Postprint: Analysis of the Fruit-Grass-Chicken Ecological Circulation Model and Coupling Effects in the Arid Tableland Region of the Loess Plateau

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Abstract

The Loess Plateau dryland region is ecologically fragile and water-scarce, and the traditional grain-cash crop dual planting model has seriously impacted and constrained sustainable agricultural development in this area. Therefore, applying system coupling and ecological cycle theories to organically integrate ecological conservation with high-quality and efficient production, and establishing an agricultural development model featuring grain-cash crop-forage ternary planting suited to the resource characteristics of the Loess Plateau dryland region, has become a critical link in achieving coordinated and sustainable ecological and economic development in the region. This study takes Qingyang City, Gansu Province, located in the central Loess Plateau, as the research area. Based on the region' s land resource characteristics and hydrothermal conditions, we designed an ecological cycle model of fruit-grass-chicken coupling centered on functional coupling and industrial coupling, configured the ecological cycle structure, proposed corresponding technical specifications, and analyzed its coupling effects. Experimental results demonstrate that this model integrates fruit, grass, and chicken subsystems for coupled production, improves the species structure of the orchard system, enhances agricultural resource utilization efficiency, and enables mutual transformation and cyclic utilization of energy within the orchard system. Compared with the traditional clean-tillage orchard model, output profit per unit area increased by 3.82-fold, water use efficiency improved by 54.1%, soil erosion decreased by 58.82%, chemical fertilizer and pesticide application rates declined by 25.24% and 5.56% respectively, and land resource utilization efficiency increased by 36.84%. The model exhibits significant ecological, economic, and social benefits and holds broad potential for application and promotion in the Loess Plateau region.

Full Text

Preamble

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Abstract: The dry highland region of the Loess Plateau is ecologically fragile and water-scarce, where traditional grain-industrial crop dual planting patterns have severely constrained sustainable agricultural development. Applying system coupling and ecological cycle theory to integrate ecological conservation with high-quality, efficient production, establishing a grain-industrial-forage ternary planting model suited to the region' s resource characteristics has become critical for achieving coordinated ecological and economic sustainability. This study, focusing on Qingyang City in central Loess Plateau, designs a fruit-grass-chicken coupled ecological cycle model centered on functional and industrial coupling based on local land resources and hydrothermal conditions. The ecological cycle structure was configured, technical specifications proposed, and coupling effects analyzed. Experimental results demonstrate that this model integrates fruit, grass, and chicken subsystems through coupled production, improving orchard species structure, enhancing agricultural resource utilization, and enabling energy transformation and recycling within the orchard system. Compared with traditional clean-cultivation orchards, per-unit-area profit increased 3.82-fold, water use efficiency improved by 54.1%, soil erosion decreased by 58.82%, chemical fertilizer and pesticide application rates dropped by 25.24% and 5.56% respectively, and land resource utilization increased by 36.84%. The model delivers significant ecological, economic, and social benefits with broad application and promotion value across the Loess Plateau region.

Keywords: Dry highland of the Loess Plateau; Fruit-grass-chicken system; Function coupling; Coupling effect; Ecological circle

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1. Study Area Overview

Qingyang City, Gansu Province, is located in the gully region of central Loess Plateau at 106°20 -108°45 E, 35°15 -37°10 N, with elevations ranging from 885 to 2,089 m. The region features a temperate continental monsoon climate with annual precipitation of 382.9–602.0 mm concentrated in July–September, evaporation of 520 mm, mean annual temperature of 9.5–10.7°C, frost-free period of 140–180 days, and annual sunshine of 2,213.4–2,540.4 hours, characterized by aridity, moderate temperatures, and abundant light. Due to irrational land use, natural vegetation is sparse, soil erosion severe, exposed parent soil infertile, and crop production relies entirely on rainfall, forming a rain-fed agricultural system dominated by dryland crops. The total land area is 2.7119 million hectares, with grain crops covering 464,400 hectares (17.13%) and orchards covering 114,500 hectares (4.22%). The city has five major rivers including Malian and Pu Rivers with total runoff of 843 million m^3, administers 1 district, 7 counties, and 116 townships, and has a population of 2.56 million. As one of China' s five optimal apple (Malus pumila Mill.) production zones and a designated apple advantage belt by the Ministry of Agriculture, apple industry has become a pillar sector. However, single agricultural structure, irrational production layout, small grassland area, severe soil degradation and erosion, aging orchards, low industrialization, and serious agricultural pollution have become bottlenecks constraining high-quality, efficient, and sustainable development.

