Postprint of Research on Planning and Construction of Farmland Buffer Strips and Natural Enemy Protection Effectiveness

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Date: 2017-11-08T00:00:00+00:00

Abstract

Buffer strip construction can provide multiple ecological service functions and constitutes an important practical measure in the development of modern ecological agriculture both domestically and internationally. This paper takes the Urban Modern Agriculture Demonstration Zone construction project in Shunyi District, Beijing as a case study to explore the planning and construction methods of farmland buffer strips, and monitors the natural enemy protection effects, aiming to investigate landscape planning approaches for ecological agriculture construction at the town-village scale. Main research conclusions: 1) Through five steps including objective determination, current situation investigation, overall spatial layout design, engineering design, construction supervision and management, the spatial layout planning, planting pattern design and construction of farmland buffer strips were completed in the study area, comprising three types (channels, roads, and shelterbelts) with a total of seven patterns; 2) Pest and natural enemy sampling monitoring results indicated that artificial forest land buffer strips had the highest spider activity density, and artificial boundaries such as channel and road buffer strips had the highest natural enemy/aphid ratio, preliminarily demonstrating the natural enemy protection effectiveness of farmland buffer strip construction; 3) Future ecological agriculture construction should strengthen large-scale spatial planning and integrated demonstration of ecological landscaping technologies such as farmland buffer strips, and the enhancement effects of their ecological service functions need to be verified through long-term monitoring experiments for different farmland types.

Full Text

Introduction

Eco-agricultural construction must seek coordination and mutual enhancement between agricultural land and non-cultivated habitats, restoring and enhancing agricultural biodiversity and related ecological service functions [1-2]. Farmland buffer strips refer to established vegetation coverage in agricultural landscapes that can provide habitats for farmland arthropods and other species, increase heterogeneity and connectivity in eco-agricultural landscapes [4], and thereby deliver multiple ecological services. Buffer strip construction occupies a crucial position in eco-agricultural landscape construction and management in developed countries such as Europe and America. For example, the UK' s Environmental Stewardship (ES) program provides farmers with guidelines for various buffer strips targeting cropland, grassland, and water bodies [5]; the USDA' s Natural Resources Conservation Service (NRCS) has widely implemented Natural Resources Conservation Practices nationwide, establishing engineering technical standards for riparian buffers, field margins, hedgerows, and other buffer types that effectively enhance ecological services such as soil carbon sequestration and water quality improvement [6-7]. In China, research on functional verification and mechanism exploration of various farmland buffer strips is relatively abundant, including quantitative analyses of sediment and nitrogen/phosphorus interception by riparian and lake buffers with different structural configurations of trees and grasses [8-9], as well as studies on the ecological service functions of field ridges [10-11], hedgerows [12-13], and field margins [14] for soil and water conservation, pest-natural enemy regulation, and biodiversity conservation, exploring their application value and construction patterns [15-17]. However, existing studies are mostly relatively isolated theoretical research that has not been transformed into systematic construction methodologies, lacking integrated planning, design, and demonstration construction of multiple farmland buffer strips and their ecological service functions at certain scales, making it difficult to directly verify the ecological service effectiveness of farmland buffer strip technologies in practical demonstration applications. Addressing these issues, this study uses the Modern Urban Agricultural Demonstration Zone construction project in Shunyi District, Beijing, as a case study to explore the planning and design methodology system for farmland buffer strips in eco-agricultural landscapes, conduct spatial layout planning, pattern design, and demonstration construction of farmland buffer strips at the landscape scale, and evaluate the effectiveness of natural enemy protection functions, aiming to provide new perspectives for spatial pattern planning and ecological construction in modern eco-agricultural development.

1.1 Concept and Classification of Farmland Buffer Strips

Farmland buffer strips can be defined as strip vegetation mosaics embedded between cropland and other landscape elements in agricultural landscapes, primarily located at field edges, including transitional zones between farmland and other land uses that are difficult to incorporate into cultivation, or marginal areas generated during land consolidation processes [18]. Buffer strips can be classified based on their attributes and functions. According to location and adjacent land use types, they can be categorized as riparian buffers [19], ditch buffers, road buffers, field/orchard margin buffers, shelterbelt and woodland edge buffers, and village periphery buffers. Based on vegetation composition and structural configuration, they can be divided into forested buffers, shrub hedgerows [20], herbaceous buffers, and nectar plant strips. According to primary ecological service functions, they can be classified as soil and water conservation buffers, non-point pollution control buffers, pollination enhancement buffers, pest control buffers, and slope/bank protection buffers.

