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Culture Performance and Growth of Chinese Soft-Shelled Turtle (*Pelodiscus sinensis*)

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Abstract The Chinese soft-shelled turtle (*Pelodiscus sinensis*) is an economically important aquaculture species in China, and its growth performance and production benefits are influenced by various factors, including culture environment, management practices, and resource utilization efficiency. To clarify the production characteristics and optimization strategies of different culture models, this review systematically compares intensive greenhouse culture, conventional pond culture, and rice-turtle co-culture in terms of water temperature, water quality, stocking density, and ecological environmental conditions based on relevant domestic and international studies. The effects of these culture models on body weight gain, survival rate, feed utilization efficiency, culture cycle, health status, and product quality are analyzed, and their overall benefits are evaluated from the perspectives of production costs, economic returns, and ecological sustainability. Previous studies indicate that intensive greenhouse culture can promote growth and shorten the culture cycle by maintaining stable environmental conditions, but it requires substantial infrastructure investment and energy consumption and may impose considerable environmental pressures under high stocking densities. Conventional pond culture provides relatively favorable natural environmental conditions, although growth performance is susceptible to seasonal variations. Rice-turtle co-culture can improve resource utilization efficiency through natural food utilization and nutrient cycling and, under certain conditions, enhance survival rates, feed utilization, and ecological environmental performance. Overall, different culture models have distinct advantages, and their suitability depends on production objectives, environmental conditions, and management practices. Future efforts should focus on stage-specific culture, appropriate stocking density management, precision nutrition, and aquatic environmental management to promote the development of efficient, high-quality, cost-effective, and ecologically sustainable Chinese soft-shelled turtle aquaculture.

Keywords Chinese soft-shelled turtle; Culture models; Growth performance; Economic benefits; Ecological sustainability

1 Introduction

Conventional pond culture is one of the most widely adopted production methods for Chinese soft-shelled turtles (Pelodiscus sinensis). It primarily utilizes natural ponds or artificially constructed culture ponds to provide a rearing environment relatively close to natural conditions. This culture model generally relies on natural fluctuations in water temperature and maintains production through appropriate stocking density, feed management, and water quality regulation. Compared with intensive greenhouse culture, conventional pond culture usually provides more space for movement and greater exposure to natural sunlight, facilitating natural behaviors such as feeding, burying, and basking (Qi et al., 2025). Pond substrate conditions and facility configurations also influence culture performance. Tang et al. (2009) found that improving pond-bottom substrates, providing basking and feeding facilities, and appropriately incorporating aquatic plants and natural animal-based food sources could improve survival, body weight gain, and economic returns in Chinese soft-shelled turtles. Qi et al. (2025) further demonstrated that, compared with greenhouse-cultured turtles, those reared in ponds and rice paddies exhibited certain advantages in nutritional indicators, including the proportion of edible parts, protein content, and amino acid composition, reflecting the influence of culture environments on product quality.

However, pond culture is strongly affected by seasonal temperature changes, weather conditions, and fluctuations in the aquatic environment. Feeding activity declines during colder seasons, potentially prolonging the culture cycle. Meanwhile, inappropriate stocking densities, excessive feed inputs, and inadequate substrate management can lead to nutrient accumulation in the water, thereby compromising growth stability. Wu et al. (2024b) found that, under certain culture conditions, pond-cultured Chinese soft-shelled turtles exhibited faster growth than those raised in rice-turtle co-culture systems, suggesting that insufficient natural food availability may limit growth performance in ecological culture environments. To address environmental problems in pond culture, Li et al. (2016) demonstrated that the introduction of floating beds planted with water spinach (Ipomoea aquatica) could reduce nitrogen, phosphorus, chlorophyll a concentrations, and water turbidity while improving turtle survival and economic returns. Therefore, conventional pond culture should take full advantage of natural environmental conditions while strengthening feed management and water quality control to improve production per unit area and ensure greater production stability.

Intensive greenhouse culture primarily relies on artificial facilities to regulate water temperature, water quality, and rearing space, thereby providing relatively stable conditions for Chinese soft-shelled turtles. This model can alleviate the constraints imposed by seasonal temperature changes and hibernation on turtle growth. By maintaining suitable water temperatures, ensuring adequate nutritional supply, and implementing refined management practices, greenhouse culture can extend the effective growing season and shorten the culture cycle (Wu et al., 2024b; Qi et al., 2025). Zhang et al. (2017) reported that a modern greenhouse culture system equipped with a ground-source heat pump, three-dimensional shelters, underwater feeding platforms, and a central drainage system achieved a production yield of 23.7 kg/m², a survival rate of 86%, and a feed conversion ratio of 1.26, demonstrating high production efficiency. Li et al. (2024) also found that appropriately low-intensity basking light promoted turtle growth, reduced cortisol levels and lipid peroxidation, and improved immune-related parameters, indicating that greenhouse culture performance can be further enhanced through optimization of environmental conditions.

Nevertheless, intensive greenhouse culture generally requires substantial infrastructure investment and a continuous energy supply. High stocking densities can also promote the accumulation of organic matter and nitrogenous metabolic wastes, increasing the difficulty of water quality management and disease prevention. Studies have shown that, compared with pond and rice-paddy ecological culture, some greenhouse-cultured Chinese soft-shelled turtles experience restricted movement, increased stress risks, and differences in product quality (Wu et al., 2024a; Qi et al., 2025). Furthermore, conventional coal-fired heating systems increase energy consumption and the environmental burden associated with emissions. To address these challenges, Lan et al. (2024) found that a Chinese herbal medicine mixture could improve growth performance, antioxidant status, and immune function in greenhouse-cultured Chinese soft-shelled turtles, providing a potential approach for greener intensive culture. Therefore, greenhouse culture should improve energy utilization, feed management, and health protection while enhancing growth efficiency, thereby achieving an appropriate balance between production benefits and cost control.

The effects of different culture models on the growth performance and production benefits of Chinese soft-shelled turtles are multifaceted, and growth rate or culture yield alone cannot provide a comprehensive evaluation of their production advantages. Existing studies indicate that intensive culture systems generally emphasize short-term production, whereas ecological systems, such as rice-turtle co-culture, can improve resource-use efficiency and environmental performance when stocking density and feeding levels are appropriately controlled (Zhang et al., 2016; Zhao et al., 2020; Wang et al., 2026b). Through a meta-analysis, Yu et al. (2023) found that integrated rice-aquatic animal farming had positive effects on soil fertility, the reduction of agricultural environmental pressures, and overall production benefits. Zhu et al. (2024) further emphasized that the actual performance of integrated culture systems is jointly influenced by field conditions, feed supply, and aquaculture management, indicating that the suitability of different culture models should be evaluated in relation to specific production conditions.

Based on these considerations, this study focuses on the major culture models used for Chinese soft-shelled turtles. By reviewing existing research, it compares water temperature, water quality, stocking density, and ecological environmental characteristics under different culture conditions, and analyzes the effects of culture models on body weight gain, survival rate, feed utilization efficiency, and culture cycle. It further examines the relationships between culture models and turtle health, product quality, and production costs. On this basis, the applicability of different culture models is evaluated from the perspectives of economic benefits and ecological sustainability. The major limitations of existing culture practices are identified, and potential improvements are proposed, including stage-specific culture, appropriate stocking density management, precision nutrition, and optimization of the aquatic environment. This study aims to provide a theoretical reference for selecting suitable culture models, optimizing production management, and improving the quality and efficiency of the Chinese soft-shelled turtle aquaculture industry.

2 Differences in Growth Environments of Chinese Soft-Shelled Turtles Under Different Culture Models

2.1 Differences in water temperature and water quality conditions

Water temperature is an important environmental factor affecting the growth and development of Chinese soft-shelled turtles (Pelodiscus sinensis), and different culture models exhibit significant differences in temperature regulation and stability. As an ectothermic animal, the Chinese soft-shelled turtle is directly affected by changes in water temperature in terms of feeding activity, digestion, nutrient absorption, and metabolism. Conventional pond culture primarily relies on natural water temperatures and is therefore characterized by pronounced seasonal fluctuations. As water temperature increases during spring and summer, feeding activity gradually intensifies, whereas declining temperatures in autumn and winter restrict growth. In contrast, intensive greenhouse culture can maintain relatively stable water temperatures through artificial heating, reducing the limitations imposed by low temperatures and extending the effective feeding period. Zhang et al. (2017) reported that modern greenhouse culture systems equipped with temperature regulation and water quality management facilities could maintain water temperatures close to 30 °C and dissolved oxygen concentrations above 5 mg/L, thereby providing a relatively stable environment for juvenile turtle growth. However, maintaining elevated water temperatures over extended periods also increases energy consumption and imposes greater demands on water quality management. Therefore, water temperature regulation should balance growth requirements, energy costs, and the stability of the aquatic environment.

Water quality conditions also influence the growth performance and health status of Chinese soft-shelled turtles. Conventional pond culture generally involves relatively large water volumes with some natural purification capacity, but water quality is susceptible to rainfall, temperature fluctuations, and residual feed accumulation, resulting in variations in dissolved oxygen, pH, ammonia nitrogen, and nitrite concentrations. Wu et al. (2021a) reported that, in open culture environments such as ponds and rice paddies, water temperatures ranged from 21.8 to 33.6 °C, pH values remained between 7.8 and 8.2, dissolved oxygen concentrations exceeded 5.0 mg/L, and ammonium nitrogen and nitrite concentrations remained below 0.5 mg/L and 0.2 mg/L, respectively. These findings indicate that open culture systems can also maintain suitable aquatic conditions under effective management. Although intensive greenhouse culture offers greater environmental controllability, high stocking densities and feeding intensities can promote the accumulation of organic matter and nitrogenous metabolic wastes. Kou et al. (2022) found that increasing dietary protein levels resulted in corresponding increases in total ammonia nitrogen and total nitrogen concentrations in culture water, indicating a close relationship between nutritional inputs and water quality changes. Furthermore, Li et al. (2016) demonstrated that introducing floating beds planted with water spinach (Ipomoea aquatica) into Chinese soft-shelled turtle ponds could reduce total nitrogen, total phosphorus, and water turbidity. Therefore, different culture models should adopt appropriate water exchange, aeration, bottom waste removal, and ecological purification measures according to their aquatic environmental characteristics to maintain stable water quality.

