the rapeseed has a high market price, and the straw and silage can be used as high-quality forage for livestock. Thus, the agricultural profits of *B. napus* are determined by its rapeseed, straw, and silage, which was estimated based on the highest yield among the seven treatments. The yield of silage was measured by its fresh weight because the weight would not change significantly during the fermentation process. As a comparison, we evaluated the yields and profits of common crops products according to the local average, including the grain and straw of maize, and the grain of soybean, sorghum, and millet. The price of each product was calculated based on the local market surveys in 2017.

2.5 | Statistical analysis

The one-way analysis of variance was employed to estimate the differences in soil porosity, soil silica-alumina ratio, soil chemical properties, and rape growth among different soil treatments. The two-way analysis of variance was used to analyze the differences in soil particle

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composition and soil elements among different soil treatments. The Duncan's multiple range test at 5% probability level was applied to determine the significant differences among each treatment. Shaprio–Wilks test and Levene's test were employed to test for data normality and homogeneity of variances, respectively. Meanwhile, in the case of non-normally distribution of data or non-homogeneity of variances, the natural logarithm or square-root transformation was performed before the ANOVA. Data analysis methods mentioned above were conducted in SPSS version 22.0 (SPSS Inc., Chicago, IL).

3 | RESULTS

3.1 | Soil microstructure

The SEM photos with ×250 magnification indicated that the soil microstructure significantly changed after its reconstruction (Figure 3). The microstructure of MR10 was loose with clear particles and outlines. Soil particles in MR10 were mainly granular sands with the shape of prismatic and semi-rounding and the surface attaching the friable minerals. Soil particles were accumulated by direct point-to-point contact with scaffold pores and larger porosity in MR10 (Figure 3a). The microstructure of MR01 was much denser, and its particle outlines were blurred. Soil particles in MR01 were primarily massive clays with irregular shapes and uneven surfaces. In MR01, the clays cemented through indirect face-to-face contact in a mosaic, intra-particle pores, and smaller porosity form (Figure 3c). The microstructure of MR11 was relatively more reasonable compared with that of MR10 and MR01. The clays that were adhered to the surface of silts and sands form aggregates in MR11, and the clay content was more than that in MR10 and less than that in MR01. The soil particles in MR11 were founded with both point-to-point contact and face-to-face contact, leading to the scaffold, mosaic, and intra-particle pores, and more appropriate porosity compared to MR10 and MR01 (Figure 3b). Meanwhile, the existence of little crop roots in each treatment could be observed, which would improve soil microstructure.

3.2 | Soil physical properties

Soil reconstruction had significantly positive impacts on soil physical properties (Figure 4). The clays and silts just accounted for 6.07% and 22.81% in MR10, respectively, while both were 26.89% and 67.04% in MR01. The proportion of the clays and silts in reconstructed soils was significantly increased in comparison with that of MR10 and obviously decreased compared to that of MR01. The ratio of the sands was up to 71.26% in MR10 and only 6.07% in MR01. The sands of reconstructed soils were ranged between MR10 and MR01, presenting obvious differences among various mixing volumetric ratios of Malan Loess and red clay. The changes in soil particles altered soil texture and its porosity. According to the USDA (United States Department of Agriculture) classification standard of soil particles, the texture of restructured soils gradually changed from sandy loam (MR10) and silty clay (MR01) to loam (MR51, MR21, and MR11) and silt loam (MR12 and MR15). The porosity of reconstructed soils was significantly lower than that of MR10 (44.24%) and higher than that of MR01 (19.90%). The porosity was decreased by 20.19%, 25.02%, 31.87%, 36.05%, and 41.73% in MR51, MR21, MR11, MR12, and MR15 in comparison with MR10. Meanwhile, the porosity in MR51, MR21, MR11, and MR12 were 77.44%, 66.68%, 51.46%, and 42.16% higher than that in MR01.

The O, Au, Si, and Al were the main mineral elements in all soils, but their content showed obvious differences among the seven soil treatments. The O content in MR51 (44.29%) was significantly higher than that in other treatments, while the Au content in MR51 (10.90%) and MR11 (15.57%) were obviously less than that in others. The highest Si content occurred at MR51 (22.20%), and no obvious difference was observed among other treatments. Meanwhile, the MR51(8.89%) and MR11 (8.58%) had a higher content of Al among all treatments. The silica:alumina ratio in MR51, MR21, MR11, MR12, MR15, and MR01 was 10.96%, 15.75%, 23.97%, 17.47%, 17.46%, and 28.42%, respectively, lower than that in MR10 (2.92%). There was no noticeable difference in silica:alumina ratio among each treatment except for MR10.

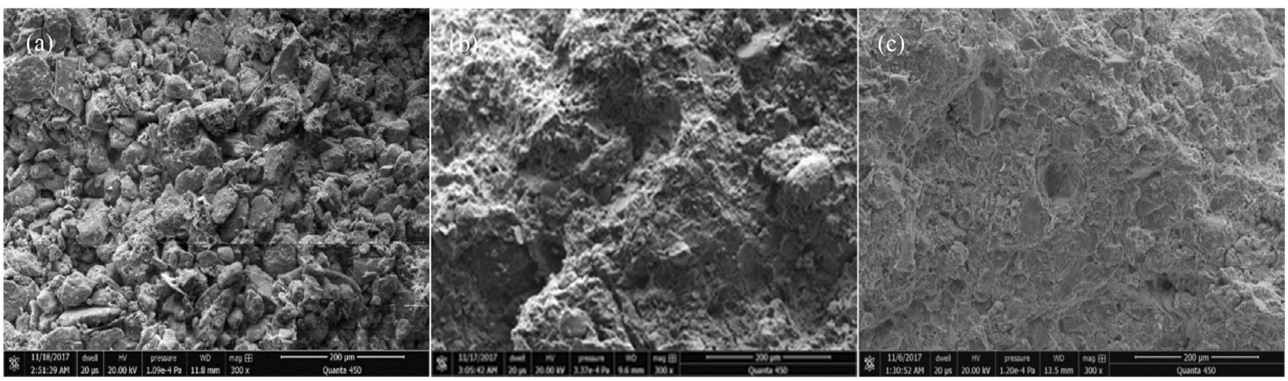

FIGURE 3 Soil microstructure of dry mixing Malan Loess and red clay at different volumetric ratios. (a: MR10, dry mixing Malan Loess and red clay at volumetric ratios of 1:0; b: MR11, dry mixing Malan Loess and red clay at volumetric ratios of 1:1; c: MR01, dry mixing Malan Loess and red clay at volumetric ratios of 0:1)