1.2 Ecological Service Functions of Farmland Buffer Strips

Ecosystem services refer to benefits humans obtain from ecosystems, including four major categories: provisioning, regulating, cultural, and supporting services [21]. The concept of landscape services, which operates at the landscape scale, depends on the comprehensive effects of landscape patterns and can guide landscape integrated management, planning, and decision-making [22]. Integrated planning and management of buffer strips at the agricultural landscape scale can provide diverse ecological services. Regarding regulating services, ditch and riparian buffers can provide water conservation and pollution control functions [18,23]; for example, Bu et al. [9] designed integrated tree-grass buffer strips that reduced farmland runoff by approximately 50%, intercepted about 80% of sediment deposits, and achieved interception rates above 50% for various forms of nitrogen and phosphorus. Shelterbelt buffers can regulate microclimate and provide windbreak and dust control functions; Kong et al. [24] demonstrated that annual average air temperature within farmland shelterbelts was 1.0°C lower than outside, while annual average relative humidity was 8% higher. Regarding supporting services, field ridges and margin buffers can provide pollination, pest control, and biodiversity conservation functions [16]; for instance, Wan et al. [10] reported that retaining weeds on rice field ridges reduced rice planthoppers (Laodelphgax striatellus, Sogatella furcifera, and Nilaparvata lugens) by 35.31%. Studies by Klein et al. [25] and Wiggers et al. [26] showed that plant strips around farmland and orchards significantly enhanced the diversity of wild bees and other pollinating insects and birds. Regarding provisioning and cultural services, constructing farmland buffer strips using forage, nursery stock, and economic crops can provide additional agricultural products, while diverse buffer strips play important roles in improving aesthetic indicators such as landscape complexity, openness, naturalness, and historicity [27-28]. In terms of landscape services, the spatial distribution of ditches, roads, and shelterbelts influences spatial pattern indicators such as landscape diversity, fragmentation, and habitat distribution [29-31].

1.3 Integrated Planning and Design of Farmland Buffer Strips

Eco-agricultural landscape construction requires adherence to functional and structural principles, maintaining the security of natural ecological processes and agricultural biodiversity, and reshaping the structural and functional integrity of farmland landscape mosaics. The integrated planning and design of farmland buffer strips centered on ecological service functions mainly includes the following steps: (1) Target identification: following multifunctional principles, balancing development strategies and demands for agricultural production, economic development, and environmental protection to determine planning and design objectives; (2) Status investigation: through field survey mapping and participatory research, detailed evaluation of landscape characteristics such as topography, vegetation, water bodies, and settlements [28], and analysis of ecological service supply and demand; (3) Overall spatial layout: constructing the overall spatial arrangement of farmland buffer strips, protecting identified non-cultivated habitats, filling habitat gaps between patches, maintaining natural ecological processes, and enhancing landscape heterogeneity and connectivity; (4) Engineering design: addressing the practical needs of grassroots managers and land users, comprehensively considering direct, indirect, and cumulative impacts of engineering design on the ecological environment, utilizing native plant species, reasonably determining plant combinations and proportions, and simulating regional natural communities for vegetation design; (5) Construction and management: controlling negative impacts of construction operations on soil and water security and biodiversity, emphasizing regular pruning and replanting of vegetation to ensure functional sustainability of farmland buffer strips.

2.1.1 Study Area Description

This paper uses the ditch-road-forest-channel and ecological landscape enhancement project within the Beijing Modern Urban Agricultural Demonstration Zone construction project as a case study. The study area is located in Zhaoquanying Town and Beishicao Town, Shunyi District, Beijing, covering 10 administrative villages with a total area of 1,732 hm^2. Farmland is the primary land use type, accounting for 57.6%, while forest resources are relatively scarce, accounting for 14.2%. The study area is situated on the alluvial plain of the Chaobai River, with light loam soil and a warm temperate continental semi-humid monsoon climate, with an annual average temperature of 11.5°C and average annual precipitation of 622 mm. Water resources mainly include the Niu River and two main irrigation channels (Qibagan Channel and Bafen Channel), which are seasonal rivers. The study area contains 63 species of vascular plants, including trees such as Populus tomentosa, Platanus orientalis, Platycladus orientalis, Fraxinus chinensis, Armeniaca vulgaris, Armeniaca mume, and Pinus tabuliformis; shrubs such as Jasminum nudiflorum, Buxus sinica, and Ilex pedunculosa; herbaceous plants such as Humulus scandens and Digitaria sanguinalis; and vines such as Pharbitis nil and Vitis vinifera.