2.2 Stocking density and space utilization

Stocking density is an important factor determining the growth environment and production efficiency of Chinese soft-shelled turtles, as it directly affects individual movement space, feeding competition, and growth uniformity within the cultured population. Conventional pond culture generally provides relatively large aquatic spaces, allowing turtles to engage in natural behaviors such as swimming, burying, and basking, with comparatively limited competition for space. Intensive greenhouse culture, however, places greater emphasis on production per unit area and typically adopts higher stocking densities to improve the utilization efficiency of culture facilities and water resources. Nevertheless, as stocking density increases, feeding competition and physical contact among turtles become more frequent, potentially increasing growth variability and physiological stress. Chen et al. (2007) found that the specific growth rate of juvenile Chinese soft-shelled turtles decreased with increasing stocking density, whereas the heterophil-to-lymphocyte ratio increased, indicating that excessive crowding may adversely affect growth. Therefore, appropriate stocking density management should consider not only the number of turtles stocked per unit area but also individual growth performance and physiological adaptability.

Space utilization efficiency under different culture models is also influenced by facility layout and environmental configuration. In pond culture, the provision of basking platforms, feeding areas, and shelters can improve activity conditions and reduce interference among individuals. Rice-turtle co-culture systems combine rice paddies with refuge ponds, providing turtles with suitable areas for foraging, hiding, and movement. Zhao et al. (2020) evaluated stocking densities of 6, 8, 10, and 12 turtles/m² in a rice-turtle co-culture system and found that turtle yield increased with stocking density, reaching (1 297.51±106.31) g/m² in the treatment stocked at 10 turtles/m². In addition, this treatment exhibited better growth performance and nutrient utilization efficiency than the turtle monoculture control. These findings indicate that appropriate stocking densities can improve space utilization efficiency. However, the optimal density identified in this experiment was associated with specific culture conditions and turtle sizes and should not be directly applied as a universal standard across different production systems. In practical production, stocking density should be determined by considering the developmental stage, individual body size, environmental carrying capacity, and facility conditions to achieve an appropriate balance between stocking intensity and spatial requirements.

2.3 Substrate conditions and ecological environmental characteristics

Substrate conditions are an important component of the culture environment of Chinese soft-shelled turtles and significantly influence their burying behavior, activity patterns, and health status. Chinese soft-shelled turtles naturally bury themselves in substrates to avoid disturbance, and suitable substrates can provide relatively stable habitats. Conventional pond culture generally uses natural muddy or sandy bottoms, which facilitate natural behaviors such as burying. However, the long-term accumulation of residual feed, excreta, and organic sediments can lead to substrate deterioration. Wang et al. (2026b) used a sandy soil layer approximately 20~30 cm thick in pond culture systems, together with feeding and basking facilities, demonstrating the combined importance of substrate conditions and spatial facilities in establishing suitable culture environments. Greenhouse culture, in contrast, generally places greater emphasis on bottom cleanliness and waste removal efficiency. Artificial pond bottoms facilitate centralized management, but their relatively simple substrate structures may restrict certain natural behaviors. Jia et al. (2026) found that different substrate conditions influenced juvenile growth and behavioral characteristics in the Asian giant softshell turtle (*Pelochelys cantorii*), suggesting that substrate configuration has potential biological significance. However, because this study involved a species other than the Chinese soft-shelled turtle, its findings require further validation in relation to the specific biological characteristics of *P. sinensis*.

Differences in ecological environmental characteristics further influence the adaptability of Chinese soft-shelled turtles to culture conditions. Pond culture and rice-turtle co-culture systems generally contain more diverse biological communities and natural environmental components, with aquatic plants, microorganisms, and other aquatic organisms jointly participating in nutrient cycling and contributing to ecological stability. Wu et al. (2021a) found that rice-turtle co-culture could maintain relatively stable soil pH and organic matter levels, while changes

in stocking density also influenced the structure of soil microbial communities. Ding et al. (2022) demonstrated that different aquaculture systems affected the intestinal microbiota and metabolic characteristics of Chinese soft-shelled turtles, indicating that environmental differences are reflected not only in external habitat conditions but also in the internal microbial ecology of the host. Meanwhile, Wu et al. (2021b) observed distinct differences in the intestinal microbial composition of Chinese soft-shelled turtles inhabiting ponds, rice paddies, and lakes, further indicating that culture environments can influence microbial community structure.

3 Effects of Different Culture Models on the Growth Performance of Chinese Soft-Shelled Turtles

3.1 Body weight gain and growth rate

Body weight gain and growth rate are important indicators for evaluating the production performance of different culture models for Chinese soft-shelled turtles (*Pelodiscus sinensis*), as they directly reflect growth potential and production efficiency under different culture conditions. The growth performance of Chinese soft-shelled turtles is influenced by various factors, including genetic background, initial stocking size, dietary nutrition, and environmental management. Among these factors, culture models primarily affect body weight gain and growth rate by altering water temperature, feeding conditions, and environmental stability. Conventional pond culture mainly relies on natural water temperatures, resulting in pronounced seasonal growth patterns. Turtles exhibit active feeding and rapid weight gain during seasons with suitable temperatures, whereas growth slows during colder periods, limiting the effective growing season throughout the year. In contrast, intensive greenhouse culture maintains relatively stable temperatures and feed availability, thereby extending the feeding period and improving growth efficiency per unit time. Zhang et al. (2017) reported that modern greenhouse culture systems incorporating artificial heating, underwater feeding platforms, and centralized waste removal achieved a production yield of 23.7 kg/m², indicating that effective environmental regulation can support highly efficient production. Qi et al. (2025) compared greenhouse, pond, and rice-paddy culture models and found that, after approximately 120 days of cultivation, turtles exhibited distinct differences in morphology, organ characteristics, and nutritional composition among the three models, suggesting that growth-related phenotypic traits can respond to changes in culture environments (Figure 1).

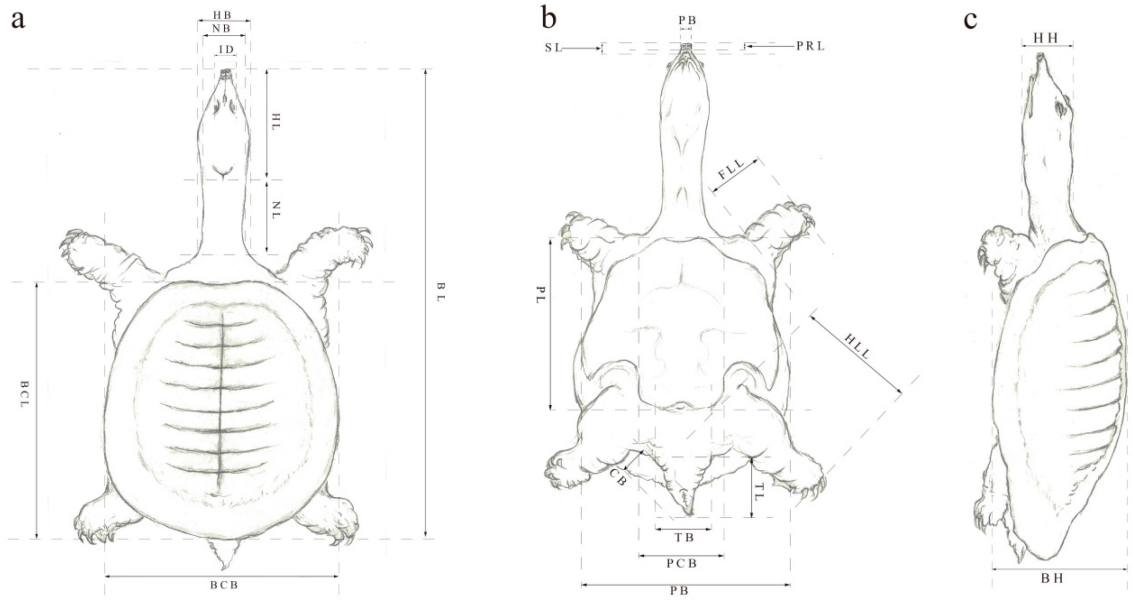

Figure 1 Schematic diagram of morphological indexes of *P. sinensis* (Adopted from Qi et al., 2025)
Image caption: (a) Indexes on back, (b) indexes on plastron, (c) indexes on flank

The effects of different culture models on growth rate are also closely associated with stocking density, natural food availability, and feeding management. Although greenhouse culture can provide favorable temperature conditions, feeding competition under high stocking densities may intensify, potentially increasing individual

variation in growth. Pond culture and rice-turtle co-culture systems provide relatively abundant space for movement, but growth performance may be constrained by natural environmental fluctuations and food availability. Wu et al. (2024b) found that Chinese soft-shelled turtles exhibited differences in growth performance and physiological responses under different culture models. Ecological culture environments facilitated the expression of natural behaviors, but insufficient natural food availability could restrict body weight gain. Zhao et al. (2020) reported that the specific growth rates and body weight gains of turtles in the TR6, TR8, and TR10 treatments of a rice-turtle co-culture system were significantly higher than those in turtle monoculture, indicating that appropriate ecological configurations can also improve growth performance. Further research showed that increasing the feeding level from 0.7% to 1.4% of body weight in rice-turtle co-culture increased the specific growth rate, whereas a further increase to 2.1% produced no additional improvement (Wu et al., 2024a). Therefore, when evaluating the growth advantages of different culture models, indicators such as weight gain rate, specific growth rate, and individual body size should be considered together with stocking density and nutritional supply, rather than relying solely on final body weight.