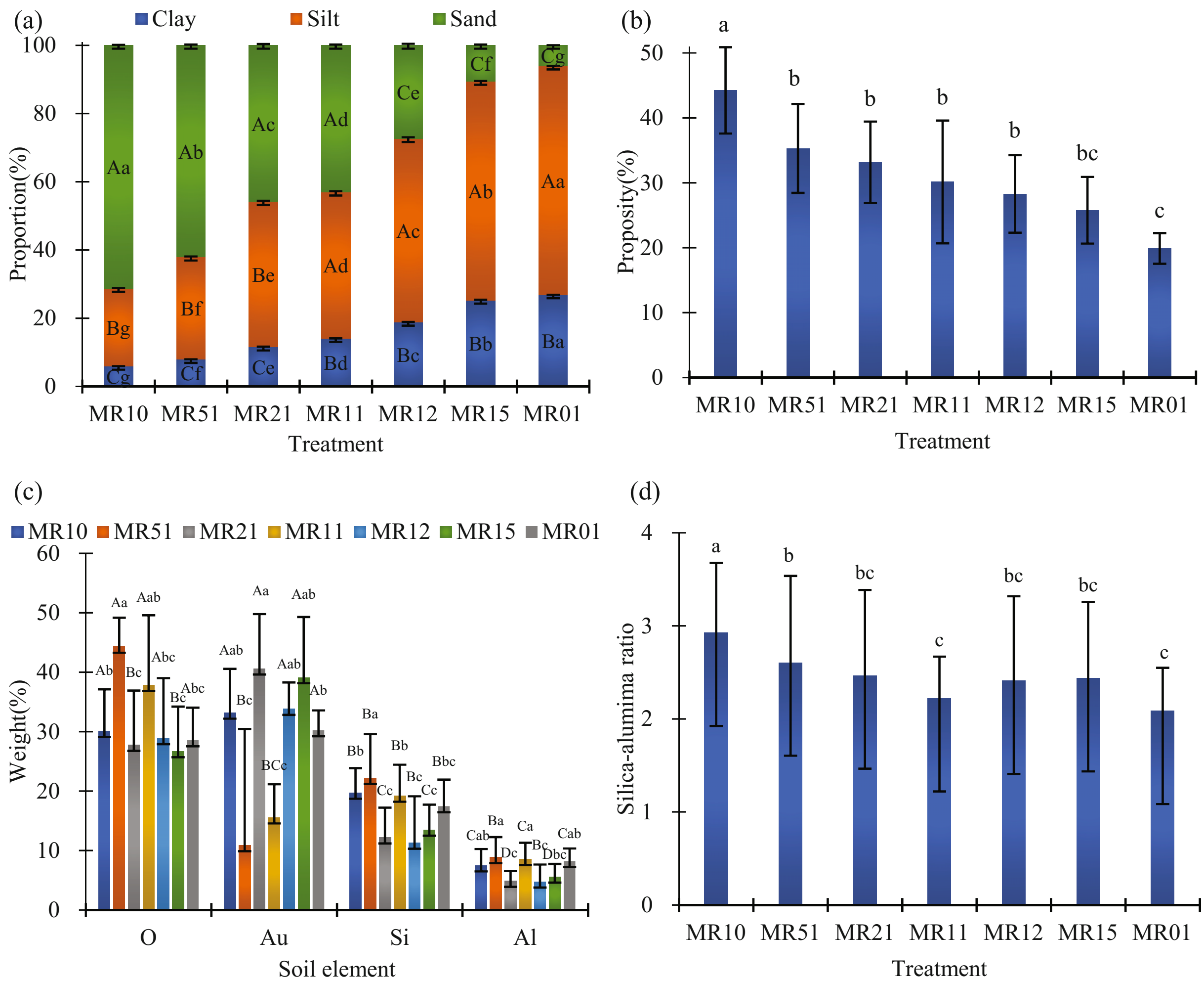

FIGURE 4 Soil particle (a), porosity (b), element (c), and silica:alumina ratio (d) of dry mixing Malan Loess and red clay at volumetric ratios of 1:0 (MR10), 5:1 (MR51), 2:1 (MR21), 1:1 (MR11), 1:2 (MR12), 1:5 (MR15), and 0:1 (MR01). The data (mean ± SD) with lower-case letters (a, b, c, or d) showed the significant differences among different soil treatments ($p < 0.05$, using the Duncan method), the data (mean ± SD) with capital letters (A, B, C, or D) showed the significant differences among different indicators in the same soil treatments ($p < 0.05$, using the Duncan method) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 The chemical properties of different soil treatments

Treatments	pH	CEC (cmol kg^{-1})	SOM (g kg^{-1})	HNO_3-K (mg kg^{-1})	$NaHCO_3$-P (mg kg^{-1})	NaOH-N (mg kg^{-1})
MR10	8.59 ± 0.02a	6.99 ± 0.55d	4.99 ± 0.01b	85.65 ± 4.39c	3.32 ± 0.12a	10.64 ± 1.74b
MR51	8.60 ± 0.02a	8.17 ± 0.82c	5.56 ± 0.55a	105.57 ± 15.10b	3.42 ± 0.60a	15.53 ± 1.80a
MR21	8.61 ± 0.03a	13.84 ± 5.92bc	4.85 ± 0.70b	114.40 ± 26.16b	2.76 ± 1.59b	12.92 ± 1.44ab
MR11	8.50 ± 0.05b	19.71 ± 1.93ab	4.47 ± 0.27c	132.98 ± 17.99b	2.43 ± 0.28b	11.05 ± 1.31b
MR12	8.55 ± 0.06ab	22.40 ± 4.80a	4.65 ± 0.58bc	156.99 ± 27.49a	2.19 ± 0.08b	10.01 ± 0.85b
MR15	8.60 ± 0.01a	19.94 ± 5.53ab	4.27 ± 0.49c	152.95 ± 11.37a	2.50 ± 0.76b	11.80 ± 1.57b
MR01	8.56 ± 0.02ab	20.13 ± 0.48a	3.87 ± 0.71d	166.03 ± 29.06a	2.60 ± 0.27b	10.73 ± 2.12b

Note: MR10, MR51, MR21, MR11, MR12, MR15, and MR01, dry mixing Malan Loess and red clay at volumetric ratios of 1:0, 5:1, 2:1, 1:1, 1:2, 1:5, and 0:1. The data (Mean ± SD) with lower-case letters (a, b, c, or d) showed the significant differences among different soil treatments ($p < 0.05$, using the Duncan method).

3.3 | Soil chemical properties

The effects of soil reconstruction on its chemical properties are shown in Table 1. The soil pH in each treatment ranged from 8.50 to 8.67 indicating high alkalinity of the soil. The CEC was increased by 16.88%, 97.99%, 181.97%, 220.46%, and 185.26% in MR51, MR21, MR11, MR12, and MR15 compared to MR10 (6.99 cmol kg^{-1}). The SOM had a maximum value of 5.56 g kg^{-1} in MR51, which was

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11.42% and 43.67% higher than that in MR10 and MR01. Other reconstructed soils also obviously increased the SOM by different degrees in comparison with MR01. The HNO_3-K showed a growing trend in reconstructed soils with the increase in mixing volumetric ratios of red clay. The HNO_3-K in reconstructed soils was higher than that in MR10 (86.65 mg kg^{-1}). The $NaHCO_3$-P in MR51 was the greatest (3.42 mg kg^{-1}) and 31.54% higher than that in MR01 (2.60 mg kg^{-1}). There was no apparent difference in $NaHCO_3$-P among MR21, MR11, MR12, MR15, and MR01. The maximum NaOH-N occurred at MR51 (15.53 mg kg^{-1}), and no noticeable difference was observed among other treatments.

