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Analysis of the Impact of Partially Replacing Chemical Fertilizer with Organic Fertilizer on Soybean Yield

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Abstract With the deepening of the concept of sustainable agricultural development, the reduction of chemical fertilizers and organic substitution have become important ways to improve crop yield and quality and protect the soil ecological environment. This study focuses on the fertilization mode of replacing part of the chemical fertilizer with organic fertilizer, systematically explores its effects on soybean yield, growth indicators and quality factors, and evaluates its feasibility and advantages. The results show that a moderate proportion of organic fertilizer substitution not only helps to improve the root vitality and biological yield of soybeans, but also improves the physical and chemical properties of the soil to a certain extent, and promotes nutrient absorption and utilization efficiency. Compared with the full chemical fertilizer treatment, the 50% substitution ratio performs better in multiple indicators, reflecting good yield stability and ecological benefits. This study systematically analyzes the yield performance and soil improvement effects under different substitution ratios, providing a theoretical basis and practical path for green and efficient planting models, so as to promote the ecological and sustainable development of soybean production.
Keywords Organic fertilizer; Chemical fertilizer substitution; Soybean yield; Nutrient utilization; Sustainable agriculture

1 Introduction

There are many problems with fertilization in soybean cultivation. Farmers generally rely on chemical fertilizers, which makes people worry that the nutrients in the soil will be used up, the soil quality will deteriorate, and there may be environmental problems such as nutrient loss and increased greenhouse gases (Wu et al., 2024). If too much chemical fertilizer is used, the soil will become less and less fertile over time, making it difficult to continue planting (Kuntyastuti et al., 2020; Sandrakirana and Arifin, 2021).

Recently, many studies have begun to focus on whether some organic fertilizers (such as manure or compost) can be used to replace part of the chemical fertilizers. In actual planting, some people have tried to use organic fertilizers and chemical fertilizers together and found that this can improve soil quality, increase good bacteria in the soil, and increase the activity of some useful enzymes. These changes help make nutrient circulation smoother and plants healthier (Peng et al., 2023). Although some experimental results show that soybean yield and soil fertility have indeed increased, some studies have shown that this improvement is not obvious in every case. Therefore, the fertilization method must be determined according to the local conditions (Lin et al., 2022; Zhao et al., 2024). However, replacing chemical fertilizers with some organic fertilizers can indeed reduce the impact on the environment and may also help farmers save a lot of costs.

This study will analyze the effect of partial replacement of chemical fertilizers with organic fertilizers on soybean yield, focusing on soil quality, microbial activity and crop productivity, review the challenges and opportunities of fertilizer management in soybean cultivation, summarize the latest research results on the combined effects of organic fertilizers and chemical fertilizers, evaluate the potential mechanism of organic fertilizers replacing chemical fertilizers on soybean yield and soil improvement, and finally propose an optimized fertilization strategy to achieve sustainable soybean production.

2 Nutrient Demands of Soybean Growth

2.1 Stage-specific nutrient requirements (N, P, K)

During the entire growth process, soybeans require a large amount of nitrogen, phosphorus and potassium, and the demand for these elements is different at different growth stages. Generally speaking, modern soybean varieties absorb about 275 kg of nitrogen, 21 kg of phosphorus and 172 kg of potassium per hectare to achieve a high yield. Among them, the utilization rate of nitrogen and phosphorus is relatively high, indicating that they are particularly important for grain formation (Bender et al., 2015). Potassium and iron are mainly absorbed in the later stage, while nitrogen and phosphorus are slowly absorbed from the early stage and are used until the filling stage. In order for soybeans to grow well and have high yields, these nutrients need to be supplied in place at the critical stage.

