SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2025, 22(3), 1073.
https://doi.org/10.62617/mcb1073

Article

Biological optimization of sustainable agricultural systems through genetic algorithms and nitrogen balance management

Changlin Wang[1,*], Zhonghua Lu[2], Jiatong Yu[3]

[1] School of Economics and Management, Weifang University of Science and Technology, Weifang 262700, China
[2] School of Logistics, Linyi University, Linyi 276000, China
[3] Chinese International College, Dhurakij Pundit University, Bangkok 10270, Thailand
*** Corresponding author:** Changlin Wang, wangchanglin152412@163.com

CITATION

Wang C, Lu Z, Yu J. Biological optimization of sustainable agricultural systems through genetic algorithms and nitrogen balance management. Molecular & Cellular Biomechanics. 2025; 22(3): 1073. https://doi.org/10.62617/mcb1073

ARTICLE INFO

Received: 11 December 2024
Accepted: 14 February 2025
Available online: 25 February 2025

Abstract: In order to improve resource efficiency and enhance sustainability in biological systems, this study investigates the optimization of biomechanical processes by combining genetic algorithms (GA) with human performance and recovery management. The study aims to minimize injury risks and maximize recovery efficiency by utilizing GA to model biomechanical processes. To ensure a dynamic balance in physical performance, the study presents an ideal optimization framework in which human biomechanics is optimized for enhanced sports performance and injury prevention. The model considers factors such as muscle strain, joint impact, and fatigue recovery to create a holistic biomechanical optimization system. By integrating principles from biological nutrient cycles—such as the efficient use of resources and minimizing waste—the approach highlights the parallels between sustainable agricultural systems and sustainable biomechanics. This framework ensures that optimization strategies not only improve performance outcomes but also maintain long-term musculoskeletal health. The research demonstrates how combining biological insights with advanced computational methods can address both physical health and performance challenges in biomechanics. Through multi-objective optimization, the work offers a novel perspective on integrating biological processes with biomechanics to support sustainable human activity and recovery, contributing to advancements in sports science, rehabilitation, and human physical performance.

Keywords: biological; agricultural development; industrial prosperity; rural revitalization; SGA algorithm optimization

1. Introduction

Optimizing biological processes is increasingly critical for the sustainable development of agricultural systems to maintain ecological balance and ensure efficient resource utilization [1]. Conventional farming methods often suffer from inefficient nutrient management, particularly nitrogen, which leads to significant resource waste and environmental harm [2]. Nitrogen, a vital nutrient for plant growth, plays a crucial role in agricultural output. However, its improper use can result in adverse effects such as soil erosion, water contamination, and loss of biodiversity. These challenges necessitate innovative approaches to nutrient management, emphasizing ecological health and sustainable practices [3,4].

Biological optimization refers to the application of natural principles, such as nutrient cycling and ecosystem balance, to enhance agricultural productivity while simultaneously reducing detrimental effects on the environment. This concept is rooted in the understanding that natural systems operate in a balanced and efficient manner, and by mimicking these processes, we can achieve sustainable agricultural practices. For example, nutrient cycling in natural ecosystems ensures that resources are reused and recycled, minimizing waste and maximizing efficiency. By applying these principles to agriculture, we can create systems that are not only productive but also environmentally friendly One promising approach is the use of genetic algorithms (GA)—a computational method inspired by evolutionary biology and natural selection [5,6]. In the context of agriculture, GA can model and optimize nutrient flows, including nitrogen cycles, to improve resource management and system efficiency [7,8]. Nitrogen is a key nutrient for plant growth, but its management in agricultural systems is often inefficient, leading to significant losses through leaching, volatilization, and denitrification. These losses not only reduce the availability of nitrogen for crops but also contribute to environmental problems such as water pollution and greenhouse gas emissions. By using genetic algorithms to model and optimize nitrogen cycles, we can develop strategies that maximize nitrogen use efficiency, reduce losses, and enhance crop productivity

This study focuses on employing genetic algorithms to enhance nitrogen balance in agricultural systems, particularly in circular farming models. Circular farming is an innovative approach that emphasizes the recycling of agricultural waste, such as manure, to close the nutrient cycle and reduce dependence on artificial fertilizers [9]. In a circular farming system, nutrients are recycled and reused within the system, minimizing the need for external inputs and reducing environmental impacts. By simulating and optimizing nutrient cycles with genetic algorithms, we aim to develop farming systems that increase crop yields while mitigating environmental impacts [1,10].

The integration of genetic algorithms with biological optimization principles offers a novel pathway to address major challenges in conventional farming. Conventional farming practices often rely on linear models of resource use, where inputs such as fertilizers are applied to crops, and waste products are disposed of, leading to inefficiencies and environmental degradation. In contrast, the integration of genetic algorithms with biological optimization principles allows us to design farming systems that operate in a circular and sustainable manner. This approach combines ecological sustainability with economic feasibility, paving the way for long-term agricultural development. By introducing cutting-edge computational tools and leveraging the principles of nutrient cycling, this research provides a framework to enhance productivity while safeguarding ecological health. The use of genetic algorithms in agriculture represents a significant advancement in our ability to model and optimize complex systems. By applying these tools to the challenge of nitrogen management, we can develop innovative solutions that improve resource use efficiency, reduce environmental impacts, and enhance agricultural productivity. This research not only contributes to the field of agricultural science but also provides practical insights that can be applied by farmers, policymakers, and other stakeholders to promote sustainable agriculture.

In summary, this study explores the potential of genetic algorithms to optimize nitrogen balance in agricultural systems, with a focus on circular farming models. By integrating computational tools with biological optimization principles, we aim to develop farming systems that are both productive and sustainable. This research represents a significant step forward in our efforts to address the challenges of conventional farming and promote the sustainable development of agricultural systems.

2. Optimization of the SGA algorithm with biomechanical applications

In the context of biomechanics, the optimization of the Simple Genetic Algorithm (SGA) can be aligned with the modeling of human biomechanical systems to enhance performance and reduce injury risk [10,11]. The parameters influencing SGA solutions, such as crossover probability and mutation rates, are analogous to the variables in biomechanical systems, including muscle force, joint angles, and movement patterns. By refining these parameters, SGA can provide insights into biomechanical optimization [12].