3.4 | *B. napus* growth

Soil reconstruction significantly affected the root thickness, height, and fresh yield of *B. napus* (Figure 5). MR51 led to the most significant root thickness of *B. napus* among seven soil treatments, which boosted the root thickness by 89.17% and 78.69% compared with MR10 and MR01, respectively. MR21 also significantly rose the root thickness of *B. napus* by 50.62% and 42.28% in comparison with MR10 and MR01. No difference in the root thickness of *B. napus* was recorded among other treatments. MR51, MR21, and MR15 improved the height of *B. napus* by 22.92%, 15.49%, and 23.79% compared with MR10. Also, there was no noticeable difference in the height of the rape among MR51, MR15, and MR01. Meanwhile, the maximum fresh yield of *B. napus* occurred at MR51 (37,562.87 kg ha^{-1}), which was 55.92% and 45.01% higher than that in MR10 and MR01. MR21 also obviously increased the fresh yield of *B. napus* by 29.13% and 20.09% compared to that of MR10 and MR01.

3.5 | Agricultural profits

The profits of *B. napus* showed an obvious difference compared with those of other crops (Figure 6). The yields of maize grain and its straw were 6276.00 kg ha^{-1} and 8660.88 kg ha^{-1}, and the total profits of which were 13813.01 RMB¥ ha^{-1} (1US$ = 6.7RMB¥) according to the local price. The grain yields of sorghum, potato, millet, and soybean were 4665.00 kg ha^{-1}, 3195.00 kg ha^{-1}, 2295.00 kg ha^{-1} and

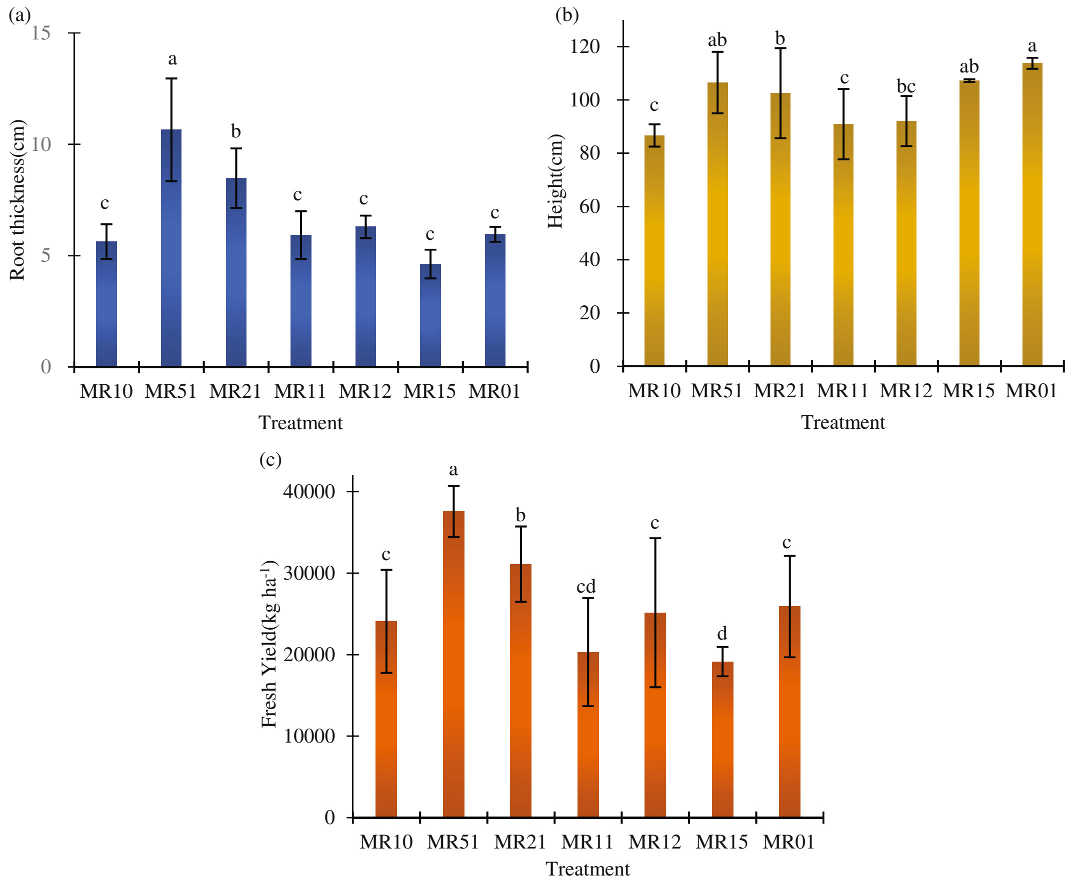

FIGURE 5 The root thickness (a), height (b) and fresh yield (c) of *B. napus* from dry mixing of Malan Loess and red clay at volumetric ratios of 1:0 (MR10), 5:1 (MR51), 2:1 (MR21), 1:1 (MR11), 1:2 (MR12), 1:5 (MR15), and 0:1 (MR01) [Colour figure can be viewed at wileyonlinelibrary.com]

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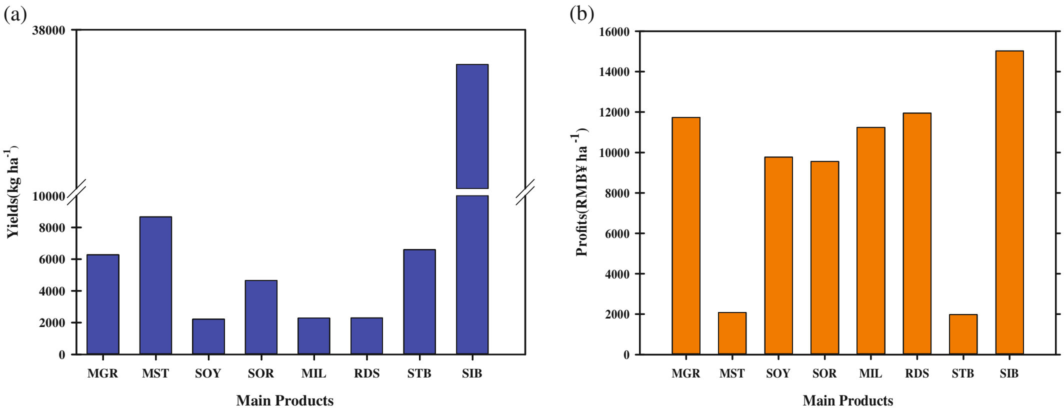

FIGURE 6 The yields (a) and profits (b) of maize grain (MGR), maize straw (MST), soybean (SOY), sorghum (SOR), millet (MIL), rapeseed (RDS), the straw of *B. napus* (STB), and the silage of *B. napus* (SIB) in 2017 [Colour figure can be viewed at wileyonlinelibrary.com]