2.1 Structure of the Fruit-Grass-Chicken Ecological Cycle Model

Sparse vegetation, water erosion, and severe soil erosion are primary ecological challenges in the Loess Plateau dry highlands. Recent agricultural restructuring in Qingyang has significantly altered land use patterns, particularly through orchard expansion driven by leading fruit enterprises, reducing cultivated land while converting some cropland, forest, grassland, and unused land to orchards. Per capita orchard area increased from 0.0053 to 0.012 hectares, representing 225% growth. However, traditional clean-cultivation orchards suffer low land and water-fertilizer utilization efficiency, limiting sustainable orchard economic development. Given the fragile ecological conditions that preclude repeated tillage, integrating ecological protection with economic development through multifunctional and multi-industry coupled management is essential for achieving both high-quality production and soil-water conservation. Therefore, developing efficient ecological agriculture with orchard grass cultivation and chicken grazing creates a coupled ecological cycle that enhances soil fertility, water conservation, moisture retention, and relative humidity while strengthening natural pest control, reducing pesticide use and pollution, improving land utilization, fruit quality, and delivering ecological and economic benefits. Based on principles combining high-quality production with soil-water conservation, this study restructured traditional orchard planting patterns in Qingyang to design a fruit-grass-chicken coupled ecological cycle model forming a composite system of functional and industrial coupling [Figure 1: see original paper]. This model leverages ecological-economic compensation mechanisms to recycle soil nutrients, conserve effective water, reduce evapotranspiration, improve water-soil resource efficiency, and achieve goals of efficient resource utilization, reduced production costs, improved product quality, and enhanced ecological-economic benefits, thereby promoting coordinated ecological, economic, and social development.

2.2 Structural Configuration of the Fruit-Grass-Chicken Ecological Cycle Model

Based on Qingyang' s land resources, hydrothermal conditions, and production requirements for fruit, grass, and chickens, the ecological cycle structure was configured . Through advanced agricultural technologies and rational resource allocation, the coupled production structure achieves efficient water-soil resource utilization, increased vegetation coverage, improved land use efficiency, and coupling of energy flow, material flow, information flow, resource flow, and value flow, enabling coordinated and stable development of high-quality orchard production with ecological conservation.

Table 1 Structure configuration of ecological circle mode of fruit-grass-chicken in the dry highland of the Loess Plateau

Parameter	Tree Orchard	Dwarf Orchard
Fruit tree spacing (m)	2.5 × 4	1 × 2.5
Forage planting way	Sowing in strip	Broadcast sowing
Varieties number of mixed forage grass	3–4	3–4
Breeding density of chicken (chicken · hm^{-2})	900–1,300	1,000–1,500
Grazing time of chicken (d)	150–160	150–160
Area proportion of fruit trees (%)	45–50	45–50
Area proportion of grass (%)	36.84	36.84
Area proportion of road and building (%)	5	5

Parameter	Tree Orchard	Dwarf Orchard
Area proportion of drainage system (%)	5	5

2.3 Technical Specifications for the Fruit-Grass-Chicken Ecological Cycle Model

Establishing the fruit-grass-chicken model in Loess Plateau dry highlands requires standardized specifications for orchard planning, variety selection, and production management:

1. **Orchard Site Selection:** New orchards should be established on gentle slopes <6°; for sunny, leeward hilly slopes of 3°–15°, construct horizontal trenches and terraces.