3.2 Survival rate and market-size development

Survival rate is an important indicator of the stability and management effectiveness of Chinese soft-shelled turtle culture systems and is also a key determinant of final production yield and economic returns. Under different culture models, turtles experience varying degrees of environmental stress, disease risk, and management conditions, which subsequently affect population survival. Conventional pond culture generally provides relatively large aquatic spaces, helping to reduce physical contact among individuals and disturbances caused by localized crowding. However, sudden temperature changes, water quality fluctuations, and pathogen accumulation may still adversely affect survival. Intensive greenhouse culture can reduce the effects of seasonal temperature fluctuations, but higher stocking densities may increase the risks of physical injury and disease transmission. Wang et al. (2026a) compared intensive pond monoculture with rice-turtle co-culture and reported survival rates of 89.42% and 95%, respectively, indicating higher population survival under rice-turtle co-culture. Zhao et al. (2020) also found that, at appropriate stocking densities, certain treatments in rice-turtle co-culture systems exhibited significantly lower mortality rates than turtle monoculture. These findings suggest that suitable ecological configurations can help reduce culture-related risks. Nevertheless, survival rates under different culture models remain dependent on seedstock quality, stocking density, and disease prevention practices, and no single culture model can be considered consistently superior under all conditions.

The development of marketable size depends not only on individual growth rate but also on population growth uniformity and the time required to reach the target market weight. By maintaining suitable temperatures and standardized feeding practices, greenhouse culture can promote faster attainment of market weight. However, differences in feeding ability among individuals under high-density conditions may lead to greater variation in body size. Growth in pond and rice-paddy culture systems is more strongly influenced by natural temperature fluctuations, and reaching marketable size generally requires a longer period. Nevertheless, appropriate stocking density management, size grading, and balanced feeding can improve size uniformity. Zhou et al. (2025b) indicated that Chinese soft-shelled turtles generally require 2-3 years to reach marketable size, highlighting the importance of shortening the grow-out period to improve production efficiency. Qi et al. (2025) also demonstrated that turtles reared in greenhouses, ponds, and rice paddies differed in body morphology and the composition of edible portions, providing a reference for production strategies that combine greenhouse rearing with ecological grow-out. Therefore, the evaluation of market-size development should consider the proportion of turtles reaching target market weight, population size uniformity, and culture duration to improve marketing efficiency while maintaining stable commercial production.

3.3 Feed utilization efficiency and culture cycle

Feed utilization efficiency is directly related to the growth performance and production costs of Chinese soft-shelled turtles and serves as an important indicator for evaluating the economic performance of different culture models. The feed conversion ratio (FCR) reflects the relationship between feed input and biomass gain,

with lower values generally indicating less formulated feed consumed per unit of weight gain. Intensive greenhouse culture maintains relatively stable temperatures and regular feeding schedules, supporting continuous feed intake. However, excessive feeding intensity may result in residual feed accumulation and feed wastage. Feed utilization efficiency in conventional pond culture is influenced by both seasonal water temperature variations and the availability of natural food resources. Ecological culture and rice-turtle co-culture systems can utilize natural food resources in rice paddies, potentially reducing the requirement for formulated feeds under suitable conditions. Wang et al. (2026b) reported that the FCR in rice-turtle co-culture was (2.80±0.27), lower than the (3.07±0.29) observed in intensive pond monoculture, indicating more favorable formulated-feed utilization under the conditions of that study. Wu et al. (2024a) further found that, within a rice-turtle co-culture system, the FCR increased progressively as feeding levels rose from 0.7% to 2.1% of body weight, while a feeding level of 1.4% provided a favorable balance between growth performance and feed input efficiency. These findings indicate that improvements in feed utilization efficiency depend not only on the culture model but also on feeding intensity and the utilization of natural food resources.

The culture cycle is an important factor influencing capital turnover and production planning in Chinese soft-shelled turtle farming. Its duration is primarily determined by the effective growing season, initial stocking size, dietary nutrition, and target market weight. Conventional pond culture is constrained by natural temperature fluctuations, with reduced feeding activity during colder seasons, generally resulting in a longer period before turtles reach marketable size. Intensive greenhouse culture can extend the effective growing season and potentially shorten the grow-out period, although continuous heating and facility operation also increase production costs. Zhang et al. (2017) reported that improvements in greenhouse heating and culture facilities resulted in high production yields per unit area and a low FCR over a 10-month culture period, demonstrating the potential of engineered management systems to improve production efficiency per unit time. Meanwhile, stage-specific culture can combine the advantages of early greenhouse rearing with subsequent pond or rice-paddy grow-out, promoting early growth while improving environmental conditions during later production stages. Previous studies have shown that appropriate adjustments to dietary protein, phosphorus, and methionine levels, together with the use of suitable fishmeal substitutes or functional feed additives, can improve growth performance and nutrient utilization efficiency in Chinese soft-shelled turtles (Kou et al., 2021; Qiu et al., 2023). Therefore, optimization of the culture cycle should not focus solely on accelerating market readiness but should also consider feed consumption, survival rate, production costs, and marketable size to achieve a balance between growth efficiency and economic returns.

4 Effects of Different Culture Models on the Health and Product Quality of Chinese Soft-Shelled Turtles

4.1 Culture environment and physiological stress responses

The culture environment is an important external factor affecting the health status of Chinese soft-shelled turtles (Pelodiscus sinensis). Different culture models influence physiological stress responses by altering water temperature, water quality, available space, and the degree of human disturbance. As ectothermic animals, Chinese soft-shelled turtles are particularly sensitive to environmental changes. Sharp fluctuations in water temperature, deterioration of water quality, or excessive stocking densities may induce physiological stress, manifested as reduced feed intake, abnormal behavior, and slower growth. Conventional pond culture is primarily influenced by natural environmental conditions, with pronounced seasonal variations in water temperature and quality, while extreme weather events may cause short-term stress. Although intensive greenhouse culture can maintain relatively stable temperatures, high stocking densities and the accumulation of metabolic wastes may increase the risk of chronic stress. Ding et al. (2025) found that acute ammonia stress induced hepatocyte swelling and vacuolization in Chinese soft-shelled turtles and activated hepatic antioxidant defense systems. Feng et al. (2021) further demonstrated that nitrite stress reduced hemoglobin levels, increased the proportion of methemoglobin, impaired blood oxygen-carrying capacity, and induced lipid peroxidation and hepatocyte apoptosis. These findings indicate that aquatic pollutants not only affect the external culture environment but may also compromise turtle health by disrupting metabolism and redox homeostasis.

Stress levels under different culture models are also associated with the behavioral requirements and environmental adaptability of Chinese soft-shelled turtles. These turtles exhibit burying, basking, and certain territorial behaviors, and sufficient space and suitable shelters help maintain normal activity patterns. Wu et al. (2024b) reported that rice-turtle co-culture provided a more diverse environment for movement and foraging and improved certain antioxidant and physiological health indicators. However, insufficient natural food availability may increase energy expenditure and metabolic demands. Furthermore, ecological culture cannot completely eliminate environmental stress. Chen et al. (2025) found that combined exposure to heatwaves and bacterial infection altered the physiological status and immune cell gene expression of Chinese soft-shelled turtles while suppressing the expression of certain antioxidant enzymes and immune-related genes. In greenhouse culture, stress can be reduced by optimizing lighting conditions, appropriately dividing culture areas, and minimizing unnecessary handling and capture. Li et al. (2024) found that, compared with high-intensity illumination, appropriately low-intensity basking light reduced cortisol and malondialdehyde levels while improving growth performance and immune-related parameters. Therefore, management practices should be tailored to the environmental characteristics of each culture model, with feeding behavior, blood biochemical parameters, and antioxidant status monitored to facilitate the timely identification of adverse environmental conditions.

4.2 Immune function and disease risk

Immune function provides an essential physiological basis for Chinese soft-shelled turtles to resist pathogen invasion and maintain normal growth. It is closely associated with culture conditions, nutritional supply, and individual stress levels. Prolonged exposure to unsuitable water temperatures, elevated ammonia nitrogen concentrations, or high stocking densities may disrupt immune regulation and increase susceptibility to pathogenic infections. Conventional pond culture involves relatively open aquatic environments with diverse potential sources of pathogenic microorganisms, while water quality fluctuations and substrate contamination may increase disease risk. Although intensive greenhouse culture facilitates centralized management, frequent contact among individuals may accelerate disease transmission once pathogens enter the culture system. Feng et al. (2021) found that nitrite stress reduced serum lysozyme levels and altered complement activity and interleukin-6 (IL-6)-related immune responses in Chinese soft-shelled turtles, indicating that water pollution can directly interfere with host immune defenses. In a stocking density experiment involving juvenile turtles, Chen et al. (2007) observed that increasing stocking density elevated the heterophil-to-lymphocyte ratio and reduced growth rates, while certain nonspecific immune indicators increased. These findings suggest that immune responses to crowding stress do not necessarily involve generalized immunosuppression but may reflect a trade-off in energy allocation between growth and immune defense. Therefore, disease risk under different culture models depends not only on pathogen exposure but also on environmental stress, host immune status, and management practices.

Under different culture conditions, the immune status of Chinese soft-shelled turtles can be assessed using indicators such as serum lysozyme activity, complement activity, antioxidant enzyme activity, and inflammation-related parameters. Suitable environmental conditions and balanced nutrition contribute to normal immune function, whereas prolonged stress may disrupt immune regulation and antioxidant homeostasis, thereby weakening the ability to resist pathogenic infections. By improving habitat conditions and microbial community structure, ecological culture may reduce disease pressure under certain circumstances. Ye et al. (2026) found that, compared with conventional monoculture, lotus-turtle co-culture improved the stability of intestinal and environmental microbial communities and promoted the overall health of cultured turtles. Related studies have also demonstrated that supplementation with a Chinese herbal medicine mixture increased immune-related indicators, including lysozyme, complement C3, and acid phosphatase activities, and improved post-infection survival (Lan et al., 2024). Dietary D-glucuronolactone supplementation also enhanced antioxidant capacity and resistance to Aeromonas hydrophila infection. Nevertheless, ecological culture does not necessarily guarantee a lower disease risk, as its actual effectiveness remains influenced by climatic conditions, stocking density, and daily management. Accordingly, disease prevention strategies should be adapted to the specific risks of different culture models, with strengthened seedstock quarantine, water quality monitoring, appropriate feeding, and pathogen control to establish a preventive health management system.