2220.00 kg ha^{-1}, respectively, which were lower than the grain yields of maize. The crops, profits calculated by the local price were ranked as follows: maize (13,813.01 RMB¥ ha^{-1}) > millet (11,245.50 RMB¥ ha^{-1}) > soybean (9768.00 RMB¥ ha^{-1}) > sorghum (9563.25 RMB¥ ha^{-1}). The highest yields of rapeseed (2298.00 kg ha^{-1}) and *B. napus*' straw (6595.26 kg ha^{-1}) were found for MR51, which was obviously lower than those of maize. But the total profits of rapeseed and *B. napus*' straw (13,928.19 RMB¥ ha^{-1}) were higher than those of other corps, which caused the local price of rapeseed (5.21 RMB¥ kg^{-1}) and *B. napus*' straw (0.30 RMB¥ kg^{-1}) to be relatively higher. According to the highest yields of *B. napus*' silage (MR51: 37,562.87 kg ha^{-1}), the profits of which (not including rapeseed and *B. napus*' straw) approximately reached at 15,025.15 RMB¥ ha^{-1} with the 0.40 RMB¥ kg^{-1} of local price. Hence, planting *B. napus*' for silage pushed up profits by 7.86%, 8.78%, 33.61%, 53.82%, 57.11%, and 135.14% compared with traditional *B. napus*, maize, millet, soybean, and sorghum planting, respectively.

4 | DISCUSSION

4.1 | Quality improvement of newly created farmland (NCF) through soil reconstruction

Soil reconstruction based on particles' complementarity of Malan Loess and red clay is an ecological and economical method to improve the quality of NCF in the LP. The farmland fertility and quality were significantly affected by soil microstructure, which was determined by the PSD (Bronick & Lal, 2005; Sivakumar et al., 2002). Especially, the clays contribute to the aggregation formation, retention of nutrients, and reduce nutrient release from farmland, while excessive clays have negative impacts on the aeration, permeability, and nutrient transport (Liu et al., 2018). Previous research indicated that the poor quality of NCF was related to the compact soil microstructure, which had no significant changes even after perennial cultivation (He et al., 2020; Ma, Chen, Zhou, et al., 2020). The aforementioned problems stemmed from the red clay moved from deeper layers of the surrounding slope, which contained excessive clay and little sand (Figure 2). In contrast, Malan Loess is a kind of soil with few clays and abundant sands, which increases the soil particles' complementarity with red clay (Figure 3). Hence, Malan Loess was selected as the soil amendment to reconstruct reasonable PSD for improving soil microstructure and quality of NCF. Malan Loess as natural material would not cause potential pollution like organic solid waste (Wang & Liu, 2020). Malan Loess is widely distributed in the LP and can be continuously obtained at a low price. The process of soil reconstruction could synchronize with the GLCP avoiding extra labors and materials inputs (Liu et al., 2018). Meanwhile, some NCF was backfilled with Malan Loess in the GLCP, the quality of which could also be improved by the above techniques (Chang et al., 2021).

The reasonable PSD effectively improves the quality of NCF and provides a suitable environment for crop growth, contributing to agricultural productivity (Bronick & Lal, 2005; Silvestri et al., 2017). Our field experiment found that clays and silts significantly decreased and sands increased after soil reconstruction in comparison with that of undeveloped red clay (Figure 4a). A reasonable PSD can promote the adhesion of clay as a binding agent to the surface of sands and silts, contributing to the formation of agglomerates. The SEM photos (Figure 3) showed that the clays on the surface of silts and sands formed stable aggregates under capillary pressure, which can improve the stability of soil microstructure (Robert & Robert, 2005). The mosaic and intra-particle pores in red clay were damaged by sands (Bronick & Lal, 2005; Duiker et al., 2003), which increased the soil porosity in reconstructed soils except for MR15 and rose their aeration, permeability, and nutrient transport (Figure 4b). With the decrease of clay content, the decreasing porosity might stimulate the activity of soil microorganisms, accelerating the nutrients transformation (Figure 4c,d). Especially, the silicon:alumina ratio of MR51 was significantly higher than that of other treatments, which indicated that the MR51 had a stronger weathering effect of releasing more soluble

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salt-based substances for nutrient transformation. Meanwhile, the higher CEC was conducive to nutrient storage. Meanwhile, *B. napus* has a kind of taproot plant that enables decent growth in loose and aerated soils. The MR51 provided the best soil microstructure and sufficient fertility for *B. napus*, and the roots development of *B. napus* would promote nutrient transformation (Liu et al., 2020). Hence, the fertility of MR51 exceeded that in NCF cultivated for three years (Ma, Chen, Wang, et al., 2020) (Table 1), and its *B. napus* growth was significantly higher than most other treatments (Figure 5).

4.2 | Agricultural profit enhancement by the optimization of crop planting structure utilizing *B. napus*

Leveraging its combined benefits including soil ecological suitability, crop physiological adaptability, and regional comparative advantage, the *B. napus* was introduced to optimize the crop structure of NCF in the LP. The traditional crops of the LP, such as maize, soybean, and sorghum, generally have lower resistance and weaker adaptability, the planting of which in NCF might reduce yield seriously or even result in no yields (Cao et al., 2017; Chen et al., 2021). With the rising price of pesticides, fertilizers, and machinery, the profits of traditional crops were diminished (Xin & Li, 2018). In contrast, *B. napus* has stronger resistance, wider adaptability, and a short-time cycle compared to the traditional crops and other forages, and so could maintain stable yields even on poor farmland such as saline-alkali soil and slope farmland (Fu et al., 2012) (Figure 6a). *B. napus* could help to ameliorate microstructure, decrease saline-alkali, enhance fertility, and accelerate maturation. These improving effects are based upon the comparisons with other forages (Wang et al., 2021). Compared with alfalfa, ryegrass, and silage maize, the silage of *B. napus* has more nutrients such as crude protein, crude fat, and nitrogen-free extract and higher yields, which could effectively alleviate the forage shortage (Wen et al., 2018). Different from the single-use of other forages, *B. napus* has multiple uses, including oil, vegetable, forage, and so forth. In addition, the *B. napus* plantation is machinery accessible, which reduces the labor input and promotes agricultural industrialization (Liu et al., 2017). Thus, *B. napus*, with its advantaged role in both plantation and breeding, can optimize crop structure in the LP. At present, *B. napus* is widely adopted by local farmers and has been extended to several typical small watersheds (Figure 7).