2. **Apple Variety and Rootstock Selection:** Follow site-adapted cultivation and market-oriented principles, considering site conditions, cultivar characteristics, stress resistance, pest resistance, and market demand. For vigorous rootstocks, use *Malus robusta* Rehd. or *Malus baccata* (Linn.) Borkh.; for dwarfing rootstocks, select types that inhibit excessive vigor, improve efficiency, and enhance fruit quality such as M26, M9, M7, Mark, and CG.

3. **Forage Species Selection:** Choose varieties that improve orchard soil fertility, reduce pest pressure, avoid competing with fruit trees for water/nutrients, are suitable for poultry consumption, and form stable communities, such as white clover (*Trifolium repens* L.), orchardgrass (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.), and Kentucky bluegrass (*Poa pratensis* L.).

4. **Chicken Breed Selection:** Select local or hybrid breeds with wide adaptability, strong disease resistance, good foraging ability, high stress tolerance, and high egg/meat production.

5. **Area Ratio Configuration:** The optimal fruit tree to understory grass area ratio is 1.77 for vigorous orchards and 2.18 for dwarf orchards, with light interception distribution ratio of 0.45–0.5:0.5. Orchards should include $ $2 pollinizer varieties at a 5:1 ratio.

6. **Grassland Establishment:** Apply 15,000 $kg \cdot hm^{-2}$ organic fertilizer incorporated through tillage at 10–30 cm depth, plus 30–45 $kg \cdot hm^{-2}$ calcium-magnesium phosphate fertilizer. Level and finely prepare soil. Use white clover, orchardgrass, and Kentucky bluegrass (or perennial ryegrass) at 30%, 30%, and 40% ratios respectively. Seeding rates: 30–40 $kg \cdot hm^{-2}$ for strip sowing and 39–52 $kg \cdot hm^{-2}$ for broadcast sowing at 1–2 cm depth.

7. **Fertilization Management:** Apply fertilizer three times annually: (1) pre- and post-budbreak with nitrogen; (2) flower bud differentiation and fruit expansion stage with phosphorus-potassium mixed with nitrogen; (3) late fruit growth with potassium. Rates depend on soil fertility and target yield. Apply foliar fertilizer 4–5 times: 2 times early (nitrogen-based) and 2–3 times late (phosphorus-potassium-based). Post-harvest basal dressing: 25–50 kg per young tree, 50–100 kg per bearing tree.
8. **Pest Management:** Introduce 2–3 key natural enemies, use insect sex pheromones for trapping or mating disruption, implement biological control to reduce pesticide application.
9. **Chicken Grazing Management:** Begin grazing in June with 6–8-week-old chicks, remove from orchard by late October, maintain post-grazing stubble height of 0.5–1 cm.
10. **Forage Utilization:** During peak growth, mow excess forage for composting to increase soil fertility or for livestock feed.
11. **Infrastructure:** Construct one 10 m^2 (5 m × 1.5 m × 2 m) simple chicken shelter per 500 m^2 of orchard grassland, with 4–5 supplementary feeding troughs and 2 water troughs per shelter. Fencing should exceed 1.5 m height.
12. **Grassland Renewal:** When grassland ages cause soil compaction and shallow root distribution with severe tree-grass competition, renovate the grassland.
13. **Disease Prevention:** Adjust grazing density based on weather conditions to improve disease resistance, establish biosecurity systems, vaccinate timely, and effectively control disease transmission.
14. **Monitoring:** Maintain complete production records, conduct regular monitoring and analysis of all production stages to track orchard dynamics and implement appropriate management strategies.

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3. Coupling Effects and Benefits of the Fruit-Grass-Chicken Ecological Cycle Model

Based on the structural configuration in Table 1, comparative trials between fruit-grass-chicken and clean-cultivation orchards were conducted at the Qingyang Loess Plateau Grassland Agro-Ecosystem Experimental Station of Lanzhou University in Xifeng District, Qingyang City from March 2015 to March 2017. Results demonstrated excellent coupling effects with significant ecological, economic, and social benefits.