4.3 Differences in product quality and nutritional composition

Product quality is an important indicator of the overall benefits of Chinese soft-shelled turtle culture and is influenced by multiple factors, including culture environment, dietary composition, developmental stage, and activity level. Different culture models affect muscle nutritional composition, tissue structure, and edible quality by altering food sources, energy allocation, and physiological status. Intensive greenhouse culture provides a stable feed supply and controllable growth conditions, facilitating rapid growth and the attainment of marketable size. However, relatively restricted movement and higher feeding intensity may alter nutrient deposition in body tissues. In contrast, pond culture and rice-turtle co-culture provide more diverse environmental structures and food sources, potentially resulting in different tissue compositions and nutritional characteristics. Qi et al. (2025) compared greenhouse, pond, and rice-paddy culture models and found that greenhouse-cultured turtles exhibited higher relative proportions of liver, viscera, and internal fat, whereas pond- and rice-paddy-cultured turtles had higher proportions of carapace, calipash, and edible parts. Regarding muscle nutritional composition, crude protein, total amino acids, essential amino acids, flavor-related amino acids, collagen, and EPA+DHA contents were significantly higher in the pond and rice-paddy groups than in the greenhouse group. Conversely, the greenhouse group exhibited higher crude fat content and higher values for certain unsaturated fatty acid indicators. These findings indicate that different culture models influence nutrient accumulation in distinct ways, and product quality cannot be evaluated solely on the basis of growth rate or fat content.

The product quality of Chinese soft-shelled turtles is also influenced by health status, age, and tissue type, suggesting that culture models and physiological conditions may exert combined effects. Yang et al. (2026) compared greenhouse-cultured Chinese soft-shelled turtles and found that healthy individuals generally exhibited better intestinal tissue integrity, antioxidant capacity, and muscle nutritional composition than diseased individuals. Adult turtles also showed certain advantages in crude protein, essential amino acid, and flavor-related amino acid contents. Hou et al. (2024) investigated pond-cultured male Chinese soft-shelled turtles of different ages and demonstrated age-related differences in muscle nutritional composition and flavor characteristics. Five-year-old turtles exhibited particularly favorable flavor-related amino acid profiles and volatile flavor characteristics, whereas six-year-old turtles showed higher levels of certain amino acids and EPA+DHA.

Therefore, evaluations of Chinese soft-shelled turtle product quality should comprehensively consider protein, fat, amino acid and fatty acid composition, and muscle texture, while controlling potential confounding factors such as sex, age, dietary composition, and culture duration whenever possible. Overall, ecological culture models, including pond and rice-paddy culture, exhibit certain advantages in selected nutritional indicators and the proportion of edible parts, whereas greenhouse culture facilitates relatively high production efficiency. In commercial production, appropriate culture models should be selected according to market demands for product size, texture, and nutritional quality. Optimizing nutritional supply and environmental management can help achieve a balance between growth efficiency and product quality.

5 Comparison of Economic Benefits Among Different Culture Models

5.1 Production Inputs and Culture Costs

Production inputs and culture costs provide an essential basis for evaluating the economic benefits of different culture models for Chinese soft-shelled turtles (Pelodiscus sinensis). These costs mainly include seedstock, feed, infrastructure construction, labor and management, water and electricity consumption, energy supply, and disease prevention and control. Different culture models vary in facility configuration, environmental control, and resource utilization, resulting in distinct cost structures (He and Zhang, 2018; Zhu et al., 2024). Conventional pond culture generally utilizes existing water bodies and requires relatively low infrastructure and energy inputs. However, natural environmental conditions and longer culture cycles may increase land occupation costs, labor requirements, and capital turnover costs. Intensive greenhouse culture maintains stable growth conditions through heating, aeration, and water quality regulation facilities, thereby improving facility utilization efficiency, but it requires substantial initial investment and continuous operating expenses. Wang et al. (2026a) compared intensive pond monoculture with rice-turtle co-culture and found that the former required more extensive infrastructure,

including concrete ponds, roads, and water supply and drainage facilities, resulting in significantly higher initial investment than rice-turtle co-culture systems, which mainly required modifications to peripheral ditches and improvements to field irrigation and drainage facilities (Figure 2). The major cost components also differed between the two models. Seedstock, feed, and facility depreciation were the primary expenses in intensive pond culture, whereas land rental costs also needed to be considered in rice-turtle co-culture. Therefore, cost comparisons among different culture models should consider not only direct production inputs but also facility depreciation, land costs, and culture duration.

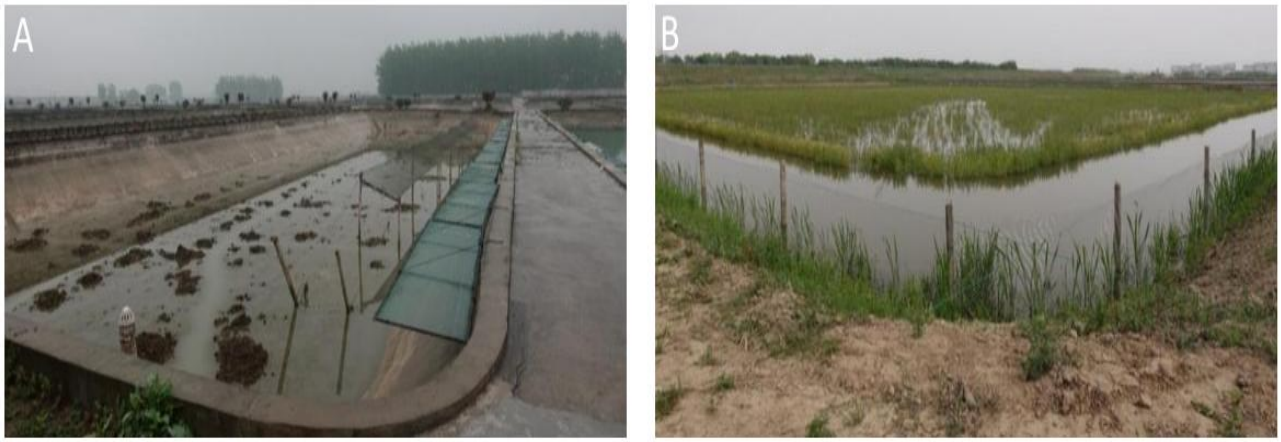

Figure 2 The photo of intensive pond monocultural base (A) and rice- *P. sinensis* co-culture base (B) (Adopted from Qi et al., 2025)

Feed costs are an important determinant of economic returns in Chinese soft-shelled turtle culture and are closely associated with natural food availability, feed utilization efficiency, and feeding management. High-density culture generally relies heavily on formulated feeds. Inappropriate feeding practices may not only cause feed wastage but also deteriorate water quality, further increasing environmental management and disease prevention costs. Ecological culture and rice-turtle co-culture systems can utilize natural food resources and potentially reduce formulated feed inputs under suitable conditions. Using stable isotope analysis, Guo et al. (2022) found that natural food resources in rice fields contributed 16.0%-50.2% of the diets of aquatic animals in integrated rice-aquatic animal farming systems, indicating the potential of integrated culture to reduce dependence on external feed inputs through ecological resource utilization. Wu et al. (2024b) further reported that increasing the feeding level from 0.7% to 1.4% of turtle body weight improved growth performance in rice-turtle co-culture systems. However, a further increase to 2.1% did not produce additional improvements in growth rate and instead increased the feed conversion ratio. These findings indicate that excessive feeding does not necessarily increase economic returns. Rather, appropriate control of feed inputs and improved nutrient utilization efficiency are essential for reducing culture costs. Cost optimization under different culture models should therefore consider seedstock size, feed prices, management technologies, and local resource availability instead of focusing solely on reducing individual expenditure items.

5.2 Yield per unit area and commercial returns

Yield per unit area is an important indicator of space utilization efficiency and production capacity in Chinese soft-shelled turtle culture. It is primarily influenced by stocking density, growth rate, survival rate, and culture duration. Intensive greenhouse culture generally increases production intensity through artificial temperature regulation, continuous feeding, and high-density management, thereby facilitating higher marketable turtle yields per unit area. Zhang et al. (2017) reported that a modern greenhouse culture system equipped with a ground-source heat pump, underwater feeding platforms, and a central drainage system achieved a yield of 23.7 kg/m², a survival rate of 86%, and a feed conversion ratio of 1.26, together with favorable economic returns. These findings demonstrate that engineered environmental regulation can support large-scale production. Intensive pond culture can also increase yield per unit area by raising stocking density. However, excessive stocking may intensify feeding competition and increase the risks of disease outbreaks and water quality

deterioration, thereby reducing survival rates and market-size uniformity. Wang et al. (2026b) found that intensive pond monoculture had a feed conversion ratio of 3.07 ± 0.29 and a survival rate of 89.42%, whereas the corresponding values in rice-turtle co-culture were 2.80 ± 0.27 and 95.00%, respectively. These results indicate that higher production intensity does not necessarily lead to better feed utilization or population survival. Therefore, assessments of yield per unit area should consider actual harvest weight, marketable size, and effective culture duration rather than evaluating production efficiency solely on the basis of stocking numbers.