Our research proposes three portfolios of *B. napus*; these are: 'silage,' 'vegetable plus rapeseed,' and 'vegetable plus silage' to enhance agricultural profits by utilizing the multi-functions of *B. napus*. The silage of *B. napus* stimulates livestock growth and boosts their weight and meat quality (Lee, 2018; Wen et al., 2018). It was found that the total weight gain in two months and daily weight gain through mixed feeding with *B. napus* and alfalfa were 151.10% and 151.38% higher than feeding with alfalfa, judged by a feeding

FIGURE 7 The planting mode of *B. napus* has been extended to some typical small watersheds of Yanchang County [Colour figure can be viewed at wileyonlinelibrary.com]

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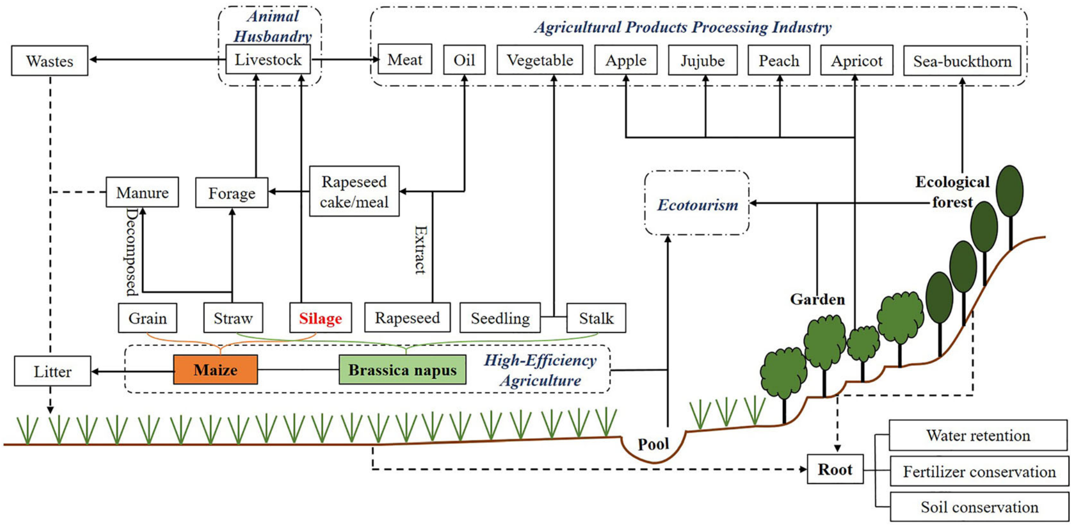

FIGURE 8 The model of '3E' agriculture in Yangjuangou catchment. Drawing with reference to Liu et al. (2006) [Colour figure can be viewed at wileyonlinelibrary.com]

experiment with sheep (breed small-tail Han). Our market survey indicated that seedling and flower stalk of *B. napus* are with high nourishment value, the economic value of which is approximately 3750 RMB ¥ ha^{-1}. Hence, the agricultural profits of the 'silage,' 'vegetable plus rapeseed', and 'vegetable plus silage' were approximately 15,025.15, 17,428.19, and 18,525.15 RMB¥ ha^{-1}, which enhanced average profits by 35.39%, 57.05%, and 66.93% in comparison with the traditional crops respectively (Figure 6b). To sum up, the *B. napus* planting in the NCF of the LP is in line with the Chinese Government's scheme on optimizing the spatial distribution of maize, which is helpful for the sustainable utilization of farmland and agricultural transformation under the background of integrating agriculture and pastoralism (Liu et al., 2017).

4.3 | Sustainable utilization of newly created farmland (NCF) through the development of '3E' agriculture

While the soil quality and agricultural profit of NCF are improved, promoting rural industrial integration can provide a guarantee for sustainable utilization of NCF (Cao et al., 2017). Considering the topographic characteristics, resources endowment, and industrial foundation of Yangjuangou catchment, industry integration could be achieved through the model of effective, ecologic, and economic (3E) agriculture (Liu et al., 2006). This model is to develop multifunctional agriculture in the stereoscopic space of small watershed through the combination of crop restructuring, GGP and diversified management, so as to promote the NCF effective utilization, ecological conservation, and rural development. Specifically, the NCF in the gully areas could be accelerated crop restructuring, the tableland above the gully areas should be developed with featured garden including apple, jujube, peach, and apricot, and the slope should be cultivated into high-quality ecological forest such as *Robinia pseudoacacia* Linn., *Hippophae rhamnoides* Linn. and *Caragana korshinskii* Kom (Figure 8).

The diversified management, including high-efficiency agriculture, animal husbandry, agricultural products processing industry, and ecotourism should be developed on the basis of NCF transfer. The reform of rural property rights should be accelerated to realize the separation of farmland ownership, contract, and management rights. The Village Committee in charge of land transfer should concentrate the NCF from scattered management. With the support of village talents, local governments, and social capital, the new agricultural entities such as specialized family farms and agricultural cooperatives uniformly transfer and manage the NCF. The diversified incomes from both land lease and agricultural production secure farmers' livelihoods. Beyond this, our findings suggest developing an interval cropping system with two crops per year based on the rising trend of the accumulated temperature (≥ 10°C) during 1961-2015 in the LP and the growth habit of *B. napus* with a shorter growing period (Liu et al., 2019). The maize could be planted during the first crop season from April 10 to July 15, and then *B. napus* could be planted during the second crop season from July 20 to October 20, which would help develop high-efficiency agriculture and provide the forage for animal husbandry. The reuse of waste from animal husbandry and cropping, and returning it to farmland could also improve the quality of NCF. In a similar vein, the processing industry could be encouraged to develope with improved agricultural products, including meat, oil, sea-buckthorn, and so forth. The integration of the farmland landscapes and pools in the gully areas with the garden in the tableland and the ecological forests on the slope would form unique rural landscape in the LP, which could advance ecotourism development (Liu et al., 2017). This model has been successfully applied to some watersheds in the LP, for example, Gutun watershed in Baota County and Nangou watershed in Ansai County. This model is suitable for promotion in small watersheds

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where the GLCP has been or will be implemented in the LP (Figure 8). However, farmland property rights should be confirmed first in the small watersheds with unclear property rights. For the small watersheds dominated by grain production, the coordinated relationships between grain production and diversified management should be correctly addresed.

Drawing upon the agronomic technology ideas and steps of agricultural geographical engineering (Liu et al., 2020), our current research carries out a systematic investigation of the NCF (Figure 2). We explored an agronomic technology that integrates the micro-mechanism of elements with the demands of macro-development (Liu, 2018). More specifically, we found that the soil reconstruction by dry-mixing Malan Loess and red clay could create soil with reasonable PSD, which improves the quality of NCF and provides suitable conditions for crop growth. Crop optimization by *B. napus* could reduce production costs, ensure agricultural productivity, and enhance agricultural profits from NCF. Setting up a good relationship between soil and crop is beneficial and can accelerate the adjustment of regional planting structure by giving full play to the multi-function of farmland. '3E' agriculture could accelerate the transfer of agricultural production space from slope to gully. Industrial integration could boost the economic profits of farmland resources in the gully and ecological restoration in the slope, which contribute to promoting the stainable utilization of NCF and simultaneously improve the production and ecological function in the small watersheds of the LP. In addition, farmers could improve their livelihoods by obtaining farmland transfer funds, wages, and share proceeds. Overall, the agronomic technology based on the agricultural geographical engineering could activate farmland resources to optimize the spatial structure, industrial structure, organizational structure, and human-environment interaction (Liu, 2020), thus helping to reduce the degradation risk of NCF and realize the synergy of socioeconomic development and ecological restoration in the LP's watershed (Lescourret et al., 2015; Liu & Li, 2017a; Li et al., 2022), which is helpful for farmland protection and rural revitalization (Liu et al., 2020) (Figure 9).