3.1 Coupled Production Effect Analysis

The fruit-grass-chicken model optimizes ecological, economic, and technical structures through resource allocation, transforming single-species, single-layer planting into multi-species, multi-layer integrated management. This creates systematic coupling effects in resource utilization during production, achieving greater per-unit benefits than monoculture operations through functional and industrial coupling effects [Figure 1: see original paper].

Functional Coupling Effects: The model first improves vegetation coverage through orchard grass cultivation, reducing soil erosion, increasing water storage, enhancing soil carbon sequestration, decreasing CO_2 emissions, regulating atmospheric conditions, and improving air quality—achieving ecological conservation functions. Second, leguminous forage nitrogen fixation increases soil fertility and reduces chemical fertilizer use. Third, biodiversity functions decrease pesticide application and improve fruit quality. Fourth, grassland chicken production yields eco-friendly meat while chicken manure and excess forage return nutrients to soil, enabling nutrient cycling. This integrates high-quality production with ecological conservation, delivering ecological, economic, and social benefits.

Industrial Coupling Effects: The model organically integrates fruit, forage, and poultry industries, creating complementary coupling effects that improve orchard production structure, optimize inter-industry advantages, fully utilize resources, and establish multi-level material cycling and expanded energy flow within the orchard ecosystem, enhancing comprehensive per-unit production levels.

3.2 Coupled Production Benefit Analysis

Implementation at the experimental station optimized land use and industrial structures, significantly improved water-soil resource utilization, reduced chemical inputs, enhanced fruit quality, and achieved remarkable ecological, economic, and social benefits while integrating high-quality production with ecological conservation .

Compared with clean-cultivation orchards, the fruit-grass-chicken model showed significant improvements across all dimensions. **Economically**, apple yield per unit area increased 18.78%, output value rose 1.88-fold, and profit increased 3.82-fold. **Ecologically**, vegetation coverage improved 54.90%, water use efficiency increased 117.88%, soil erosion decreased 58.82%, water conservation capacity enhanced 71.36%, 0–10 cm soil organic matter increased 11.87%, bacterial distribution in 0–10 cm soil layer increased 4.7%, fungal numbers decreased 33.4%, chemical fertilizer use dropped 20.15%, and pesticide application fell 5.27%. **Socially**, land resource utilization increased 58.33%, per-unit output efficiency improved 45.45%, fruit quality (premium grade) enhanced 5.17%, and per capita income contribution rose 140.00%.

Table 2 Ecological and economic benefits of the ecological circle mode of fruit-grass-chicken in the dry highland of the Loess Plateau

Benefit Category	Indicator	Fruit-Grass-Chicken Model	Clean Cultivation Orchard
Economic	Apple price (¥ · kg^{-1})	4.5	3.8
	Apple yield (kg · hm^{-2})	42,000	35,360
	Chicken price (¥ · kg^{-1})	20	–
	Production value (¥ · hm^{-2})	234,000	81,168
	Cost (¥ · hm^{-2})	84,240	48,700
	Benefit (¥ · hm^{-2})	149,760	31,468
Ecological	Vegetation coverage (%)	95	40.67
	Water use efficiency (%)	65.23	29.94
	Soil erosion (%)	41.18	100
	Water conservation (%)	171.36	100
	Soil organic matter (g · kg^{-1})	14.96	13.38
	Bacterial distribution (%)	104.7	100
	Fungal distribution (%)	66.6	100

Benefit Category	Indicator	Fruit-Grass-Chicken Model	Clean Cultivation Orchard
	Chemical fertilizer (kg · hm^{-2})	795	996
	Pesticide (kg · hm^{-2})	18	19
Social	Land resource utilization (%)	95	60
	Output efficiency per unit area (%)	160	110
	Fruit quality (premium) (%)	81.7	76.53
	Per capita income contribution (%)	240	100