For instance, when modeling human motion, the objective function can be designed to minimize joint impact forces and muscle strain while maximizing efficiency in energy utilization. This is particularly relevant in sports biomechanics, where improper force distribution often leads to injuries. An optimized SGA can simulate complex biomechanical processes like gait analysis or the optimization of athletic movements, identifying optimal movement patterns that reduce stress on joints and muscles [13,14].

The flowchart of the genetic algorithm can be adapted to represent biomechanical optimization, where the input parameters include anthropometric data, muscle activation patterns, and joint kinematics [1]. The algorithm iterates through potential solutions, selecting movement strategies that minimize fatigue and maximize recovery. By encoding biomechanical variables as genes in the algorithm, we can simulate and refine multi-objective biomechanical models that cater to individual needs, ensuring personalized optimization strategies [12].

Moreover, the conceptual framework of circular agriculture in **Figure 1** can be paralleled with human biomechanics. Just as circular farming emphasizes resource recycling and efficiency, sustainable biomechanics focuses on optimizing movement strategies to conserve energy and promote recovery. For example, the recycling of energy in biomechanical terms could involve the efficient storage and release of elastic energy in tendons, akin to energy transformation in agricultural systems [3].

The logical selection of the four parameters that influence the genetic algorithm solution and solution effect—does not have a theoretical basis. Finding the right values and ranges of the parameters in practice usually requires a series of trial calculations [15].

The genetic algorithm can be expressed as Equation (1).

$$SGA = (C * E * P_0 * M, \Phi, \Gamma, \Psi, T) \tag{1}$$

The flow of the related algorithm is shown in **Figure 1**.

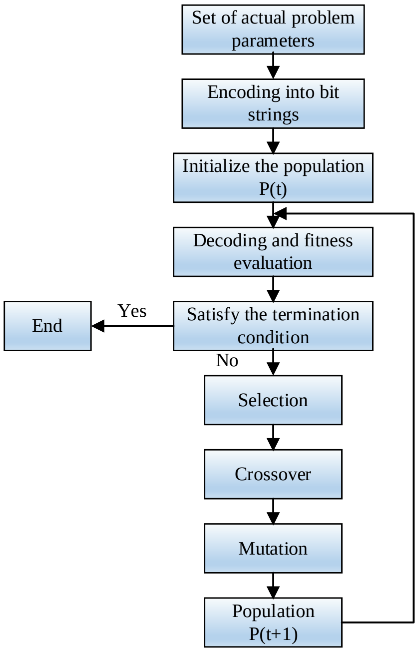

Figure 1. The genetic algorithm.

When designing encoding for real-world application challenges, the encoding, crossover, variation, and decoding methods must all be taken into account cohesively.

If the objective function is the maximum problem:

$$Fit\big(f(x)\big) = f(x) - c_{min}, f(x) > c_{min} \tag{2}$$

By utilizing scientific design, scale design, and sufficient theory as the basis, this model's construction aims to accomplish multi-level energy transformation and resource recycling during the agricultural planting and breeding process. By handling the original waste resources in a harmless way, it also seeks to accomplish waste recycling and efficient usage. The cycle agriculture system model diagram is shown in **Figure 2**.

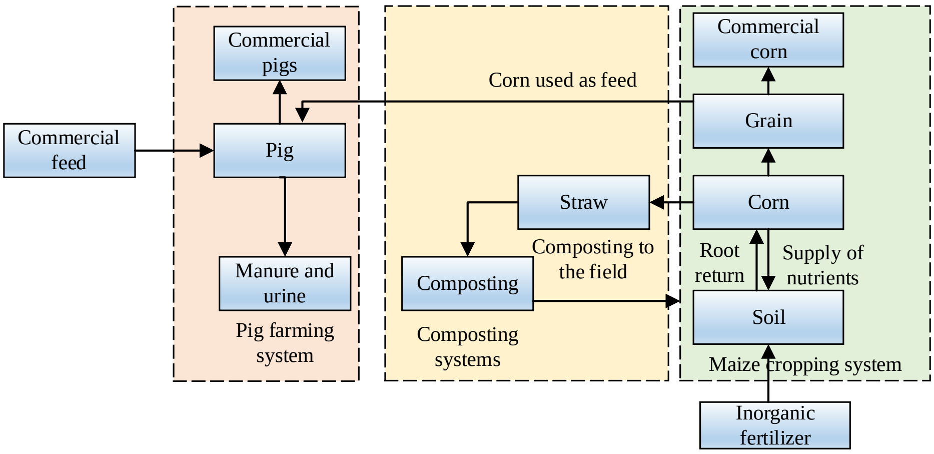

Figure 2. Ideal model of circular farming.

The idea behind this model's construction is to achieve multi-level energy transformation and resource recycling. It also aims to achieve waste recycling and efficient use by treating the original waste resources in a harmless manner [16]. **Figure 3** displays the system's model diagram for cycle agriculture.

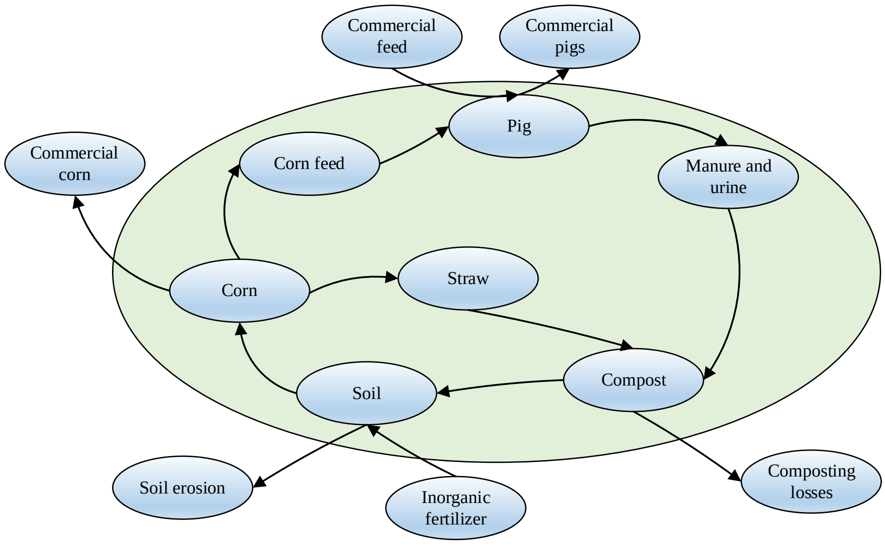

Figure 3. The nitrogen balance boundary conditions.