5 | CONCLUSIONS

This study explored an agronomic technology based on the agricultural geographical engineering to improve soil quality and agricultural profits, which can help to reduce the land degradation risk and promote the sustainable utilization of NCF by GLCP in the LP. The agronomic technology included soil reconstruction, crop optimization, and industrial integration. Our results showed that soil reconstruction based on the physical complementarity of the soil particles of Malan Loess and red clay effectively improved soil microstructure and physico-chemical properties. More specifically, dry mixing Malan

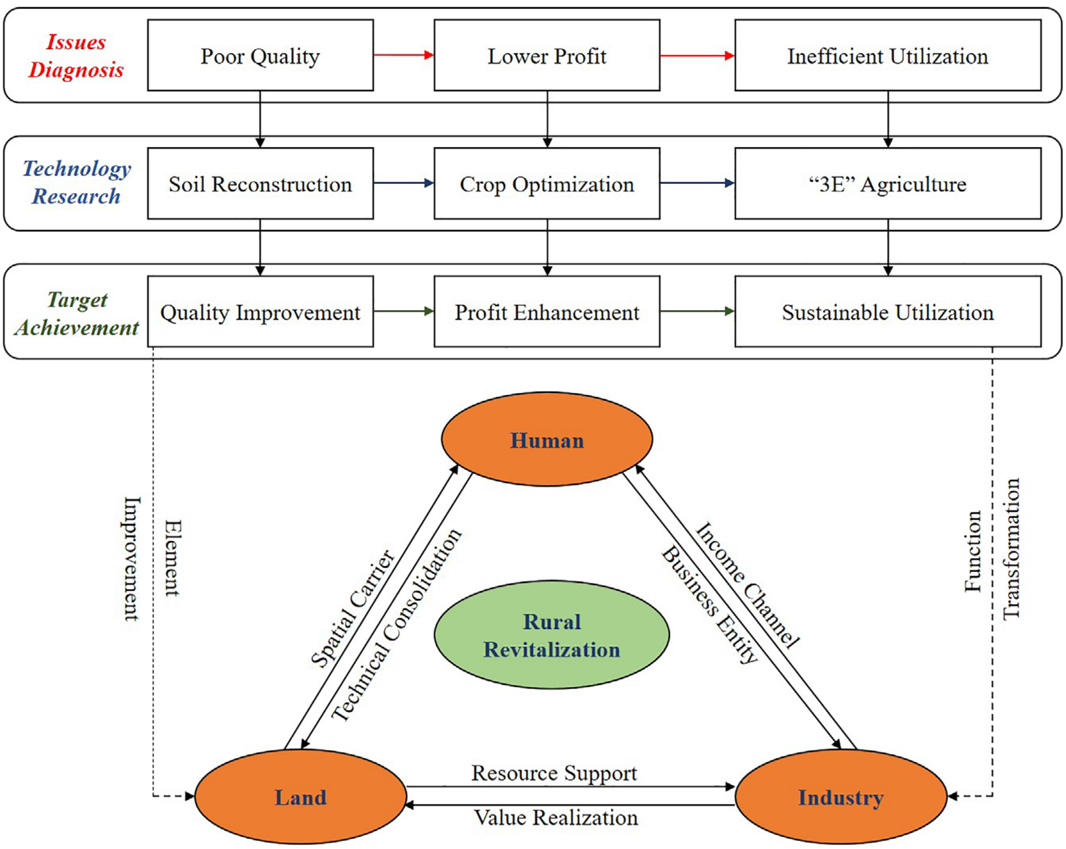

FIGURE 9 The framework of agronomic technology promoting sustainable utilization of newly created farmland (NCF) and rural revitalization [Colour figure can be viewed at wileyonlinelibrary.com]

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Loess and red clay at volumetric ratios of 5:1 (MR51) boosted the root thickness and fresh weight by 78.69% and 45.01% in comparison with that of red clay (MR01). Coupling soil ecological suitability, crop physiology adaptability, and regional comparative advantage, the optimization of crop planting structure by using *B. napus* significantly enhanced agricultural profits of NCF. The three portfolios of *B. napus* increased average profits by 53.12% in comparison with that of traditional crop planting. Finally, '3E' agriculture model is proposed to promote industrial integration based on the topographic characteristics, resources endowment, and industrial foundation, which could advance the sustainable utilization of NCF. The study reveals that problem diagnosis and technology research focusing on the micro-mechanism of the elements could effectively reduce the inefficient utilization and degradation risk of NCF and thus meet the demands of local development. It is worth noting that this study only depicts preliminary research on agronomic technology application. Significant differences have not yet been observed in some soil physicochemical properties and *B. napus* performance. Therefore, a long-term field experiment on various crops is well merited to identify appropriate volumetric ratios of Malan Loess and red clay for each crop.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

Aksakal, E. L., Angin, I., & Oztas, T. (2012). Effects of diatomite on soil physical properties. *Catena*, *88*, 1–5. https://doi.org/10.1016/j.catena.2011.08.004

Bronick, C. J., & Lal, R. (2005). Soil structure and management: A review. *Geoderma*, *124*, 3–22. https://doi.org/10.1016/j.geoderma.2004.03.005

Cao, S. X., Xia, C. Q., Li, W. M., & Xian, J. L. (2021). Win-win path for ecological restoration. *Land Degradation & Development*, *32*, 430–438. https://doi.org/10.1002/ldr.3739

Cao, S. X., Zheng, X. Y., Chen, L., Ma, H., & Xia, J. (2017). Using the green purchase method to help farmers escape the poverty trap in semiarid China. *Agronomy for Sustainable Development*, *37*(8), 7. https://doi.org/10.1007/s13593-017-0420-3

Cao, Z., Li, Y. R., Liu, Y. S., Chen, Y. F., & Wang, Y. S. (2018). When and where did the Loess Plateau turn "green"? Analysis of the tendency and breakpoints of the normalized difference vegetation index. *Land Degradation & Development*, *29*, 162–175. https://doi.org/10.1002/ldr.2852

Castro, P., Pedrosoa, R., Lautenbachc, S., & Vicensd, R. (2020). Farmland abandonment in Rio de Janeiro: Underlying and contributory causes of an announced development. *Land Use Policy*, *95*(11), 104633. https://doi.org/10.1016/j.landusepol.2020.104633

Chang, F., Jia, F. J., Lv, R., Li, Y., Wang, Y., Jia, Q. G., & Zhen, L. S. (2021). Soil bacterial communities reflect changes in soil properties during the tillage years of newly created farmland on the Loess Plateau. *Applied Soil Ecology*, *161*(12), 103853. https://doi.org/10.1016/j.apsoil.2020.103853

Chen, Y. P., Su, C. C., Wang, X. L., Wang, Y., Wang, K. B., Zhang, W. B., Zhang, G. H., & Zhang, R. S. (2021). Selection of suitable cropand its best cultivar in newly created farmland of Yan'an region. *Journal of Earth Environment*, *12*(2), 202–213. https://doi.org/10.7515/JEE202039

Chen, Y. P., Wang, K. B., Lin, Y. S., Shi, W. Y., Song, Y., & He, X. H. (2015). Balancing green and grain trade. *Nature Geoscience*, *8*, 739–741. https://doi.org/10.1038/ngeo2544