4. Conclusions and Discussion

The fruit-grass-chicken coupled ecological cycle model represents a land resource utilization pattern coordinating ecological and economic development in Loess Plateau dry highlands. All ecological, economic, and social benefit indicators exceed those of traditional clean-cultivation orchards. By integrating ecological conservation with high-quality production and centering on functional and industrial coupling, the model improves orchard species structure, enhances agricultural resource utilization, enables energy flow transformation between subsystems, and maintains system stability and self-sustaining capacity. The complementary effects among fruit, grass, and chicken subsystems generate coupled production benefits, significantly improving ecological, economic, and social outcomes compared with conventional orchards, with broad application and promotion value.

The Loess Plateau dry highlands are transitioning from conventional petrochemical agriculture to modern ecological agriculture. With deepening agricultural supply-side structural reform, traditional grain-industrial crop dual patterns with excessive chemical inputs have caused ecological degradation and poor product quality, becoming incompatible with modern ecological agriculture requirements. Adjusting planting structures to establish integrated crop-livestock ecological cycle patterns that couple ecological conservation with high-quality production represents the necessary path for sustainable agricultural development. Implementing the fruit-grass-chicken model requires rational spatial-temporal structural configuration to create multi-level energy cycling and expanded flow, achieving coupling effects of ecological conservation, comprehensive resource utilization, high-quality production, and increased benefits.

Model promotion requires advanced agricultural technologies and development of distinctive, high-quality, eco-friendly agricultural economies. Based on species complementarity in resource utilization and niche differentiation, market-oriented cultivation of regional advantage varieties should follow technical specifications for pollution-free, green, and organic products. Under leading enterprise guidance, integrated production-processing-marketing systems should be established. Due to varying natural conditions and management levels across regions, locally adapted coupling models should be constructed with government support in policy, technology, information, and funding to establish safeguard mechanisms for ecological agriculture development, promoting coordinated ecological, economic, and social sustainability in the Loess Plateau dry highlands.

References

[1] Cheng X. The ecological construction and the selection of major agro-industry in developing Northwest China[J]. Eco-Agriculture Research, 2000, 8(3): 89–91

[2] Liu X Y, Wang S M, Guo Z G. The compound management model of agricultural resources and its eco-economic coupling effects in the semi-arid area of Northwest China[J]. Journal of Natural Resources, 2004, 19(5): 624–631

[3] Zhang H Q, Liu X L. Analysis of the land use structure in Xifeng District, Qingyang City[J]. Chinese Agricultural Science Bulletin, 2014, 30(36): 193–197

[4] Luo S M. Agroecology transition and suitable pathway for eco-agricultural development in China[J]. Chinese Journal of Eco-Agriculture, 2017, 25(1): 1–7

[5] Sun W Y, Shao Q Q, Liu J Y. Assessment of soil conservation function of the ecosystem services on the Loess Plateau[J]. Journal of Natural Resources, 2014, 29(3): 365–376

[6] Liu Y, Gao M S, Wu W, et al. The effects of conservation tillage practices on the soil water-holding capacity of a non-irrigated apple orchard in the Loess Plateau, China[J]. Soil and Tillage Research, 2013, 130: 7–12

[7] Wang Y, Wu F Q, Peng X Y, et al. Analysis of economic efficiency and energy flow characteristics of a circular and integrated agriculture model in the Loess hilly region[J]. Transactions of the Chinese Society of Agricultural Engineering, 2016, 32(S2): 308–315

[8] Wang H G, Zhai H Y. Research review and outlook of agricultural circular economy[J]. Journal of Huazhong Agricultural University: Social Sciences Edition, 2016, (4): 59–66

[9] Li W H, Cheng S K, Mei X R, et al. Study on strategies for the sustainable development of China' s agricultural resources and environment[J]. Engineering Sciences, 2016, 18(1): 56–64