2.1.2 Research Methods

1) Farmland buffer strip planning and design: From April to June 2013, field landscape surveys were conducted using regional remote sensing imagery (Google Earth) as base maps, with mapping and photo collection of roads, ditches, and shelterbelts. A farmland landscape geographic database was established using CASS and ArcGIS software for mapping and digitization. The current ecological landscape status of the study area was qualitatively evaluated, and the overall spatial layout of farmland buffer strips was proposed based on land use patterns, ecological environmental problems, and ecological service function demands. Planting pattern designs were developed for three main landscape element types—roads, ditches, and shelterbelts—utilizing native plants to propose plant configuration patterns, construction methods, and provided ecological services. Planning and design were completed in August 2013, with construction finishing in April 2014 when initial green vegetation coverage had formed [Figure 1: see original paper].

2) Natural enemy protection effect monitoring: From April to June, wheat (Triticum aestivum) fields adjacent to four types of farmland boundaries—field ridges, natural boundaries, artificial boundaries, and woodlands—were selected as sample plots to investigate the biodiversity of aphids [Rhopalosiphum padi, Macrosipham avenae, Schizaphis graminum] and predatory natural enemies. Field ridges were approximately 1 m wide, bare boundaries without vegetation coverage, such as production roads. Natural boundaries were approximately 1 m wide, weed-covered, unmanaged farmland boundaries and ditches. These two types served as control areas maintaining original conditions without buffer strip construction. Artificial boundaries were road and ditch buffer strips, while woodlands were shelterbelt buffer strips or small woodlands adjacent to farmland, representing the implementation outcomes of farmland buffer strip construction. Aphids were surveyed in wheat fields at 10-11 m from boundaries along 15 m transects, with 25 wheat plants randomly selected at 3 m intervals, recording the number of each aphid species per plant. Predatory natural enemies were sampled using insect samplers, with sampling conducted every 10 days in May-June (three times total), randomly selecting four quadrats within buffer strips each time, with quadrat size determined by insect sampler parameters.

2.2.1 Farmland Buffer Strip Planning and Design

Farmland landscape status survey results indicated: (1) In terms of landscape pattern, the study area exhibited obvious characteristics of large-scale grain fields, relatively complete agricultural infrastructure including ditches, roads, forests, and channels, and an open landscape, but suffered from homogenization problems; (2) Regarding infrastructure, some roads had low utilization rates and lacked maintenance, ditches exhibited abandonment, occupation, blockage, bare surfaces, and unevenness, some active ditches had severe water pollution, and shelterbelts had monotonous species composition and structure lacking hierarchy and seasonal variation; (3) Concerning ecological service function demands, settlements on the east and west sides prioritized improving living environment quality, large-scale grain fields in the north and south focused on enhancing supporting and regulating functions of agricultural infrastructure, and the central tourism route emphasized leisure and aesthetic appreciation functions. Based on these findings, ditch slopes, road shoulders, shelterbelts, and small woodlands were utilized to construct a spatial layout of farmland buffer strips comprising three types with seven patterns total [Figure 1: see original paper].

During plant species selection, harmless native plants were retained, and easily established, low-maintenance perennial native plants were selected for planting, prioritizing species with high natural value such as nectar plants, beneficial insect-attracting or pest-repelling plants, and legumes. Specific pattern designs were as follows:

Road Buffer Strip Design: Roadways in the study area were mainly lined with trees such as Salix matsudana, Sophora japonica, and Populus tomentosa, but lacked herbaceous and shrub coverage with severely bare surfaces. Different road types and functional requirements were addressed using native species to ensure green vegetation coverage and improve species composition and functional complexity.

Pattern 1: For main roads with high traffic volume and fast speeds, emphasizing leisure and recreation functions. Strongly adaptable and ornamental ground cover plants such as Pennisetum alopecuroides, Hemerocallis fulva, and Spiraea japonica were selected to create an open farmland landscape atmosphere, combined with easily established, low-maintenance native wildflowers such as Taraxacum mongolicum, Viola philippica, and Potentilla reptans to ensure surface coverage [Figure 1b: see original paper].

Pattern 2: For field roads with less motor vehicle traffic but frequent pedestrian use, emphasizing living environment improvement functions. Colorful shrubs with seasonal changes such as Swida alba, Kerria japonica, Euonymus alatus, Syringa pekinensis, and Lonicera maackii were selected, combined with ground cover plants such as Coronilla varia and Festuca elata for soil fixation and slope protection, improving residents' daily travel viewing experience [Figure 1c: see original paper].