Demetriou, D., Stillwell, J., & See, L. (2012). Land consolidation in Cyprus: Why is an integrated planning and decision support system required? *Land Use Policy*, *29*, 131–142. https://doi.org/10.1016/j.landusepol.2011.05.012

Dessalew, G., Beyene, A., Nebiyu, A., & Ruelle, M. L. (2017). Use of industrial diatomite wastes from beer production to improve soil fertility and cereal yields. *Journal of Cleaner Production*, *157*, 22–29. https://doi.org/10.1016/j.jclepro.2017.04.116

Duiker, S. W., Rhoton, F. E., Torrent, J., Smeck, N. E., & Lal, R. (2003). Iron (hydr)oxide crystallinity effects on soil aggregation. *Soil Science Society of America Journal*, *2*, 606–611. https://doi.org/10.2136/sssaj2003.6060

Feng, W. L., & Li, Y. (2021). Measuring the ecological safety effects of land use transitions promoted by land consolidation projects: The case of Yan'an City on the Loess Plateau of China. *Land*, *10*(8), 783. https://doi.org/10.3390/land10080783

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., BDonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., & Gibbs, H. K. (2005). Global consequences of land use. *Science*, *309*, 570–574. https://doi.org/10.1126/science.1111772

Fu, B. J., Wang, S., Liu, Y., Liu, J. B., Liang, W., & Miao, C. (2017). Hydrogeomorphic ecosystem responses to natural and anthropogenic changes in the Loess Plateau of China. *Annual Review of Earth and Planetary Sciences*, *45*, 223–243. https://doi.org/10.1146/annurev-earth-063016-020552

Fu, T. D., Liang, H. D., & Zhou, G. S. (2012). The advantage and development suggestion of green manuring by rape in modern agriculture. *China Agricultural Technology Extension*, *8*, 27–29.

Fu, W., Yong, C. X., Ma, D. H., Fan, J., Zhang, J. B., Wei, H. A., Feng, X. L., Wei, R. Z., Liu, X. F., Wang, G. D., & Tan, J. (2019). Rapid fertilization effect in soils after gully control and land reclamation in loess hilly and gully region of China. *Transactions of the Chinese Society of Agricultural Engineering*, *35*, 252–261. https://doi.org/10.11975/j.issn.1002-6819.2019.21.031

Gerber, J. D., Knoepfel, P., Nahrath, S., & Varone, F. (2009). Institutional resource regimes: Towards sustainability through the combination of property-rights theory and policy analysis. *Ecological Economics*, *68*, 798–809. https://doi.org/10.1016/j.ecolecon.2008.06.013

Godfray, H. C., Beedington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., & Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. *Science*, *327*, 812–818. https://doi.org/10.1126/science.1185383

Han, J. Q., Dong, Y. Y., & Zhang, M. (2021). Chemical fertilizer reduction with organic fertilizer effectively improve soil fertility and microbial community from newly cultivated land in the Loess Plateau of China. *Applied Soil Ecology*, *165*(11), 103966. https://doi.org/10.1016/j.apsoil.2021.103966

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He, M. N., Wang, Y. Q., Tong, Y. P., Zhao, Y. L., Qiang, X. K., Song, Y. G., Wang, L., Song, Y., Wang, G. D., & He, C. X. (2020). Evaluation of the environmental effects of intensive land consolidation: A field-based case study of the Chinese Loess Plateau. *Land Use Policy*, *94*(11), 104523. https://doi.org/10.1016/j.landusepol.2020.104523

Lee, M. A. (2018). A global comparison of the nutritive values of forage plants grown in contrasting environments. *Journal of Plant Research*, *131*, 641–654. https://doi.org/10.1007/s10265-018-1024-y

Lescourret, F., Dutoit, T., Rey, F., Cote, F., Hamelin, M., & Lichtfouse, E. (2015). Agroecological engineering. *Agronomy for Sustainable Development*, *35*, 1191–1198. https://doi.org/10.1007/s13593-015-0335-9

Li, Y. R., Li, Y., Fan, P. C., & Long, H. L. (2019). Impacts of land consolidation on rural human–environment system in typical watershed of the Loess Plateau and implications for rural development policy. *Land Use Policy*, *86*, 339–350. https://doi.org/10.1016/j.landusepol.2019.04.026

Li, Y., Li, Y. R., Fang, B., Wang, Q. Y., & Chen, Z. F. (2022). Impacts of ecological programmes on land use and ecosystem services since 1980s: A case-study of a typical catchment in the Loess Plateau, China. *Land Degradation & Development*, *33*(16), 3271–3282. https://doi.org/10.1002/ldr.4387

Li, Y. R., Zhang, X. C., Cao, Z., Liu, Z. J., Lu, Z., & Liu, Y. S. (2021). Towards the progress of ecological restoration and economic development in China's Loess Plateau and strategy for more sustainable development. *Science of the Total Environment*, *756*(14), 143676. https://doi.org/10.1016/j.scitotenv.2020.143676

Li, Z. W., Liu, C., Dong, Y. T., Chang, X. F., Nie, X. D., Liu, L., Xiao, H. B., Lu, Y. M., & Zeng, G. M. (2017). Response of soil organic carbon and nitrogen stocks to soil erosion and land use types in the loess hilly–gully region of China. *Soil and Tillage Research*, *166*, 1–9. https://doi.org/10.1016/j.still.2016.10.004

Liu, Y. S. (2018). Introduction to land use and rural sustainability in China. *Land Use Policy*, *74*, 1–4. https://doi.org/10.1016/j.landusepol.2018.01.032

Liu, Y. S. (2020). Modern human-earth relationship and human-earth system science. *Scientia Geographica Sinica*, *40*(8), 1221–1234. https://doi.org/10.13249/j.cnki.sgs.2020.08.001

Liu, Y. S., Chen, Z. F., Li, Y. R., Feng, W. L., & Cao, Z. (2017). The planting technology and industrial development prospects of forage rape in the loess hilly area. *Journal of Natural Resources*, *12*, 2065–2074. https://doi.org/10.11849/zrzyxb.20161142

Liu, Y. S., Fang, F., & Li, Y. H. (2014). Key issues of land use in China and implications for policy making. *Land Use Policy*, *40*, 6–12. https://doi.org/10.1016/j.landusepol.2013.03.013

Liu, Y. S., Feng, W. L., & Li, Y. R. (2020). Modern agricultural geographical engineering and agricultural high-quality development: Case study of loess hilly and gully region, *Acta Geographical Sinica*, *75*(10), 2029–2046. https://doi.org/10.11821/dlxb202010001

Liu, Y. S., Jin, X. M., & Hu, Y. C. (2006). Study on the pattern of rural distinctive eco-economy based on land resources: A case study of Suide County in loess hilly areas. *Journal of Natural Resources*, *21*, 738–745. https://doi.org/10.11849/zrzyxb.2006.05.007

Liu, Y. S., & Li, Y. H. (2017a). Revitalize the world's countryside. *Nature*, *548*, 275–277. https://doi.org/10.1038/548275a

Liu, Y. S., & Li, Y. R. (2017b). Engineering philosophy and design scheme of gully land consolidation in the Loess Plateau. *Transactions of the Chinese Society of Agricultural Engineering*, *33*, 1–9. https://doi.org/10.11975/j.issn.1002-6819.2017.10.001