Commercial returns depend not only on turtle yield but also on marketable size, product quality, and market prices. Greenhouse culture can improve the continuity of market supply by shortening the production cycle, but whether higher yields translate into greater profits still depends on selling prices and cost control. Although pond and ecological culture generally require longer production periods, product quality differences may generate price premiums under certain market conditions. Rice-turtle co-culture can also produce both rice and turtles, thereby improving overall land productivity. Through four consecutive years of field experiments, Guo et al. (2022) found that average rice yield in rice-turtle co-culture systems increased by 8.69% compared with rice monoculture, while the average annual turtle yield reached 2.66 t/ha. These results indicate that integrated culture can increase aquatic animal production while maintaining rice productivity. Zhang et al. (2016) similarly demonstrated that rice-turtle co-culture could produce Chinese soft-shelled turtles without significantly reducing rice yield. Wang et al. (2026a) further reported that the increased net returns from rice-turtle co-culture were primarily attributable to additional revenue from turtle sales rather than solely to improvements in rice yield. Collectively, these findings suggest that the economic advantages of integrated culture mainly arise from comprehensive land utilization and multiple product revenue streams. Therefore, evaluations of commercial returns should consider the yields, selling prices, and production costs of both turtles and rice, rather than assessing the economic advantages of a culture model solely on the basis of turtle yield.

5.3 Input-output ratio and overall economic benefits

The input-output ratio and net profit comprehensively reflect the relationship between financial investment and economic returns in Chinese soft-shelled turtle culture and are important indicators for evaluating the profitability of different culture models. Although intensive greenhouse culture offers advantages such as rapid growth, relatively high yields per unit area, and shorter production cycles, facility depreciation, energy consumption, and high-density management costs may reduce profit margins. Conventional pond culture generally requires lower fixed infrastructure investment, but longer culture cycles, prolonged capital occupation, and environmental fluctuations may affect actual returns. Ecological culture places greater emphasis on integrated resource utilization and production cost control, with its economic advantages largely determined by culture technologies, market conditions, and resource allocation efficiency. Liu et al. (2019) conducted an energy analysis and economic assessment of a rice-turtle-fish co-culture system and reported an energy output-input ratio of 5.17 and a net profit of CNY 98,729.96/ha, indicating that integrated culture can provide advantages in both economic performance and resource utilization. Through a meta-analysis of 224 studies on integrated rice-aquatic animal farming, Yu et al. (2023) found that integrated culture systems increased net ecological and economic benefits by 31.7%-71.1% compared with rice monoculture, while also improving soil fertility and reducing certain agricultural environmental pressures. However, these findings encompass various types of integrated rice farming systems and cannot be directly interpreted as benefits attributable exclusively to rice-turtle co-culture. Therefore, economic evaluations of different culture models should account for specific production conditions and adopt consistent cost accounting boundaries and operating periods to avoid misleading comparisons of economic returns across independent studies.

Comprehensive assessments of economic benefits should also consider production risks, resource utilization, and operational stability. Wang et al. (2026b) compared intensive pond monoculture with rice-turtle co-culture and found that both systems demonstrated a certain degree of economic feasibility. However, intensive pond culture required greater initial capital investment, with an estimated investment payback period of approximately 4.7 years, making it more suitable for large-scale producers with sufficient financial resources and strong technical

management capabilities. In contrast, rice-turtle co-culture required relatively lower infrastructure investment and imposed less pressure on environmental management, potentially providing an alternative production option for small- and medium-scale aquaculture operations when stable marketing channels are available.

Furthermore, conventional pond culture can improve production benefits through ecological modifications. Li et al. (2016) found that introducing floating beds planted with water spinach (Ipomoea aquatica) into Chinese soft-shelled turtle ponds improved water quality and increased turtle survival, yield, and net returns. These findings indicate that improvements in production efficiency and economic performance do not necessarily depend on increasing stocking density or infrastructure investment. Overall, the selection of Chinese soft-shelled turtle culture models should comprehensively consider investment scale, production costs, net profit, capital payback period, and operational risks. Production strategies should also be optimized according to regional climatic conditions, land resources, and market demand to achieve coordinated improvements in growth efficiency, economic returns, and operational stability.

6 Ecological Benefits and Sustainability of Different Culture Models

6.1 Water Resource Utilization and Aquaculture Effluent Discharge

Water resource utilization efficiency is an important indicator for evaluating the ecological benefits of different culture models for Chinese soft-shelled turtles (Pelodiscus sinensis). Different culture systems exhibit significant differences in water circulation, nutrient transformation, and aquaculture effluent discharge. Conventional pond culture primarily relies on natural water bodies and generally involves relatively large water volumes with a certain degree of self-purification capacity. However, the continuous accumulation of residual feed, excreta, and organic matter in bottom sediments during long-term culture can lead to the enrichment of nutrients such as nitrogen and phosphorus. Frequent water exchange or the direct discharge of untreated aquaculture effluent may increase pollutant loads in surrounding aquatic environments. Intensive greenhouse culture is characterized by high production intensity and relatively concentrated rearing spaces, resulting in greater nutrient loads per unit area of culture water and higher demands for water quality regulation and effluent treatment. Through long-term field investigations and comparative experiments, Zhang et al. (2016) found that, under equivalent nutrient inputs, nitrogen and phosphorus concentrations in turtle monoculture systems were significantly higher than those in rice-turtle co-culture systems. In turtle monoculture, only 20.4% of dietary nitrogen and 22.8% of dietary phosphorus were utilized by the turtles, while most of the remaining nutrients entered the culture environment. In contrast, rice-turtle co-culture systems enabled rice plants to absorb and utilize part of the residual nutrients, thereby reducing nitrogen and phosphorus accumulation in water and soil. These findings indicate that the ecological differences among culture models depend not only on nutrient input levels but also on nutrient recycling and utilization pathways.

Water resource utilization efficiency under different culture models is also influenced by water quality regulation technologies and ecological purification measures. In conventional pond culture, controlling feed inputs, removing accumulated sediments in a timely manner, and incorporating aquatic plants can reduce the accumulation of organic matter and nutrients. Intensive greenhouse culture can improve water reuse through centralized waste removal, sedimentation, filtration, and biological purification technologies. However, the actual water-saving performance and pollutant removal efficiency of these measures still require evaluation using monitoring data. Li et al. (2016) introduced floating beds planted with water spinach (Ipomoea aquatica) into Chinese soft-shelled turtle ponds and conducted a 122-day culture experiment. Compared with the control group without floating beds, the treatment group exhibited reductions of 27.9% and 42.5% in total nitrogen and total phosphorus concentrations, respectively, together with significant decreases in total ammonia nitrogen, chlorophyll a concentration, and turbidity. These results demonstrate the potential of plant-assisted purification to improve aquaculture water quality. Guo et al. (2022) further found that rice plants absorbed and utilized 13.0%-35.1% of feed-derived nitrogen in integrated rice-aquatic animal farming systems, reflecting nutrient complementarity between crops and cultured animals. Therefore, water resource management should not focus solely on reducing water exchange frequency but should also consider water quality stability, nutrient fate, and

actual pollutant discharge. Optimizing water circulation and effluent treatment measures can improve resource utilization efficiency throughout the culture process.

6.2 Ecological effects of integrated culture systems

Integrated culture systems combine Chinese soft-shelled turtle farming with crop production or aquatic ecosystems to establish diversified production systems capable of recycling nutrients. Rice-turtle co-culture is a representative example. As Chinese soft-shelled turtles move, feed, and excrete within rice paddies, their metabolic wastes undergo microbial decomposition and transformation, allowing some nutrients to be absorbed and utilized by rice plants. Meanwhile, rice paddies provide turtles with shelter and natural food resources, thereby promoting the integrated utilization of land, water, and nutrients. Ji et al. (2023) and Ge et al. (2023a) reported that integrated rice-aquatic animal farming systems facilitate nutrient cycling, organic matter decomposition, and improvements in agricultural ecosystem functions through species complementarity and ecological interactions. Using stable isotope techniques, Guo et al. (2022) found that 16.0~50.2% of the food consumed by aquatic animals in integrated culture systems originated from natural organisms in rice fields, while rice plants absorbed a proportion of feed-derived nitrogen. These findings demonstrate clear resource complementarity between crops and cultured animals. For Chinese soft-shelled turtles, such ecological interactions can improve nutrient utilization within the culture system while increasing aquatic animal production. Nevertheless, the actual benefits remain influenced by field conditions, stocking density, and artificial feeding levels.

The ecological value of integrated culture systems is also reflected in soil fertility, biological community structure, and greenhouse gas emissions. Wu et al. (2021b) found that rice-turtle co-culture maintained relatively stable soil pH and organic matter content, whereas these indicators declined over time in conventional rice paddies. Turtle stocking density also influenced soil microbial community structure. Zhao et al. (2020) demonstrated that appropriate stocking densities improved nitrogen and phosphorus utilization efficiency and aquatic environmental conditions in rice-turtle co-culture systems. Further regional studies have indicated that integrated rice farming systems may also reduce greenhouse gas emissions under certain conditions. Through a meta-analysis of 4,707 observations from 224 publications, Yu et al. (2023) found that methane emissions from various integrated rice-aquatic animal farming systems decreased by an average of 14.8% compared with rice monoculture, with a reduction of 22.1% in East Asia. However, these findings involved multiple crop-animal combinations and cannot be directly interpreted as effects attributable exclusively to rice-turtle co-culture. Empirical research specifically examining rice-turtle co-culture revealed different greenhouse gas emission responses between two experimental farms. Total emissions decreased by 27.7% at one farm, whereas no significant change was observed at the other, indicating that the climate-related benefits of integrated culture depend on field water management and production inputs (Wang et al., 2026a). Therefore, the ecological advantages of integrated culture systems should be comprehensively evaluated using indicators related to soil, water, biological communities, and greenhouse gas emissions, rather than simply assuming that ecological culture necessarily results in lower pollution or emissions.