2.2 Complementarity between rhizobial nitrogen fixation and applied nitrogen

Although soybeans can cooperate with rhizobia to obtain some nitrogen through biological nitrogen fixation, this is usually not enough. In order to have high yields and high protein content, some additional nitrogen fertilizers must be applied. If nitrogen fertilizer is used together with inoculants such as bradyrhizobium, soybeans can grow faster, photosynthesize more efficiently, and produce higher yields. Combining organic fertilizers, chemical fertilizers, and inoculants is now a recommended nutrient management method, which allows nutrients to be better absorbed by plants and helps crop health and yield.

2.3 Long-term chemical fertilizer use and soil health impacts

If only chemical fertilizers are used for a long time, the nutrients in the soil will become unbalanced, the microbial activity will deteriorate, and it will easily cause nutrient loss and environmental pollution, which will eventually affect the overall health of the soil (Singh et al., 2024). Therefore, many people now advocate the use of organic fertilizers, such as compost or manure, to replace part of the chemical fertilizers. These organic fertilizers can improve soil structure, allow more microorganisms in the soil, and promote nutrient circulation. This practice not only maintains soybean yields, but also benefits the long-term fertility and ecological environment of the soil.

3 Fertilization Strategies with Partial Organic Substitution

3.1 Setting replacement ratios

The common practice now is to replace part of chemical fertilizer with 25%, 50% or 75% organic fertilizer. Studies have found that when the replacement ratio is around 45% to 50%, the soybean yield and soil quality are better, and it can also reduce the emission of some harmful gases such as nitrous oxide (Xu et al., 2024). If the replacement ratio is lower, such as 15% to 30%, it is also good for the environment, but the long-term improvement effect on the soil may not be obvious. If the ratio is too high, such as more than 75%, it may not only fail to increase the yield, but it may also easily cause problems such as uneven nutrients and increased costs (Hou et al., 2022).

3.2 Types of organic fertilizers and nutrient profiles

There are many types of organic fertilizers that can replace chemical fertilizers, such as pig manure, cow manure, compost, straw, and urban sludge compost. They contain different nutrients and have different effects on the soil (Tang et al., 2021; Yang et al., 2024a). Manure, for example, has a more appropriate carbon-nitrogen ratio and can provide a variety of nutrients; while compost and straw are more conducive to increasing organic carbon and microbial species in the soil. The choice of organic fertilizer will affect the enzyme activity and microbial composition in the soil, which will affect the growth of crops and the sustainable planting capacity of the field.

3.3 Optimization of timing and methods of application

When and how to use organic fertilizer is also critical. It is best to apply it when soybeans are just planted or are still in the growth period, so that they are more easily absorbed (Zhai et al., 2022). In addition, organic fertilizer should be turned into the soil instead of being spread on the surface, which can reduce nutrient loss and make it more usable by crops. Usually, we should pay more attention to the nutrient status of the soil and adjust the amount of fertilizer according to the situation. Only by persisting in the long term and managing according to local conditions can soybeans grow well without damaging the land.

4 Effects on Soybean Growth Parameters

4.1 Emergence rate, seedling establishment, and plant vigor

Soybeans need sufficient nutrients and good soil conditions from germination to seedling growth. With sufficient nutrients, especially after the use of organic fertilizers, seedlings grow faster and have stronger vitality. Studies have found that if the light conditions are good, the weight of the aboveground part and the roots will increase, the stems will be thicker, and the leaves will become larger (Figure 1) (Huynh et al., 2025). Some organic fertilizers can also improve soil structure, especially when the soil acidity is high, which helps to increase the germination rate and the health of seedlings (Sattar et al., 2023).