Initially, we set up the particles whose fitness can be maximized on the program based on the objective function, whose multi-objective function can be written as follows:

$$\begin{aligned} f(x) &= [f_1(x), \dots, f_n(x)] \\ \text{s.t.} \quad & g_j(x) \le 0, j = 1,2, \dots, l \\ & h_i(x) = 0, i = 1,2, \dots, m \end{aligned} \tag{3}$$

$$v_{i+1} = w \times v_i + c_1 \times rand \times (p\_\text{best}_i - x_i) + c_2 \times rand \times (\text{best}_i - x_i) \tag{4}$$

The extensive use of genetic algorithms has led to the proposal of numerous coding techniques, which can be categorized into three groups: symbolic, binary, and real number coding techniques.

3. Methods and big data in biomechanics

The application of big data in biomechanics has revolutionized the ability to analyze and optimize human movement. By integrating particle swarm optimization (PSO) methods, biomechanical models can predict the most efficient movement patterns for various activities. The PSO algorithm, as depicted in **Figure 4**, can be adapted to biomechanical contexts where particles represent different movement strategies [5]. The algorithm evaluates these strategies based on predefined fitness criteria, such as minimizing metabolic cost, joint stress, and recovery time.

Hierarchical structures, like those shown in **Figure 5**, can be employed in biomechanical evaluations to assess the effectiveness of different interventions. For example, a hierarchical model could include levels such as joint kinematics, muscle activation, and overall performance. Each level contributes to the comprehensive evaluation of biomechanical efficiency, enabling targeted interventions for injury prevention or performance enhancement.

Big data also plays a critical role in advancing biomechanics through motion capture technologies and wearable sensors. These tools generate vast amounts of data on human movement, which can be analyzed using algorithms like SGA and PSO. For instance, gait analysis datasets can be processed to identify patterns associated with injuries or inefficiencies, guiding the development of personalized rehabilitation programs.

The PSO algorithm evaluates movement strategies based on predefined fitness criteria. A generic fitness function for biomechanical optimization can be expressed as:

$$F(x) = w_1 \cdot E(x) + w_2 \cdot S(x) + w_3 \cdot R(x) \tag{5}$$

where:

$F(x)$: Fitness value of a movement strategy *x*.

$E(x)$: Metabolic cost of the movement (e.g., energy expenditure).

$S(x)$: Joint stress (e.g., load on the knee or shoulder joints).

$R(x)$: Recovery time from the movement (e.g., time to return to resting heart rate).

$w_1,\ w_2,\ w_3$: Weight coefficients, adjusted based on biomechanical priorities.

Joint angle (θ\theta$\theta$) as a function of time in a biomechanical context:

$$\theta(t) = \theta_0 + \omega t + \frac{1}{2}\alpha t^2 \tag{6}$$

where:

$\theta(t)$: Joint angle at time t.

θ_0: Initial joint angle.

ω: Initial angular velocity.

α: Angular acceleration.

For vertical and horizontal components of ground reaction force during running or jumping:

$$F_{\text{GRF}} = m \cdot g + k \cdot x - c \cdot v \tag{7}$$

where:

F_{GRF}: Ground reaction force.

m: Mass of the individual.

g: Acceleration due to gravity.

k: Spring constant representing stiffness of muscles and tendons.

x: Displacement (compression/stretch) of the spring.

c: Damping coefficient for energy dissipation.

v: Velocity of the joint or foot.

To quantify the activation level of a muscle group:

$$A(t) = \int_{t_0}^{t} [\text{EMG}(t) - \text{EMG}_{\text{baseline}}] dt \tag{8}$$

where:

$A(t)$: Muscle activation level.

$\text{EMG}(t)$: Measured electromyographic signal at time *t*.

$\text{EMG}_{\text{baseline}}$: Baseline EMG signal during rest.

The energy efficiency of a movement can be expressed as:

$$\eta = \frac{W_{\text{useful}}}{E_{\text{total}}} \tag{9}$$

where:

η: Energy efficiency ratio.

W_{useful}: Work output useful for movement (e.g., distance covered).

E_{total}: Total energy expenditure during the activity.

One significant outcome of the information age is the application of big data technology. Big data technology is currently widely utilized across all societal governing levels. Big data is crucial for altering the government's conventional governing model. Big data thinking supports the logical distribution of public resources, scientific decision-making, the adoption of a more sophisticated administrative management style, and the provision of more compassionate public services—all of which are examples of innovative governance thinking and governance [14]. To optimize the economic benefits and resource optimization of circular agriculture, this experiment employs the particle swarm method. **Figure 4** illustrates the particle swarm technique's step-by-step procedure.

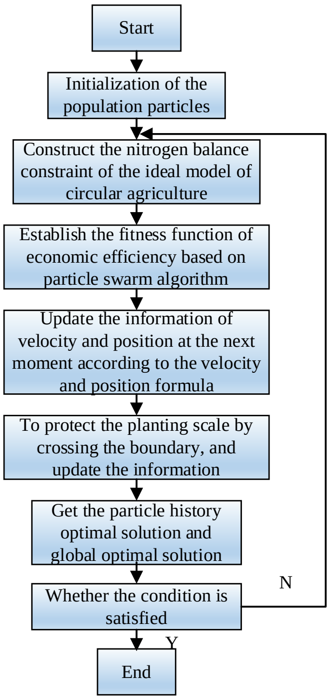

Figure 4. Flow chart of optimized PSO algorithm.