Pattern 3: For field production roads less than 3 m wide, emphasizing soil and water conservation, natural pollination, and natural enemy protection functions. Shrub hedgerows composed of Hibiscus syriacus, Jasminum nudiflorum, and Euonymus alatus were planted to fix soil, reduce runoff, and intercept diffused particles and pesticides, while enhancing farmland landscape heterogeneity and connectivity between patches to provide better habitat and dispersal conditions for pollinating insects, pest natural enemies, and birds [Figure 1d: see original paper].

Ditch Buffer Strip Design: Ditch surfaces in the study area were mainly unhardened bare sandy soil, with a few cement-lined sections. Overall, constructed ditches had low utilization rates, with problems of occupation, unevenness, blockage, and water pollution. Different ditch types and problems were addressed by utilizing plant root growth to increase water infiltration, reduce surface runoff velocity, and filter nutrients and pollutants, while creating field biological islands and wildlife resource pools to provide habitats for pest natural enemies and pollinating insects.

Pattern 1: For flood control channels wider than 10 m, emphasizing soil and water conservation and biodiversity protection functions. Populus tomentosa was planted in the tree layer, with shrubs such as Rosa xanthina, Syringa pekinensis, Sorbaria sorbifolia, Swida alba, and Amorpha fruticosa planted more than 1 m from ditch slopes for windbreak and sand fixation and soil erosion control. Ground cover plants such as Phragmites australis, Coreopsis basalis, Platycodon grandiflorus, Dianthus chinensis, and Eschscholzia californica were selected as aquatic and nectar plants to attract pollinating insects and provide shelter for wildlife [Figure 1e: see original paper].

Pattern 2: For farmland channels with gentle slopes and no tree layer vegetation in the study area, emphasizing non-point pollution control, natural pollination, and natural enemy protection functions. Low shrubs such as Amorpha fruticosa, Lespedeza bicolor, Vitex negundo, and Forsythia suspensa were planted at ditch edges to stabilize slopes, reduce surface runoff velocity, and prevent surface collapse and gully formation. Native plants were retained in the ground cover layer, with hexagonal grass planting bricks used for additional slope stabilization, supplemented with soil-fixing plants such as Festuca elata and Coronilla varia, combined with nectar plants such as Eschscholzia californica, Dianthus chinensis, Coreopsis basalis, and Platycodon grandiflorus to attract pest natural enemies and pollinating insects [Figure 1f: see original paper].

Shelterbelt Buffer Strip Design: Addressing problems of monotonous species composition and structure and widespread gaps in shelterbelts in the study area, existing vegetation was maintained as much as possible while supplementing trees in the arbor layer and vegetation in the shrub and herb layers to construct a near-natural plant community structure with trees, shrubs, and grasses, improving the structural stability, functional complexity, and disturbance resistance of the shelterbelt system.

Pattern 1: For restoration and renovation of farmland shelterbelt networks, emphasizing soil and water conservation and microclimate regulation functions. Trees such as Sophora japonica and Populus tomentosa were planted, with low shrubs such as Euonymus alatus, Lagerstroemia indica, Jasminum nudiflorum, and dwarf Hibiscus syriacus planted under the forest canopy, and ground cover plants such as Iris lactea and Festuca elata combined with native wildflowers such as Echinacea purpurea, Viola philippica, and Taraxacum mongolicum to improve surface vegetation coverage and shelterbelt connectivity, providing functions of soil fixation, dust reduction, wind speed reduction, atmospheric particulate interception, and moderating farmland temperature and humidity changes [Figure 1g: see original paper].

Pattern 2: For existing woodlands or grasslands around main road intersections and villages, small woodland patches were restored or newly created, emphasizing biodiversity protection and leisure functions. Populus tomentosa was used as the main tree species, with flowering shrubs such as Sorbaria sorbifolia, Amorpha fruticosa, and Vitex negundo, evergreen shrubs such as Juniperus formosana and Platycladus orientalis, combined with perennial flowers such as Dianthus chinensis, Echinacea purpurea, and Eschscholzia californica to form stepping stones for biological habitats, promoting migration, dispersal, and settlement of farmland wildlife including birds, pollinating insects, and pest natural enemies, while creating colorful and seasonally varied native landscape nodes for human viewing [Figure 1h: see original paper].