6.3 Coordination between culture efficiency and environmental carrying capacity

Achieving an appropriate balance between culture efficiency and environmental carrying capacity is essential for the sustainable development of Chinese soft-shelled turtle aquaculture. Conventional production practices often prioritize increasing stocking density and yield per unit area. However, when production intensity exceeds the self-purification capacity of the water body and the carrying capacity of the ecosystem, the accumulation of residual feed and excreta may accelerate water quality deterioration, increase disease risks, and raise environmental management costs. Although intensive greenhouse culture can improve growth efficiency through artificial environmental regulation, higher production intensity also places greater demands on water purification and waste treatment capacity. Pond and ecological culture systems possess certain advantages in natural environmental regulation, but their carrying capacities remain constrained by water volume, substrate conditions, and biological community composition. Bashir et al. (2020) emphasized that the sustainability of integrated rice-aquatic animal farming depends on resource complementarity between crops and cultured animals and the

implementation of appropriate management practices, rather than simply increasing stocking numbers. Zhu et al. (2024) further indicated that field conditions, supplementary feeding, aquaculture management, and rice cultivation practices jointly determine the production performance of integrated culture systems, while excessive production loads may undermine ecological benefits. Therefore, culture efficiency should not be evaluated solely on the basis of yield per unit area. Resource inputs, pollutant emissions, and environmental stability should also be considered to ensure that production intensity remains within the actual assimilative capacity of the ecosystem.

Coordinating culture efficiency with environmental carrying capacity requires the integration of appropriate stocking density management, precision feeding, and ecological environmental management. Zhao et al. (2020) evaluated stocking densities of 6, 8, 10, and 12 turtles/m² in a rice-turtle co-culture system and found that turtle yield increased with stocking density, reaching (1 297.51±106.31) g/m² in the treatment stocked at 10 turtles/m². In addition, the relevant treatment groups exhibited better nitrogen and phosphorus utilization efficiency and aquatic environmental performance than the turtle monoculture control, indicating that appropriate stocking densities can help balance production efficiency and environmental protection. However, these results are applicable only to the specific experimental conditions investigated. Wu et al. (2024b) further found that increasing the feeding level from 0.7% to 1.4% of turtle body weight improved the specific growth rate, whereas a further increase to 2.1% did not enhance growth and instead increased the feed conversion ratio. These findings suggest that excessive feeding may increase resource consumption and environmental burdens. In addition to stocking density and feeding regulation, measures such as lotus cultivation, ecological floating beds, and improvements to pond substrates can enhance the ecological regulation capacity of culture environments (Tang et al., 2009; Li et al., 2016; Ye et al., 2026). Therefore, future management strategies should be adapted to regional climatic conditions, water resources, and aquaculture infrastructure. Greater emphasis should be placed on water quality monitoring and nutrient mass balance assessments, together with comprehensive evaluations of water consumption per unit yield, nitrogen and phosphorus discharge intensity, and energy consumption. Such approaches can facilitate the transition of Chinese soft-shelled turtle aquaculture from a production model focused primarily on maximizing yield toward more resource-efficient and environmentally sustainable farming systems.

7 Optimization of Chinese Soft-Shelled Turtle Culture Models and Strategies for Improving Growth Performance and Production Benefits

7.1 Stage-specific culture and appropriate stocking density management

Stage-specific culture is an important strategy for improving the growth efficiency and resource utilization of Chinese soft-shelled turtles (*Pelodiscus sinensis*). Its core principle is to select suitable culture conditions and management practices according to the physiological characteristics and environmental requirements of turtles at different developmental stages. Chinese soft-shelled turtles differ in feeding capacity, growth rate, and environmental adaptability during the hatchling, juvenile, and adult stages. Maintaining a uniform culture model throughout the production cycle may therefore limit the growth potential of individual developmental stages. Zhou et al. (2025a) conducted integrated transcriptomic and metabolomic analyses and identified differences in physiological processes, including fatty acid synthesis, amino acid metabolism, and the urea cycle, among turtles at different growth stages, indicating that nutritional metabolism is closely associated with individual development. Hatchlings and juveniles are relatively sensitive to water temperature fluctuations and environmental disturbances. Greenhouse rearing can maintain stable growth conditions and improve early survival and growth efficiency. Zhang et al. (2017) reported that a modern greenhouse culture system incorporating artificial temperature regulation, three-dimensional shelters, underwater feeding platforms, and centralized waste removal achieved a survival rate of 86% and a feed conversion ratio of 1.26, demonstrating that effective engineering-based management can support juvenile turtle growth. Once turtles reach an appropriate size and external environmental conditions become stable, they may be transferred to ponds or ecological culture systems to utilize natural water bodies and food resources, thereby reducing certain operating costs. Combining early greenhouse rearing with subsequent outdoor pond culture may help balance early growth efficiency and later production costs. However, temperature differences should be carefully controlled during transfer, transportation and handling disturbances should be minimized, and turtles should be gradually acclimated to the new environment to reduce stress.

Appropriate stocking density management is essential for ensuring the effectiveness of stage-specific culture. Chinese soft-shelled turtles of different sizes have varying requirements for movement space and aquatic environmental conditions. Stocking density should therefore be dynamically adjusted as individuals grow and total population biomass increases. Although high-density culture can increase the initial number of turtles stocked per unit area, excessive crowding may intensify feeding competition, physical injuries, and water pollution, thereby reducing survival rates and market-size uniformity. Chen et al. (2007) found that increasing juvenile turtle stocking density reduced the specific growth rate while increasing the heterophil-to-lymphocyte ratio, suggesting that crowding may induce physiological stress. An energy budget study by Jing and Niu (2008) also found that juvenile turtles maintained at lower stocking densities exhibited higher feed intake and faster growth. Conversely, Zhao et al. (2020) demonstrated that moderately increasing stocking density in rice-turtle co-culture systems could improve yield per unit area. The treatment stocked at 10 turtles/m² achieved a yield of 1,297.51 ± 106.31 g/m², together with favorable growth performance and nitrogen and phosphorus utilization efficiency. Wang et al. (2026a) further reported that rice-turtle co-culture systems could reduce interference among individuals and improve survival by adopting lower stocking densities, providing more shelter, and utilizing natural food resources. Therefore, practical stocking density management should comprehensively consider pond area, water depth, individual body size, and water quality regulation capacity. Regular weight sampling, timely grading and separation, and optimization of feeding areas should be implemented to dynamically adjust stocking densities and maintain an appropriate balance between space utilization efficiency and environmental carrying capacity.

7.2 Precision nutrition and aquatic environmental management

Precision nutrition is an important approach to improving feed utilization efficiency and reducing production costs in Chinese soft-shelled turtle culture. Its primary objective is to match dietary nutrient composition with the physiological requirements of turtles at different developmental stages rather than simply increasing feed inputs. Hatchlings grow rapidly and have relatively high requirements for feed palatability, protein, and mineral supply, making balanced nutrition and feed quality particularly important. During the juvenile and adult stages, nutrient levels should be adjusted according to individual body size, feeding behavior, and growth performance. Kou et al. (2022) evaluated diets containing different protein levels and found that increasing dietary protein from 14.38% to 26.19% improved the specific growth rate and several hematological and immune parameters, whereas further increases produced little additional improvement. Broken-line regression analysis based on the specific growth rate estimated an appropriate dietary protein level of 27.11%. Wang et al. (2022) further found that juvenile turtles fed diets containing 1.00% available phosphorus exhibited favorable final body weight, specific growth rate, and phosphorus retention, while regression analysis estimated an appropriate available phosphorus level of approximately 1.04%. Excessive phosphorus supplementation reduced phosphorus utilization efficiency and increased phosphorus losses. These findings indicate that optimizing dietary nutrient composition can not only promote growth but also reduce the environmental burden associated with excessive nutrient inputs.

Aquatic environmental management is closely associated with precision nutrition, and together they determine growth efficiency and production stability in Chinese soft-shelled turtle culture. Inappropriate feeding practices can cause the accumulation of residual feed and nitrogenous metabolic wastes, affecting ammonia nitrogen, nitrite, and other water quality parameters. Kou et al. (2022) found that, under the same feeding regime, increasing dietary protein levels elevated total ammonia nitrogen and total nitrogen concentrations in culture water, indicating a direct relationship between dietary nutrient levels and aquatic environmental loading. Wu et al. (2024a) reported that increasing the feeding level from 0.7% to 1.4% of turtle body weight in rice-turtle co-culture systems improved the specific growth rate, whereas a further increase to 2.1% did not enhance growth. Meanwhile, the feed conversion ratio increased with feeding level, suggesting that excessive feeding may simultaneously reduce feed utilization efficiency and ecological benefits. In addition to conventional nutritional regulation, functional feed additives also have potential applications. Ge et al. (2023b) found that supplementation with 0.02% sodium butyrate increased weight gain and specific growth rates while improving certain immune and intestinal microbial indicators. Fu et al. (2023) demonstrated that appropriate levels of chito-oligosaccharides and

β-glucan improved intestinal morphology, nonspecific immune responses, and certain muscle nutritional indicators, while also exerting beneficial effects on water quality in rice-paddy culture environments. Therefore, Chinese soft-shelled turtle farming should establish a dynamic management system based on feed intake, body weight gain, feed conversion ratio, and water quality indicators. Appropriate water exchange, bottom waste removal, microbial regulation, and biological filtration should be implemented according to the characteristics of different culture models. The gradual integration of automated feeding and water quality monitoring technologies could further improve coordination between nutritional supply and aquatic environmental management.

7.3 Ecological culture and improvement of overall production benefits

Ecological culture is an important direction for promoting green development and improving the overall benefits of the Chinese soft-shelled turtle aquaculture industry. Its core principle is to optimize culture environments and biological resource configurations to reduce resource wastage and environmental burdens while maintaining favorable growth efficiency and product quality. Conventional high-density culture mainly relies on artificial feeding and engineered environmental regulation, whereas ecological culture places greater emphasis on the coordinated functioning of water bodies, substrates, and biological communities. Pond culture can improve aquatic environmental stability through appropriate aquatic plant cultivation, substrate improvement, and enhanced effluent purification facilities. Rice-turtle co-culture integrates turtle farming with rice production and improves the overall utilization efficiency of land and water resources through natural food utilization and nutrient cycling within rice paddies. Wang et al. (2026a) demonstrated that, compared with intensive pond monoculture, rice-turtle co-culture improved certain water quality and production indicators and increased turtle survival under relatively low stocking densities. Zhao et al. (2020) further found that appropriate stocking density management improved nitrogen and phosphorus utilization efficiency in rice-turtle co-culture systems. Wu et al. (2021b) also reported that rice-turtle co-culture maintained relatively stable soil organic matter content and pH while altering soil microbial community structure. These findings indicate that the advantages of ecological culture arise not only from reducing artificial inputs but also from improving resource utilization through interactions among crops, animals, and microorganisms. However, ecological culture does not imply complete reliance on natural regulation. When stocking densities or feeding levels exceed the assimilative capacity of the environment, water quality deterioration and growth limitations may still occur. Therefore, ecological culture should be based on moderate production intensity and appropriate biological configurations to maintain a balance among yield, resource utilization, and environmental protection.