As seen in **Figure 5**, the hierarchical structure of the quantitative evaluation study of agricultural production is built in accordance with the hierarchical analysis procedure for this quantitative assessment of the agricultural production program.

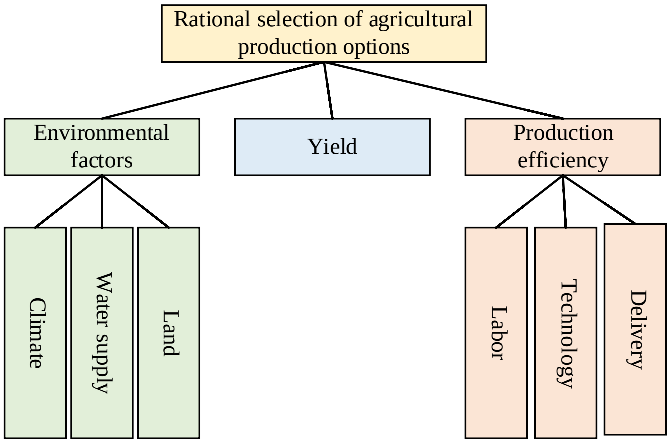

Figure 5. Quantitative evaluation of agricultural production.

4. Bridging agriculture and biomechanics

The parallels between agricultural systems and human biomechanics underscore the importance of sustainability in both domains. Just as circular farming seeks to optimize nutrient cycles, sustainable biomechanics aims to optimize energy cycles within the human body. By leveraging computational tools like SGA and PSO, both fields can address complex challenges through innovative solutions.

Rural rejuvenation is the ultimate goal of agricultural development, which starts with the realization of agricultural modernization, farmers' income growth, and rural economic expansion [13,14]. **Figure 6** displays the gross regional product for the previous years, and **Figure 7** displays the gross regional product composition for 2006 [15].

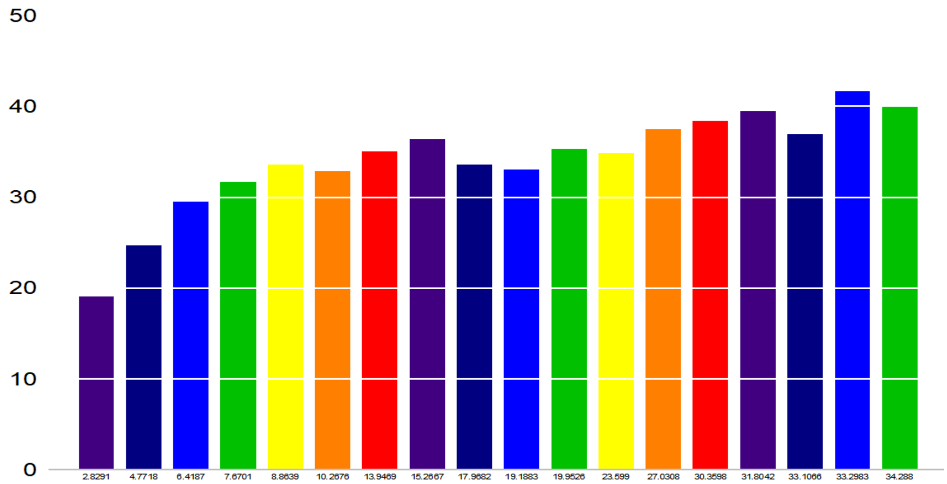

Figure 6. Gross regional product by year.

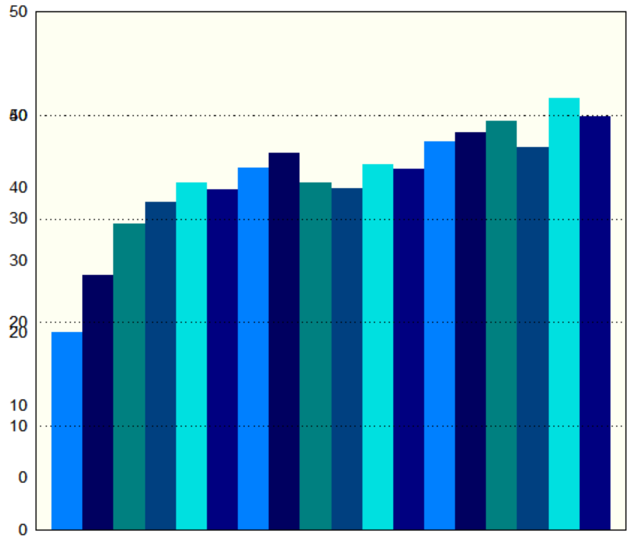

Figure 7. Composition of Yangzhou's GDP in 2006.

As a result, the new rural collective economy has made it possible to combine various aspects and dispersed resources inside the community. **Table 1** displays the water consumption figures for 2006, and **Figure 8** displays the water consumption structure. **Figures 9–12** display the total water use as well as the water consumption of agricultural irrigation over the last four years.

Table 1. Water consumption statistics in Yangzhou in 2006.

	Agricultural irrigation	Forestry, Animal Husbandry and Fishery	Industry	Living	Ecological Environment	Total
Water consumption (billion m^3)	28.42	1.80	7.91	1.55	12.18	51.85
Share (%)	54.78	3.48	15.25	2.96	23.52	100

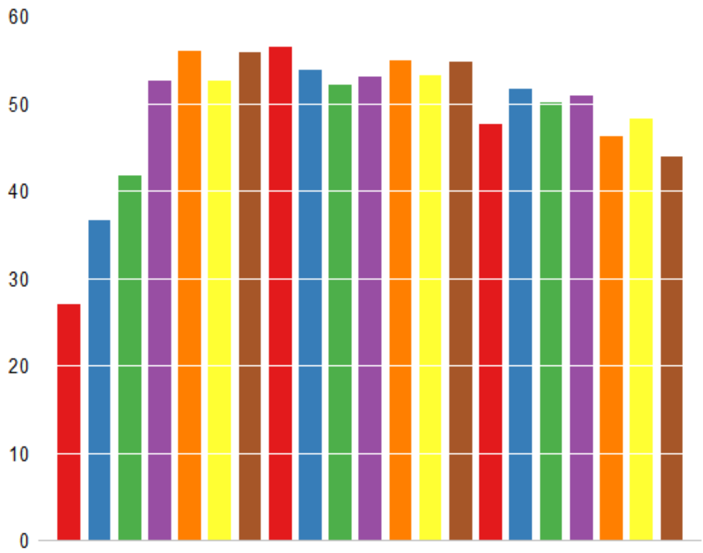

Figure 8. Water use structure in Yangzhou in 2006.