2.2.2 Evaluation of Natural Enemy Protection Effect

Survey and evaluation results showed: (1) Natural enemy diversity in wheat fields adjacent to different farmland buffer strips varied significantly. Taking spiders (Araneae) as an example, spider activity density in wheat fields adjacent to artificial woodlands was significantly higher than in fields adjacent to the other three buffer strip types (field ridges, natural boundaries, and artificial boundaries). Spider activity density in wheat fields with natural and artificial boundaries showed no significant difference and was significantly lower than in fields adjacent to field ridges and artificial woodlands [Figure 2: see original paper]. (2) The natural enemy/aphid ratio in wheat fields adjacent to different buffer strips also varied significantly. Wheat fields adjacent to artificial boundaries had the highest natural enemy/aphid ratio, significantly higher than fields adjacent to field ridges. No significant differences existed between field ridges, natural boundaries, and artificial woodlands, nor among natural boundaries, artificial boundaries, and artificial woodlands [Figure 3: see original paper].

Discussion

Diverse land cover in agricultural landscapes can provide habitats and survival resources for more species, thereby increasing biodiversity and the diversity of ecological service functions [32]. Eco-agriculture should improve ecological service functions at three levels: regional ecological landscape strategic planning, landscape-scale spatial pattern planning, and ecological landscaping of engineering technologies [33]. This study considered the spatial pattern of farmland buffer strips at the landscape scale during planning and design, and used ecological service functions as criteria for plant selection in pattern design, aiming to develop a multifunctional, multi-scale landscape planning perspective for eco-agricultural construction. In the effectiveness evaluation, this study only monitored natural enemy protection functions to reduce sampling difficulty and shorten the experimental period. Monitoring results showed that woodlands supported the highest spider activity density, while wheat fields near natural and artificial boundaries had the lowest spider activity density. The natural enemy/aphid ratio within the four buffer strip types did not show large differentiation, but the ratio within artificial boundaries was significantly higher than that within field ridges. Both artificial woodlands and artificial boundaries demonstrated certain pest-natural enemy regulation effects. Woodlands, with larger patch areas and higher vegetation coverage, can provide more ideal shelters and may be more conducive to spider settlement, while artificial boundaries may promote the dispersal of some predatory arthropods. However, the overall natural enemy protection effects of various farmland buffer strips were not obvious, possibly because the monitoring period was short, vegetation was not fully developed during sampling, and construction processes disturbed natural enemy activities such as spiders, making it difficult to meet their dispersal and settlement conditions and thus failing to achieve ideal buffer strip benefits.

The actual effectiveness of comprehensive planning and construction of agricultural ecological landscaping technologies such as farmland buffer strips at the landscape scale requires further verification through long-term monitoring of multiple indicators. A series of conservation projects by the US NRCS only showed ideal effects after 1-3 years [34]. The Water Friendly Farming research project in the UK demonstrated wetland restoration, buffer strip construction, and other technologies, whose impacts on multiple indicators including soil, water bodies, and biodiversity were only preliminarily confirmed after three years of monitoring [35]. Therefore, various eco-agricultural construction projects urgently need to shift from pursuing short-term, direct effects to considering synergistic and cumulative effects of multiple ecological service functions at larger scales with increased management efforts. Additionally, this study designed buffer strips for typical dryland farming in plain areas; for farmland buffer strip construction under other topographic, climatic, and hydrological conditions, spatial layout and plant selection should be adjusted according to specific landscape characteristics and ecological service function demands.

Conclusion

Based on clarifying the definition, classification, functions, and planning methods of farmland buffer strips, this study used the Modern Urban Agricultural Demonstration Zone in Shunyi District, Beijing, as a case study. Through landscape investigation and evaluation, an overall spatial layout of farmland buffer strips was proposed, comprising three types (roads, ditches, and shelterbelts) with seven construction patterns, combined with planting pattern design based on ecological service function demands. After project completion, typical buffer strips were categorized into four types (field ridges, natural boundaries, artificial boundaries, and woodlands) for natural enemy-pest sampling surveys, preliminarily demonstrating the natural enemy protection effects of farmland buffer strips and providing reference and guidance for landscape construction in eco-agricultural development. Future eco-agricultural landscape construction should strengthen comprehensive spatial planning of ecological landscaping engineering technologies such as farmland buffer strips at the landscape scale and widely conduct practical demonstrations and long-term monitoring research for different agricultural landscape types.

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Note: Figure translations are in progress. See original paper for figures.