Improving overall production benefits requires an integrated evaluation framework incorporating growth performance, health status, economic returns, and ecological impacts, rather than simply pursuing higher yields or lower inputs. Different culture models have distinct characteristics in terms of environmental controllability, production costs, and resource utilization. Suitable technological combinations should therefore be selected according to regional climatic conditions, water resources, existing infrastructure, and market demand. For aquaculture operations with reliable energy supplies and strong engineering management capabilities, optimizing greenhouse heating, feeding, and waste removal facilities can improve early-stage rearing efficiency. In regions with favorable natural water conditions and relatively abundant land resources, ecological pond culture or rice-turtle co-culture may be more suitable. Zhang et al. (2017) demonstrated that improvements in engineered facilities could enhance production efficiency in greenhouse culture. Studies by Fu et al. (2023) and Ge et al. (2023a) further indicated that improving intestinal health and immune status through prebiotics and functional feed additives has the potential to integrate enhanced nutrient utilization with health management. In addition, Liao et al. (2026) proposed that regulating intestinal microbial communities using endogenous probiotics isolated from Chinese soft-shelled turtles could provide a promising approach to improving host health and aquatic environmental quality. These findings suggest that optimization of Chinese soft-shelled turtle culture should not be limited to individual facilities or management measures. Instead, stage-specific rearing, appropriate stocking density control, precision nutrition, water quality monitoring, and ecological environmental improvement should be integrated, with management strategies continuously adjusted according to actual production performance. Future efforts should also strengthen the application of automated feeding systems, water quality sensors, and

digital monitoring technologies to establish comprehensive evaluation and regulation systems suitable for different regions and production scales, thereby promoting stable yields, high product quality, reduced costs, and environmentally sustainable development in Chinese soft-shelled turtle aquaculture.

8 Conclusions and Prospects

Different culture models have distinct effects on the growth performance of Chinese soft-shelled turtles (Pelodiscus sinensis), and no single model is optimal for all production objectives. Intensive greenhouse and pond culture systems can promote rapid growth and increase yield per unit area through environmental regulation and intensive feeding. However, substantial infrastructure investment, environmental management costs, and disease risks may limit their overall benefits. In contrast, although individual growth rates in rice-turtle co-culture systems may be relatively low under certain conditions, these systems can improve survival rates and feed utilization efficiency while reducing nitrogen and phosphorus accumulation through rice uptake and nutrient cycling. Previous studies have shown that rice-turtle co-culture can increase turtle production while maintaining rice yields, and broader research on integrated rice-aquatic animal farming has demonstrated its potential to improve soil fertility, reduce certain agricultural environmental pressures, and enhance overall benefits. Therefore, the evaluation of Chinese soft-shelled turtle culture systems should comprehensively consider growth rate, marketable yield, resource utilization efficiency, and production stability rather than relying solely on individual growth indicators.

The major challenge facing Chinese soft-shelled turtle aquaculture is improving production efficiency while maintaining an appropriate balance between culture intensity and environmental carrying capacity. Intensive culture may increase water quality management and operational pressures due to high stocking densities, intensive feeding, and energy consumption, while ecological culture may also experience reduced production efficiency when stocking densities or feed inputs are excessive. Therefore, future development could explore stage-specific culture systems that combine early greenhouse rearing with subsequent ecological grow-out in ponds or rice paddies, together with dynamic adjustments to stocking density and nutritional supply according to developmental stage. Previous studies have shown that, under specific rice-turtle co-culture conditions, a stocking density of 10 turtles/m² can achieve a favorable balance between yield and environmental performance, while a feeding level of 1.4% of body weight can provide a relatively favorable balance between growth and feed utilization efficiency. However, these parameters should be adjusted according to seedstock size and regional conditions. Future research should also strengthen systematic evaluations of feed formulations, field facility configurations, regional adaptability, and precision management technologies.

Chinese soft-shelled turtle aquaculture is expected to gradually shift from a production model focused primarily on maximizing yield toward an integrated system that considers growth efficiency, health status, product quality, and ecological benefits. Rice-turtle co-culture, lotus-turtle integrated culture, and ecological modifications to conventional ponds can improve the stability of culture systems by enhancing habitat conditions, promoting nutrient cycling, and regulating microbial communities. Existing studies have demonstrated that lotus-turtle co-culture can improve turtle health, floating beds planted with water spinach can enhance pond water quality and production benefits, and certain rice-turtle co-culture systems have the potential to reduce greenhouse gas emissions. Accordingly, the sustainable development of Chinese soft-shelled turtle aquaculture does not necessarily require the complete replacement of intensive production. Instead, integrating greenhouse seedstock rearing, precision feeding, ecological grow-out, and regionally adapted management practices may establish diversified culture systems that achieve stable yields, high product quality, reduced costs, and environmental protection, thereby promoting coordinated improvements in economic and ecological benefits.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Bashir M.A., Liu J., Geng Y., Wang H., Pan J.T., Zhang D., Rehim A., Aon M., and Liu H.B., 2020, Co-culture of rice and aquatic animals: an integrated system to achieve production and environmental sustainability, Journal of Cleaner Production, 249: 119310.
https://doi.org/10.1016/j.jclepro.2019.119310

Chen J.Y., Meng Q.Y., Qian W., and Qu Y.F., 2025, Effects of bacterial infections under heatwaves on Chinese soft-shelled turtles and their single-cell transcriptomic landscapes, Environmental Science & Technology, 59(17): 8357-8367.
https://doi.org/10.1021/acs.est.4c09111

Chen X., Niu C.J., and Pu L.J., 2007, Effects of stocking density on growth and non-specific immune responses in juvenile soft-shelled turtle, Pelodiscus sinensis, Aquaculture Research, 38: 1380-1386.
https://doi.org/10.1111/j.1365-2109.2007.01813.x

Ding X., Jin F., Xu J., Zhang S., Chen D., Hu B., and Hong Y., 2022, The impact of aquaculture system on the microbiome and gut metabolome of juvenile Chinese softshell turtle (*Pelodiscus sinensis*), iMeta, 1(2): e17.
https://doi.org/10.1002/imt2.17

Ding Y., Tan Z., Xu C., Munang'andu H., Huang Q., Liu C.T., Wang W., Qian G., and Xu J.H., 2025, Transcriptomic and physiological analyses reveal the response mechanism of the liver under acute ammonia stress in the Chinese soft-shelled turtle (*Pelodiscus sinensis*), Aquaculture, 596: 741891.
https://doi.org/10.1016/j.aquaculture.2024.741891

Feng R., Zhang Z., and Guan Y., 2021, Physiological and transcriptional analysis of Chinese soft-shelled turtle *(Pelodiscus sinensis*) in response to acute nitrite stress, Aquatic Toxicology, 237: 105899.
https://doi.org/10.1016/j.aquatox.2021.105899

Fu H., Qi M., Yang Q.M., Li M., Yao G.H., Bu W., Zheng T., and Pi X., 2023, Effects of dietary chito-oligosaccharide and β-glucan on the water quality and gut microbiota, intestinal morphology, immune response, and meat quality of Chinese soft-shell turtle (*Pelodiscus sinensis*), Frontiers in Immunology, 14: 1266997.
https://doi.org/10.3389/fimmu.2023.1266997

Ge L., Sun Y., Li Y., Wang L.Y., Guo G.Q., Song L., Wang C., Wu G.G., Zang X., Cai X.H., Li S.X., and Li P., 2023a, Ecosystem sustainability of rice and aquatic animal co-culture systems and a synthesis of its underlying mechanisms, Science of the Total Environment, 880: 163314.
https://doi.org/10.1016/j.scitotenv.2023.163314

Ge L., Yu Y., Wen X., Xiao H.W., Liu K., Liu Z.Y., Liu S., Li Q., Wang X.Q., Deng Z.F., and Hu Y.Z., 2023b, Effects of dietary sodium butyrate on growth performance, immune function, and intestinal microflora of Chinese soft-shelled turtle (*Pelodiscus sinensis*), Frontiers in Cellular and Infection Microbiology, 13: 1271912.
https://doi.org/10.3389/fcimb.2023.1271912

Guo L., Zhao L., Ye J., Ji Z., Tang J.J., Bai K., Zheng S., Hu L., and Chen X., 2022, Using aquatic animals as partners to increase yield and maintain soil nitrogen in the paddy ecosystems, eLife, 11: e73869.
https://doi.org/10.7554/eLife.73869

He Z.Y., and Zhang H.Q., 2018, Soft-shelled turtle culture, In: Gui J.F., Tang Q., Li Z., and Liu J. (eds.), Aquaculture in China: Success Stories and Modern Trends, John Wiley & Sons, Ltd., pp. 335-352.
https://doi.org/10.1002/9781119120759.ch3_13

Hou M., Sun W., Ma Y., Ye H., Zhai X., Xue Y., Tang R., Teng S., Wu R., and Luo H., 2024, Comparative analysis for nutrients, flavor compounds, and lipidome revealed the edible value of pond-cultured male *Pelodiscus sinensis* with different ages, Food Chemistry, 454: 139795.
https://doi.org/10.1016/j.foodchem.2024.139795

Ji Z.J., Zhao L.F., Zhang T., Dai R., Tang J.J., Hu L.L., and Chen X., 2023, Coculturing rice with aquatic animals promotes ecological intensification of paddy ecosystem, Journal of Plant Ecology, 16(6): rtad014.
https://doi.org/10.1093/jpe/rtad014

Jia X., Cai K., Pan L., Wei C., Li W., Liu X., Zhu X., Ye L., and Hong X., 2026, Effects of different substrates on growth, serum biochemical parameters, and behavioral characteristics of juvenile Asian giant softshell turtles, Pelochelys cantorii, Animals, 16(3): 383.
https://doi.org/10.3390/ani16030383

Jing R.Z., and Niu C.J., 2008, Effect of stocking density on the energy budget of juvenile soft-shelled turtles (*Pelodiscus sinensis*), Asiatic Herpetological Research, 11: 45-49.