[10] Li F L, Zheng Y R, Zheng T, et al. Research advances on soil and water conservation effect of pasture-planting in orchard[J]. Chinese Agricultural Science Bulletin, 2013, 29(34): 34–39

[11] Wardle D A, Yeates G W, Bonner K I, et al. Impacts of ground vegetation management strategies in a kiwifruit orchard on the composition and functioning of the soil biota[J]. Soil Biology and Biochemistry, 2001, 33(7/8): 893–905

[12] Du S B, Zhang J K. Research advances of pasture-planting in apple orchard on semi-dry region of the Loess Plateau[J]. Chinese Agricultural Science Bulletin, 2014, 30(28): 81–86

[13] Liu Y H. Analysis of grassland farming systems' economic benefit based on the short-term production model[J]. Acta Prataculturae Sinica, 2016, 25(2): 223–230

[14] Deng F C. Ecological effect and application prospect of growing grass in orchard[J]. Northern Horticulture, 2009, (1): 133–136

[15] Du L Q, Wu H, Zheng L Y. Review of eco-environmental effect of orchard sod culture[J]. Chinese Agricultural Science Bulletin, 2015, 31(11): 217–221

[16] Wang H, Wang Y Q, Jiao C Q, et al. Effects of chicken-raising stereoscopic agriculture in orchards on soil calcium nutrient and apple quality on Weibei Dryland[J]. Agricultural Research in the Arid Areas, 2014, 32(4): 178–182

[17] Liu Y Q, Guo X M, Du T Z, et al. Study on compound ecological models of orchard taking grain amaranths as a link[J]. Chinese Journal of Eco-Agriculture, 2002, 10(4): 118–120

[18] Yin C B, Zhou Y, Liu L H. Theory and practice of recycle agriculture in China[J]. Chinese Journal of Eco-agriculture, 2013, 21(1): 47–53

[19] Yang Y, Gai A H. Evaluation on land use benefits in hilly and gully area of the loess plateau —A case study of Qingyang City[J]. Journal of Gansu Agricultural University, 2013, 48(6): 131–134

[20] Ma F W. Reflect on the development for apple industry in the northwest loess plateau[J]. Scientific of Planting and Breeding, 2006, (4): 4–6

[21] Liu X Y, Shen Y Y, Zhao H. The couple model of ecological conservation and high quality production for urban agriculture of arid areas in northwestern China[J]. Pratacultural Science, 2017, 34(3): 644-652

[22] Deng Z Y, Zhang Q, Wang Q, et al. Influence of water storage capacity on yield of winter wheat in dry farming area in the Loess Plateau[J]. Acta Ecologica Sinica, 2011, 31(18): 5281-5290

[23] Li M X, Du S N, Bai G S, et al. Problems and solutions of apple production in Weibei Loess Plateau[J]. Research of Soil and Water Conservation, 2010, 17(4): 252-257

[24] Zhao Z Y, Li H K. The effects of interplant different herbage on soil water in apple orchards in the area of Weibei Plateau[J]. Acta Horticulturae Sinica, 2006, 33(3): 481-484

[25] Wang S Q, Zhang S Q, Wang X L. Transpiration of maize under different cultivation patterns in the Loess Tableland[J]. Chinese Journal of Eco-Agriculture, 2013, 21(4): 432-439

[26] Zhang J Y, Wu B Q, Liu Y M, et al. Optimize models of agro-forestry ecosystem —A case study from Raoyang County of Hebei[J]. Eco-Agriculture Research, 1998, 6(3): 55-58

[27] Zhu H J, He S F. The coupling effects of the exploitation of agricultural resources[J]. Journal of Natural Resources, 2003, 18(5): 583-588

[28] Chen X P, Guo X J, Wang G K, et al. The coupling evolution analysis of resource-environment-economic system in the poor areas of Gansu[J]. Journal of Arid Land Resources and Environment, 2013, 27(11): 1-8