Liu, Y. S., & Wang, Y. S. (2019). Rural land engineering and poverty alleviation: Lessons from typical regions in China. *Journal of Geographical Sciences*, *29*, 643–657. https://doi.org/10.1007/s11442-019-1619-9

Liu, Y. S., Zheng, X. Y., Wang, Y. S., Cao, Z., Li, Y. H., Wu, W. H., Liu, Z. J., Liu, H. H., & Li, R. (2018). Land consolidation engineering and modern agriculture: A case study from soil particles to agricultural systems. *Journal of Geographical Sciences*, *28*, 1896–1906. https://doi.org/10.1007/s11442-018-1570-1

Liu, Z. J., Liu, Y. S., & Li, Y. R. (2019). Extended warm temperate zone and opportunities for cropping system change in the Loess Plateau of China. *International Journal of Climatology*, *2*, 658–669. https://doi.org/10.1002/joc.5833

Lu, R. (2000). *Soil analytical methods of agronomic chemicals*. Beijing, PRC: China Agricultural Science and Technology Press.

Lü, Y. H., Fu, B. J., Feng, X. M., Zeng, Y., Chang, R. Y., Sun, G., & Wu, B. F. (2012). A policy-driven large scale ecological restoration: Quantifying ecosystem services changes in the Loess Plateau of China. *PLoS One*, *7*(10), e31782. https://doi.org/10.1371/journal.pone.0031782

Ma, J. F., Chen, Y. P., Wang, H. J., Wang, H., Wu, J. H., Su, C. C., & Xu, C. (2020). Newly created farmland should be artificially ameliorated to sustain agricultural production on the Loess Plateau. *Land Degradation & Development*, *31*, 2565–2576. https://doi.org/10.1002/ldr.3618

Ma, J. F., Chen, Y. P., Zhou, J., Wang, K. B., & Wu, J. H. (2020). Soil quality should be accurate evaluated at the beginning of lifecycle after land consolidation for eco-sustainable development on the Loess Plateau. *Journal of Cleaner Production*, *267*(11), 122244. https://doi.org/10.1016/j.jclepro.2020.122244

Prosdocimi, M., Jordan, A., Tarolli, P., Keesstra, S., Novara, A., & Cerda, A. (2016). The immediate effectiveness of barley straw mulch in reducing soil erodibility and surface runoff generation in Mediterranean vineyards. *Science of the Total Environment*, *547*, 323–330. https://doi.org/10.1016/j.scitotenv.2015.12.076

Robert, D., & Robert, D. G. (2005). Rowcrop response to topsoil replacement on high traffic vs low traffic soil reconstruction systems. *Proceedings of the National Academy of Sciences of the United States of America*, *6*, 302–307. https://doi.org/10.21000/JASMR05010302

Silvestri, N., Pistocchi, C., & Antichi, D. (2017). Soil and nutrient losses in a flat land-reclamation district of Central Italy. *Land Degradation & Development*, *28*, 638–647. https://doi.org/10.1002/ldr.2549

Sivakumar, V., Doran, I. G., & Graham, J. (2002). Particle orientation and its influence on the mechanical behavior of isotopically consolidated reconstituted clay. *Engineering Geology*, *66*, 197–209. https://doi.org/10.1016/S0013-7952(02)00040-6

Smiraglia, D., Ceccarelli, T., Bajocco, S., Salvati, L., & Perini, L. (2016). Linking trajectories of land change, land degradation processes and ecosystem services. *Environmental Research*, *147*, 590–600. https://doi.org/10.1016/j.envres.2015.11.030

Song, W., & Liu, M. (2017). Farmland conversion decreases regional and national land quality in China. *Land Degradation & Development*, *28*, 459–471. https://doi.org/10.1002/ldr.2518

Song, W., & Pijanowski, B. C. (2014). The effects of China's Cultivated Land Balance Program on potential land productivity at a national scale. *Applied Geography*, *46*, 158–170. https://doi.org/10.1016/j.apgeog.2013.11.009

Tallis, H., Kareiva, P., Marvier, M., & Chang, A. (2008). An ecosystem services framework to support both practical conservation and economic development. *Proceedings of the National Academy of Sciences of the United States of America*, *105*, 9457–9464. https://doi.org/10.1073/pnas.0705797105

Veloso, M. G., Cecagno, D., & Bayer, C. (2019). Legume cover crops under no-tillage favor organ mineral association in microaggregates and soil C accumulation. *Soil and Tillage Research*, *190*, 139–146. https://doi.org/10.1016/j.still.2019.03.003

Wang, B., Wen, J., Zhang, F. H., Li, L. J., Lai, Y. C., Ren, C. Z., Lu, J. W., Shen, J. X., Guo, L., Zhou, G. S., & Fu, T. D. (2021). Research progress in breeding of saline-alkaline tolerant rapeseed and restoring the salinated land. *Science & Technology Review*, *39*(23), 59–64. https://doi.org/10.3981/j.issn.1000-7857.2021.23.009

Wang, J., Fu, B. J., Lu, N., & Zhang, L. (2017). Seasonal variation in water uptake patterns of three plant species based on stable isotopes in the semi-arid Loess Plateau. *Science of the Total Environment*, *609*, 27–37. https://doi.org/10.1016/j.scitotenv.2017.07.133

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Wang, Y. S., & Liu, Y. S. (2020). New material for transforming degraded sandy land into productive farmland. *Land Use Policy*, *92*(4), 104477. https://doi.org/10.1016/j.landusepol.2020.104477

Wen, J., Liu, G. Q., Jiang, X. P., Zhou, G. S., Fu, T. D., Liu, C. H., & Zhong, Y. Q. (2018). Biomass, nutrition of forage rape and effect of its fermented total mixed ration on growth, carcass and meat quality in Hu sheep. *Journal of Huazhong Agricultural University*, *2*, 71–75. https://doi.org/10.13300/j.cnki.hnlkxb.2018.02.011

Xin, L., & Li, X. B. (2018). China should not massively reclaim new farmland. *Land Use Policy*, *72*, 12–15. https://doi.org/10.1016/j.landusepol.2017.12.023s

Yang, Y., Duan, M. L., Zhou, B. B., Li, X. Q., Yang, L., Liang, C. F., & Xiao, F. (2020). Effect of organic acid amendment on secondary saline soil amelioration in gully land consolidation area in northern Shaanxi, China. *Arabian Journal of Geosciences*, *13*(13), 1273. https://doi.org/10.1007/s12517-020-06277-8

Yeomans, J. C., & Bremner, J. M. (1988). A rapid and precise method for routine determination of organic carbon in soil. *Communications in Soil Science and Plant Analysis*, *19*, 1467–1476. https://doi.org/10.1080/00103628809368027

Zhang, X. C., Li, Y. R., Liu, Y. S., Huang, Y. X., Wang, Y. S., & Lu, Z. (2021). Characteristics and prevention mechanisms of artificial slope instability in the Chinese Loess Plateau. *Catena*, *207*(12), 105621. https://doi.org/10.1016/j.catena.2021.105621

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