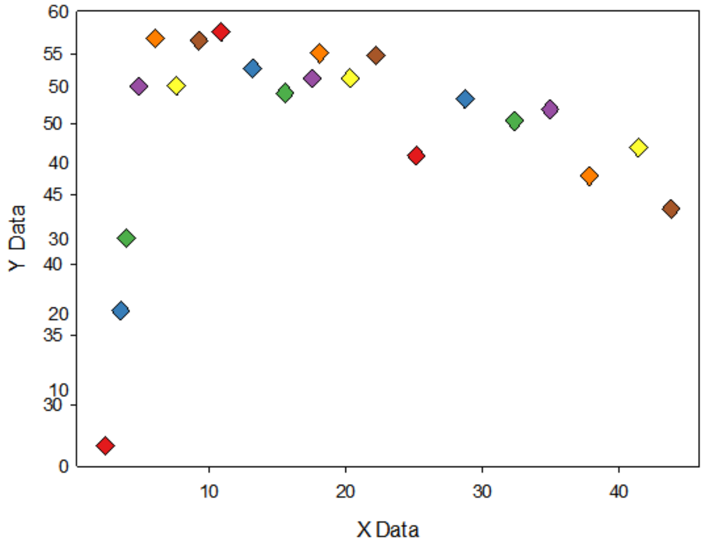

Figure 9. Water consumption and total water consumption.

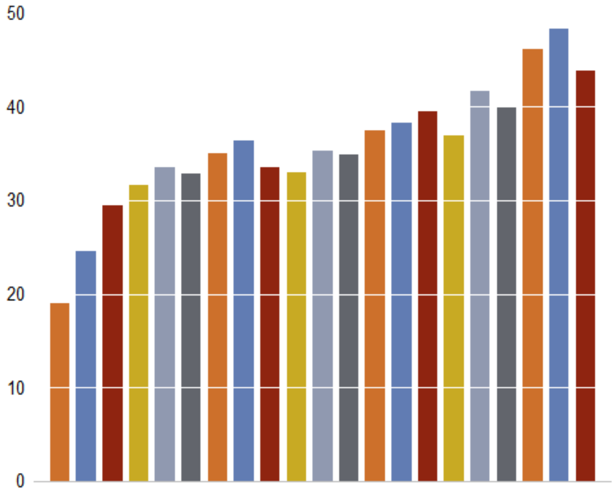

Figure 10. Crop planting layout in Yangzhou City, 2006.

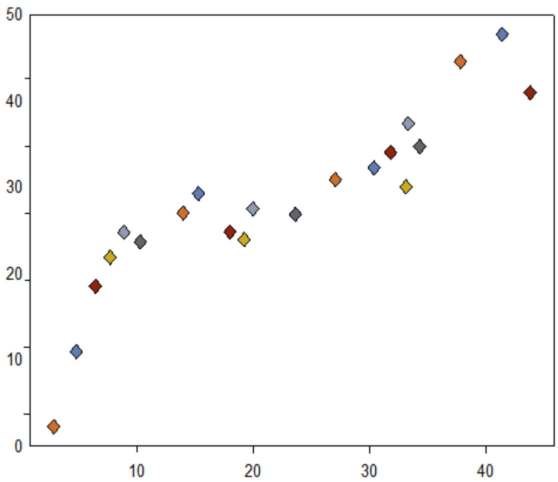

Figure 11. Grain crops and non-food crops cultivation area.

The new rural collective economy gives competent rural residents and those who are eager to return to their villages a stage on which to express their goals and draw resources that have left the countryside to their communities. By putting their knowledge and insights into practice, the capable elites use the new rural collective economy to guide farmers in creating new industries and innovative agricultural development models. This allows farmers to see the promising future of rural development and draws more exceptional young workers back to their villages to work on construction projects.

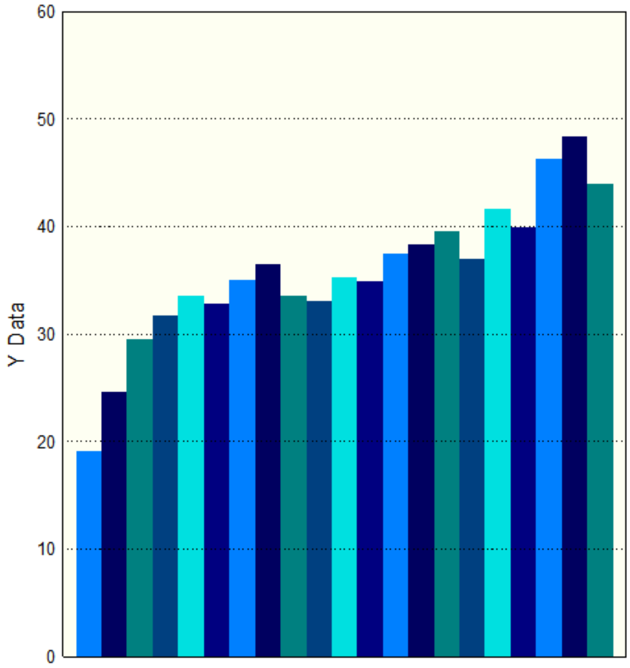

Figure 12. Total agricultural output value.

The analysis of rural industries highlights the importance of industrial prosperity from multiple perspectives, including industrial modernization, the development of professional farmers, and agricultural informatization. This approach aligns with China's overarching strategy of "economic development as the core" and addresses key challenges faced by rural industries. Achieving rural revitalization is a complex task that requires sustained effort and patience, rather than rushing for immediate results. Industrial prosperity is the fundamental prerequisite for rural revitalization, as it provides a robust material foundation that supports and drives other sectors, fostering comprehensive and coordinated rural development.