Kou H.Y., Hu J., Wang A.L., Pan X.B., Vijayaraman S.B., Miao Y.T., and Lin L., 2022, Effects of dietary protein on water quality, growth performance, RNA/DNA ratio and haemato-immunological indices of soft-shelled turtle (*Pelodiscus sinensis*), Fish & Shellfish Immunology, 123: 127-135.
https://doi.org/10.1016/j.fsi.2022.02.027

Kou H.Y., Li F., Zhou M., Zou C.Y., Zhang K., Zhao L.J., Miao Y.T., Pan X.B., Wang A.L., and Lin L., 2021, Impacts of dietary protein on growth performance, feed utilization, amino acid profile, activities of digestive and amino acid metabolizing enzymes of the soft-shelled turtle (*Pelodiscus sinensis*), Aquaculture Research, 52(6): 2862-2872.
https://doi.org/10.1111/are.15137

Lan M., Wang Y.G., Mu Y., Li Y., Zhang Z., and Guan Y., 2024, Effects of a Chinese herbal medicine mixture on growth performance, immune response, and gene expression in Chinese soft-shelled turtles (*Pelodiscus sinensis*), Animal Feed Science and Technology, 316: 116084.
https://doi.org/10.1016/j.anifeedsci.2024.116084

Li H., Ji M.D., Shitu A., Ye Z., Zhao J., and Zhu S.M., 2024, Effects of light intensity on growth, stress, immune-related parameters, and antioxidant enzyme activities of Chinese soft-shelled turtle (*Pelodiscus sinensis*) in a greenhouse, Aquaculture International, 32(4): 3801-3813.

Li W., Ding H., Zhang F.Y., Zhang T.L., Liu J.S., and Li Z.J., 2016, Effects of water spinach Ipomoea aquatica cultivation on water quality and performance of Chinese soft-shelled turtle Pelodiscus sinensis pond culture, Aquaculture Environment Interactions, 8: 567-574.
https://doi.org/10.3354/aei00198

Liao Y.H., Fu H., Lv G., Quan H.H., Qiu Q., Mao H., Xing J., Wang Z.R., Yang Q.M., and Pi X., 2026, Novel endogenous probiotics enhance host intestinal health, liver immune capacity, meat nutritional composition, and aquatic environmental quality in Pelodiscus sinensis, Aquaculture Nutrition, 2026(1): 7893677.
https://doi.org/10.1155/anu/7893677

Liu G.Z., Huang H., and Zhou J.W., 2019, Energy analysis and economic assessment of a rice-turtle-fish co-culture system, Agroecology and Sustainable Food Systems, 43: 299-309.
https://doi.org/10.1080/21683565.2018.1510870

Qi M., Wang Y., Hu L., Chen G., Zheng T., Ding X., Bei Y., Tang J., Ma W., and Chen X., 2025, Investigation of plasticity in morphology, organ traits and nutritional composition in Chinese soft-shelled turtle (*Pelodiscus sinensis*) under different culturing modes, Fishes, 10(3): 89.
https://doi.org/10.3390/fishes10030089

Qiu Z., Xu Q., Xie D., Zhao J., Yamamoto F.Y., Xu H., and Zhao J., 2023, Effects of the replacement of dietary fish meal with poultry by-product meal on growth and intestinal health of Chinese soft-shelled turtle (*Pelodiscus sinensis*), Animals, 13(5): 865.
https://doi.org/10.3390/ani13050865

Tang G.Q., Zhang Q.M., and Qin X.D., 2009, Effects of different pond environments and feeds on performance and economic benefits of Chinese soft-shelled turtle (*Trionyx sinensis*), Guangxi Agricultural Sciences, 40: 307-310.

Wang F., Chen Z., Song G., Xu X., Zhao X., Zhou X., Ji S., Zhu C., Fang G., Su Y., Jiang Y., Wang M., Zhu W., Saikia S., Qu C., and Hou G., 2026a, Chinese soft-shelled turtle*, Pelodiscus sinensis,* monoculture and co-culture with rice models—Ecological and economic result, Turkish Journal of Fisheries and Aquatic Sciences, 26(4): TRJFAS27233.
https://doi.org/10.4194/TRJFAS27233

Wang X., Bao T., Li F.B., Wang M.J., Chen K., Xu C.C., Feng J.F., and Fang F.P., 2026b, Co-culture of rice-Chinese soft-shell turtle increased the food yields and economic benefit with less greenhouse gas emissions, Agronomy, 16(15): 1451.
https://doi.org/10.3390/agronomy16151451

Wang Y., Geng Y.R., Shi X., Wang S., Yang Z.C., Zhang P.Y., and Liu H.Y., 2022, Effects of dietary phosphorus levels on growth performance, phosphorus utilization and intestinal calcium and phosphorus transport-related genes expression of juvenile Chinese soft-shelled turtle (*Pelodiscus sinensis*), Animals, 12(22): 3101.
https://doi.org/10.3390/ani12223101

Wu B., Huang L., Wu C., Chen J., Chen X., and He J., 2024b, Comparative analysis of the growth, physiological responses, and gene expression of Chinese soft-shelled turtles cultured in different modes, Animals, 14(6): 962.
https://doi.org/10.3390/ani14060962

Wu B.L., Wu C., Huang L., Chen J., Chen X.J., and He J.X., 2024a, Adaptation and feeding preference of Chinese soft-shelled turtle (Pelodiscus sinensis) to different feeding levels in rice-turtle co-culture system, Aquaculture Reports, 38: 102281.
https://doi.org/10.1016/j.aqrep.2024.102281

Wu B.L., Chen J., Huang L., Zhang Y., Fang T., and He J.X., 2021a, Dynamics of soil fertility and microbial community response to stocking density in rice-turtle co-culture, Aquaculture Reports, 20: 100765.
https://doi.org/10.1016/j.aqrep.2021.100765

Wu B., Huang L., Chen J., Zhang Y., Wang J., and He J., 2021b, Gut microbiota of homologous Chinese soft-shell turtles (Pelodiscus sinensis) in different habitats, BMC Microbiology, 21: 142.
https://doi.org/10.1186/s12866-021-02209-y

Yang Q., Liao Y., Quan H., Qiu Q., Mao H., Gong D., Tu X., Wang Z., Fu H., and Pi X., 2026, Effects of growth stage and physiological state on gut health, antioxidant capacity, and muscle nutritional composition in greenhouse-cultured *Pelodiscus sinensis*, Antioxidants, 15(9): 1100.
https://doi.org/10.3390/antiox15091100

Ye J., Shi L.K., Jiang L.X., Jiang J., Wang L., Chen Z., Guo S.R., Zhang X.D., and Xu T., 2026, Lotus (*Nelumbo nucifera*)-based co-culture systems reshape gut microbiota and enhance health and microbial stability in Chinese soft-shelled turtle (*Pelodiscus sinensis*), BMC Microbiology, 26: 1-18.
https://doi.org/10.1186/s12866-026-05600-9

Yu H.Y., Zhang X., Shen W., Yao H., Meng X., Zeng J.Y., Zhang G.B., and Zamanien K., 2023, A meta-analysis of ecological functions and economic benefits of co-culture models in paddy fields, Agriculture, Ecosystems & Environment, 341: 108195.
https://doi.org/10.1016/j.agee.2022.108195

Zhang J., Hu L.L., Ren W.Z., Guo L.D., Tang J.J., Shu M., and Chen X., 2016, Rice-soft shell turtle coculture effects on yield and its environment, Agriculture, Ecosystems & Environment, 224: 116-122.
https://doi.org/10.1016/j.agee.2016.03.045

Zhang J., Wang F., Jiang Y.L., Hou G.J., Cheng Y.S., Chen H.L., and Li X., 2017, Modern greenhouse culture of juvenile soft-shelled turtle, Pelodiscus sinensis, Aquaculture International, 25: 1607-1624.
https://doi.org/10.1007/s10499-017-0137-y

Zhao J., Zou Y., Chen H., Xu J.H., Liang Z., and Xu H.S., 2020, Effects of stocking density of Chinese soft-shelled turtle and interactions between cultivated species on growth performance and the environment in a turtle-rice coculture system, Journal of the World Aquaculture Society, 51(3): 788-803.
https://doi.org/10.1111/jwas.12665

Zhou T., Chen G.B., Cao L., Cao J., Ji H., Zou G.H., and Liang H., 2025a, Global analysis of transcriptome and metabolomics revealed that fatty acid synthesis and urea cycle process regulate the growth of Chinese soft-shelled turtle, Aquaculture Reports, 42: 102814.
https://doi.org/10.1016/j.aqrep.2025.102814

Zhou T., Wu W., Xue M., Zhou Y., Liang H., and Liu W., 2025b, Antioxidant capacity and disease resistance enhanced by dietary D-glucuronolactone supplementation in Chinese soft-shelled turtles (*Pelodiscus sinensis*), Antioxidants, 14(5): 534.
https://doi.org/10.3390/antiox14050534

Zhu Z., Zhu Y.G., Chan F., Xu M., Li G., and Feng M.L., 2024, A systematic review of factors affecting the performance of the rice-aquaculture system and regional perspectives, Critical Reviews in Environmental Science and Technology, 54: 1757-1776.
https://doi.org/10.1080/10643389.2024.2361505

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