Promoting industrial growth enhances employment opportunities for farmers, providing them with a secure livelihood. This, in turn, allows attention to be given to areas such as spiritual enrichment, cultural advancement, and ecological balance, creating a more holistic development process. **Figure 13** illustrates the statistics on crop disaster areas in China from 2010 to 2019.

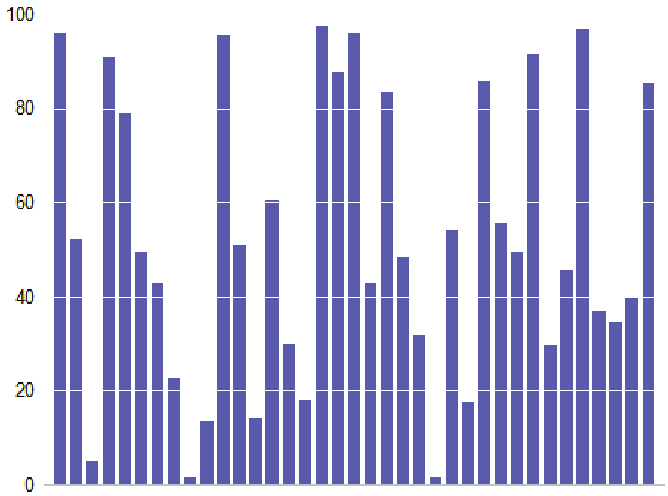

Figure 13. Area of crop damage in China.

Figure 14 illustrates that, although there may be minor ups and downs every two or three years, China's crop disaster area is typically on the decline from 2010 to 2019.

While the annual grain sowing area for 2019 is 116,064 thousand hectares, the disaster area proportion is as high as 21.54%, despite the ten-year average disaster area from 2010 to 2019 being about 25,000 thousand hectares. The percentage is still rather high, and the considerable portion of the affected area has a major influence on the stability of China's crop yield. Furthermore, changes in the price of agricultural products lead to an increase in consumer spending and a decrease in consumption levels. Natural catastrophes caused China's direct economic losses between 2010 and 2018. The total loss situation varies a lot, with a slight increase in losses occurring every two or three years, followed by a decline in losses the following year or two.

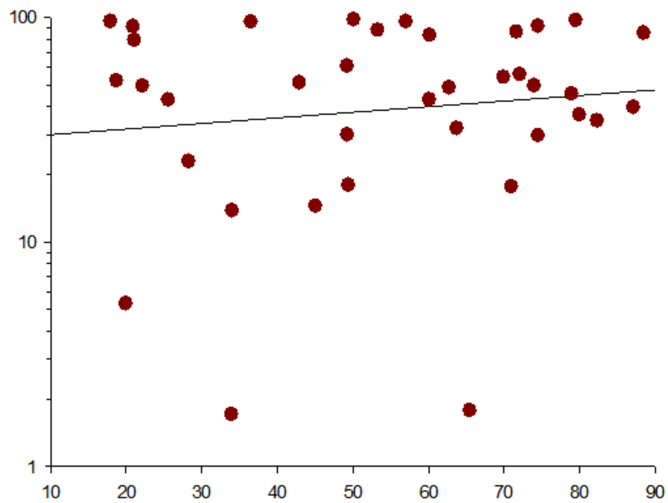

Figure 14. Direct losses from natural disasters.

In addition to agricultural loans, agricultural fixed asset investment is one of the inputs used by rural finance to support agricultural development. As seen in **Figure 15**, its annual growth rate has fluctuated wildly, showing negative growth in the years 2010, 2017, and 2019.

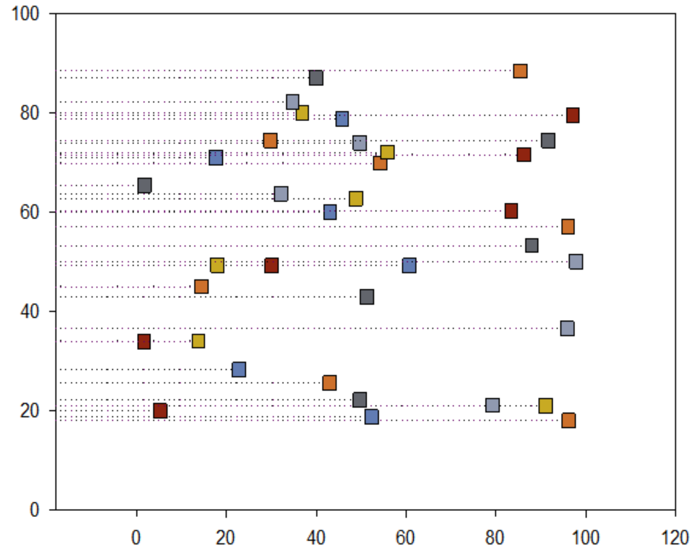

Figure 15. Change rate of investment in fixed assets.

Villagers have realized the importance of the soft power of industry. The support of resource-saving environment-friendly and strong sustainable development power is the lowest, accounting for 11.63%. It proves that villagers' awareness of green development is weak, and in the process of industrial prosperity and adhere to green agricultural development, as **Figure 16**.

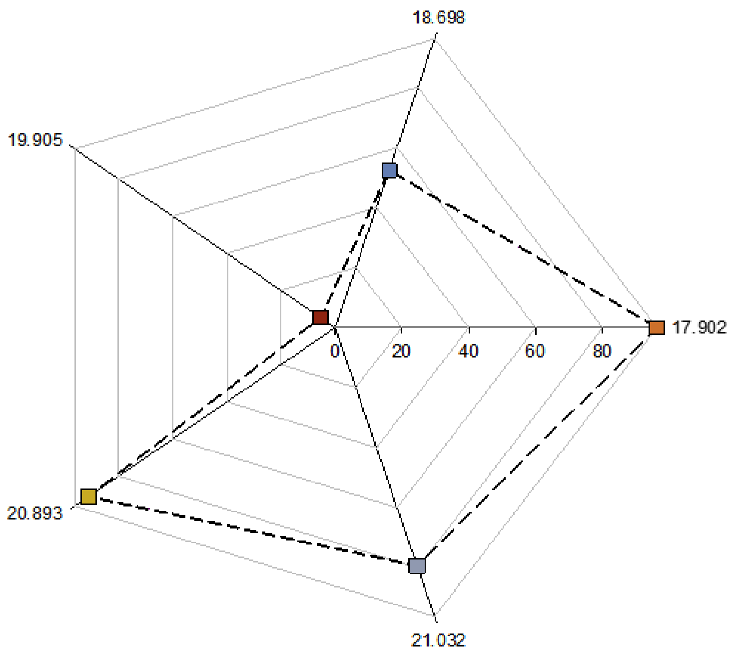

Figure 16. The government gives financial support where industrial prosperity should be spent.

5. Discussion

The integration of GA and particle swarm optimization (PSO) into agricultural and biomechanical systems represents an innovative approach to optimizing biological processes. This discussion examines how these computational techniques can bridge the gaps between sustainable agricultural practices and human biomechanics, shedding light on their mutual benefits and challenges. The findings suggest that both fields can significantly benefit from the application of advanced computational methods, particularly in terms of resource optimization, energy efficiency, and system sustainability.

5.1. Optimization of agricultural systems

The optimization of nitrogen use in agricultural systems through GA is a key example of how computational tools can address complex ecological challenges. As nitrogen is a crucial nutrient for plant growth, inefficient management often leads to environmental degradation, including soil erosion and water contamination. Circular farming models, which recycle agricultural waste and minimize artificial fertilizer use, present a promising solution. By applying GA to model and optimize nutrient cycles, such as nitrogen, agricultural systems can be more efficient, sustainable, and ecologically balanced. This not only increases crop yields but also mitigates the environmental impact of farming.

In particular, the integration of GA into nutrient management systems in circular farming offers a holistic approach to sustainable agriculture. By optimizing the recycling of waste products like manure, GA can help close the nutrient cycle, reducing the need for external inputs and minimizing the environmental footprint. This demonstrates the potential of computational tools in fostering a more sustainable agricultural model, aligning with global sustainability goals.

5.2. Biomechanics optimization through GA and PSO

The application of GA and PSO in biomechanics follows a similar logic of optimizing systems, but in the context of human movement. By modeling biomechanical systems, GA and PSO can be used to enhance performance and reduce the risk of injury. For example, in sports biomechanics, improper movement patterns often lead to joint stress and muscle strain. By optimizing movement strategies, GA and PSO can identify optimal solutions that reduce stress on joints and muscles, enhancing both athletic performance and injury prevention.

The optimization process involves adjusting parameters such as joint angles, muscle forces, and movement patterns, much like the nutrient cycles in agriculture. The use of big data and motion capture technologies further enriches the biomechanical modeling process, providing more precise data for optimization. Wearable sensors and motion analysis tools generate vast amounts of data, which can be processed through algorithms like GA and PSO to identify the most efficient and injury-free movement strategies. This personalized approach to biomechanical optimization ensures that each individual’s unique physiological needs are met, further enhancing the effectiveness of the solutions.

5.3. Bridging agriculture and biomechanics

The parallels between agriculture and biomechanics extend beyond the use of similar computational techniques. Both fields aim to optimize energy and resource flows—whether it is optimizing nutrient cycles in farming or energy cycles in human movement. Circular farming's emphasis on resource recycling mirrors sustainable biomechanics, which seeks to optimize the use of energy within the human body. Just as GA and PSO can be used to optimize agricultural resource flows, they can also be applied to enhance energy efficiency in biomechanics, such as maximizing the storage and release of elastic energy in tendons during movement [17,18].

The concept of resource recycling is central to both fields. In agriculture, this involves recycling waste materials to optimize nutrient use, while in biomechanics, it refers to optimizing the reuse of energy in the body's musculoskeletal system. By understanding these systems through computational tools, we can create more sustainable and efficient practices in both domains. This interdisciplinary approach not only addresses immediate challenges but also opens new avenues for future research and development.

5.4. Challenges and future directions

Despite the promising potential of these computational techniques, several challenges remain. One key challenge is the accurate representation of biological systems in computational models. Both agricultural and biomechanical systems are complex, involving numerous variables that interact in non-linear ways. As such, the accuracy of optimization models depends heavily on the quality of the data and the precision of the algorithms used. Additionally, the parameterization of GA and PSO models, such as the selection of mutation rates, crossover probabilities, and other genetic operators, requires careful consideration and fine-tuning. This often involves a trial-and-error process, which can be time-consuming and computationally expensive.

Moreover, the integration of big data into both agriculture and biomechanics raises issues related to data privacy, storage, and processing. The vast amounts of data generated by motion capture systems, wearable sensors, and agricultural monitoring tools necessitate robust data management systems to ensure that the data is both secure and usable for optimization purposes.

Looking ahead, the integration of AI and ML into GA and PSO models offers exciting possibilities. AI and ML algorithms can automate the optimization process, making it more adaptive and capable of handling complex, real-time data. This could lead to even more precise and personalized solutions in both agriculture and biomechanics, enhancing their sustainability and efficiency.

6. Conclusion

This study shows that biological optimization, especially through nitrogen balance control, can greatly improve the sustainability and efficiency of agricultural systems when combined with GA. We have demonstrated that it is feasible to maximize nutrient cycling, decrease environmental damage, and lessen reliance on synthetic fertilizers by using GA to predict the flow and transformation of nitrogen in circular agricultural systems. Combining cutting-edge computer techniques with biological concepts like ecological balance and nutrient recycling presents a viable route to sustainable farming approaches.

We can guarantee that agricultural systems are both environmentally conscious and productive by optimizing the use of nitrogen. The study emphasizes how crucial it is to preserve a dynamic nutrient balance in agricultural ecosystems in order to support long-term soil health, cut waste, and shield the environment from pollution. In the end, applying genetic algorithms to biological process management, such as nitrogen balance, offers a scalable and effective means to address some of the most important issues facing contemporary agriculture and opens the door to a more sustainable future for agricultural development.

Author contributions: Conceptualization, CW and ZL; methodology, CW; software, ZL; validation, CW, ZL and JY; formal analysis, CW; investigation, CW; resources, ZL; data curation, CW; writing—original draft preparation, CW; writing—review and editing, ZL; visualization, CW; supervision, JY; project administration, JY; funding acquisition, ZL. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Education, China, through 2022 Humanities and Social Sciences Research Planning Fund Project "Research on the Coupling and Coordinated Development of Ecological Protection and Farmers' Common Prosperity in the Middle and Lower Yellow River Regions" under Grant 22YJA790056 and in part by the Shandong Key R&D Plan (Soft Science) Project under Grant 2022RKY06001.

Data availability: The experimental data used to support the findings of this study are available from the corresponding author upon request.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

References

1. Sakthipriya S, Naresh R. Precision agriculture based on convolutional neural network in rice production nutrient management using machine learning genetic algorithm. Engineering Applications of Artificial Intelligence. 2024; 130: 107682. doi: 10.1016/j.engappai.2023.107682
2. Zhu F, Zhang L, Hu X, et al. Research and Design of Hybrid Optimized Backpropagation (BP) Neural Network PID Algorithm for Integrated Water and Fertilizer Precision Fertilization Control System for Field Crops. Agronomy. 2023; 13(5): 1423. doi: 10.3390/agronomy13051423
3. Tynchenko V, Kukartseva O, Tynchenko Y, et al. Predicting Tilapia Productivity in Geothermal Ponds: A Genetic Algorithm Approach for Sustainable Aquaculture Practices. Sustainability. 2024; 16(21): 9276. doi: 10.3390/su16219276
4. Zhan Y, Zhu J. Response surface methodology and artificial neural network-genetic algorithm for modeling and optimization of bioenergy production from biochar-improved anaerobic digestion. Applied Energy. 2024; 355: 122336. doi: 10.1016/j.apenergy.2023.122336
5. Masuda K. Combined Application of a Multi-Objective Genetic Algorithm and Life Cycle Assessment for Evaluating Environmentally Friendly Farming Practices in Japanese Rice Farms. Sustainability. 2023; 15(13): 10059. doi: 10.3390/su151310059
6. Dogan H, Aydın Temel F, Cagcag Yolcu O, et al. Modelling and optimization of sewage sludge composting using biomass ash via deep neural network and genetic algorithm. Bioresource Technology. 2023; 370: 128541. doi: 10.1016/j.biortech.2022.128541

7. Fernández Izquierdo P, Cerón Delagado L, Ortiz Benavides F. An artificial neuronal network coupled with a genetic algorithm to optimise the production of unsaturated fatty acids in Parachlorella kessleri. Artificial Intelligence in Agriculture. 2024; 13: 32-44. doi: 10.1016/j.aiia.2024.06.003
8. Cui C. Full-size Computer Simulation Model Design of 3D Braided Composites. Mari Papel Y Corrugado. 2024; 2024(1): 98–105.
9. Hamouda YEM. Optimally sensors nodes selection for adaptive heterogeneous precision agriculture using wireless sensor networks based on genetic algorithm and extended Kalman filter. Physical Communication. 2024; 63: 102290. doi: 10.1016/j.phycom.2024.102290
10. Mohamad N, Ab. Aziz NA, Ghazali AK, Salleh MR. Improving Ammonia Emission Model of Urea Fertilizer Fluidized Bed Granulation System Using Particle Swarm Optimization for Sustainable Fertilizer Manufacturing Practice. Processes. 2024; 12(5): 1025. doi: 10.3390/pr12051025
11. Kalichkin VK, Maksimovich KYu, Fedorov DS, et al. Conceptual Model of Digital Nitrogen Management in Agricultural Crops. Russian Agricultural Sciences. 2024; 50(2): 197-206. doi: 10.3103/s1068367424700071
12. Sun Y, Zhang J, Bai J, et al. Comprehensive assessment of soil quality in greenhouse agriculture based on genetic algorithm and neural network. Journal of Soils and Sediments. 2023; 24(3): 1302-1315. doi: 10.1007/s11368-023-03706-5
13. Feng T, Liu B, Ren H, et al. Optimized model for coordinated development of regional sustainable agriculture based on water-energy-land-carbon nexus system: A case study of Sichuan Province. Energy Conversion and Management. 2023; 291: 117261. doi: 10.1016/j.enconman.2023.117261
14. Kontos YN, Rompis I, Karpouzos D. Optimal Pollution Control and Pump-and-Fertilize Strategies in a Nitro-Polluted Aquifer, Using Genetic Algorithms and Modflow. Agronomy. 2023; 13(6): 1534. doi: 10.3390/agronomy13061534
15. Wang X, Liu J, Zhang C. Network intrusion detection based on multi-domain data and ensemble-bidirectional LSTM. EURASIP Journal on Information Security. 2023; 2023(1). doi: 10.1186/s13635-023-00139-y
16. Vázquez-Sánchez AY, Lima EC, Abatal M, et al. Biosorption of Pb(II) Using Natural and Treated Ardisia compressa K. Leaves: Simulation Framework Extended through the Application of Artificial Neural Network and Genetic Algorithm. Molecules. 2023; 28(17): 6387. doi: 10.3390/molecules28176387
17. Zahmatkesh S, Gholian-Jouybari F, Klemeš JJ, et al. Sustainable and optimized values for municipal wastewater: The removal of biological oxygen demand and chemical oxygen demand by various levels of geranular activated carbon- and genetic algorithm-based simulation. Journal of Cleaner Production. 2023; 417: 137932. doi: 10.1016/j.jclepro.2023.137932
18. Mathur P, Singh S. Advanced Anaerobic Digestion With Optimization Techniques Using Genetic Algorithm and Fuzzy Logic. Indian Journal of Science And Technology. 2023; 16(22): 1624-1634. doi: 10.17485/ijst/v16i22.2195