(a) (b)

Figure 1 Soybean seedlings: (a) A0_11, high light intensity, uniform PPFD distribution; (b) B0_11, nonuniform PPFD distribution. Discoloration of leaves indicates nutrient deficiency symptoms (Adopted from Huynh et al., 2025)

4.2 Plant height, number of branches, and LAI changes

Plant height, number of branches and leaf area index are several important indicators to measure whether soybeans grow well. If nutrients are managed properly, such as using organic fertilizers, the plants will grow taller, the leaves will become larger, and some can even increase branches. Studies have found that after taking these measures, plant height can be increased by 21%, leaf area by 18.7%, and leaf dry weight can even increase by 66.4% (Wang et al., 2025). However, if high temperature or drought occurs, the leaves may become smaller, with fewer branches, and the whole plant will be shorter, all of which will lead to a decrease in yield (Hu and Wiatrak, 2012; Jumrani and Bhatia, 2018). At this time, if organic fertilizers with good water retention are added, these adverse effects can be alleviated and the plants can continue to grow normally.

4.3 Root activity and nodulation dynamics

The health of the roots is directly related to the ability of soybeans to absorb water and nutrients, and also affects biological nitrogen fixation. Using organic fertilizers and some beneficial bacteria, such as growth-promoting bacteria or mycorrhizal fungi, can make the roots grow more and longer, with a larger surface area, and the number of nodules will also increase, up to 68% more (Ngosong et al., 2022). These changes are related to increased acid phosphatase activity in the rhizosphere, an enzyme that helps plants absorb nutrients and thus increase yields. Good nodule growth can also increase the content of protein, sugar, and trace elements in the grains, indicating that the relationship between roots and microorganisms is important for high soybean yields.

5 Impacts on Yield and Seed Quality

5.1 Pod number per plant, 100-seed weight, and total yield

The yield of soybean mainly depends on three aspects: the number of pods per plant, the size of seeds (that is, the 100-grain weight), and the total harvest. Scientific nutrient management, such as replacing chemical fertilizers with part of organic fertilizers, is helpful in these aspects. Experiments have found that when nutrients are more fully supplied, there will be more pods, larger seeds, and naturally higher yields (Si et al., 2022). Like other oil crops, soybeans respond very well to fertilization. The more pods, the higher the yield. In addition, management measures such as crop rotation and timely topdressing can also help increase yields (Assefa et al., 2019).

5.2 Improvements in protein and oil content

The quality of soybean seeds mainly depends on protein and oil content. Studies have shown that if part of organic fertilizer is used, combined with appropriate nitrogen fertilizer management, the protein content of seeds can be increased. Sometimes, whether it is organic nitrogen or chemical nitrogen, as long as there is more nitrogen fertilizer, the protein content will increase, but this may reduce the oil content, because the two sometimes affect each other (Digrado et al., 2024). However, in general, if the fertilizer is properly matched, not only can the protein content be increased, but the oil content will not decrease too much, so that the nutritional value and selling price of the seeds can be maintained.

5.3 Effects on seed safety (nitrate, heavy metals)

Soybean safety is also very important, especially harmful substances such as nitrates and heavy metals. Although many studies mainly look at yield and quality, there are also data showing that if too much chemical fertilizer is used, nitrates and heavy metals may accumulate in the soil or seeds (Maity et al., 2023). Relatively speaking, good use of organic fertilizers can reduce such problems. As long as the source of organic fertilizers is safe, coupled with regular inspections of soil and seed quality, soybeans can be guaranteed to be both safe and high-yielding.

6 Regional Trials and Practical Applications

6.1 Yield increase under partial substitution in Northeast China

In Northeast China, a study found that soybean yields have been rising in recent years, increasing by about 1.68% each year. This increase is mainly due to better management, such as the use of conservation tillage, more reasonable planting methods, and often the use of organic + chemical fertilizers. Studies in the Northeast Agricultural Region also pointed out that without expanding the planting area, as long as the planting methods are improved, such as replacing chemical fertilizers with part of organic fertilizers, soybean yields can be increased by up to 60%. Among them, the Songliao Plain is considered to have the greatest potential for yield increase (Zhao et al., 2023). Variety improvement and improved field management (such as more scientific fertilization) also make each plant have more pods, and the yield naturally increases (Figure 2) (Zhang et al., 2023).

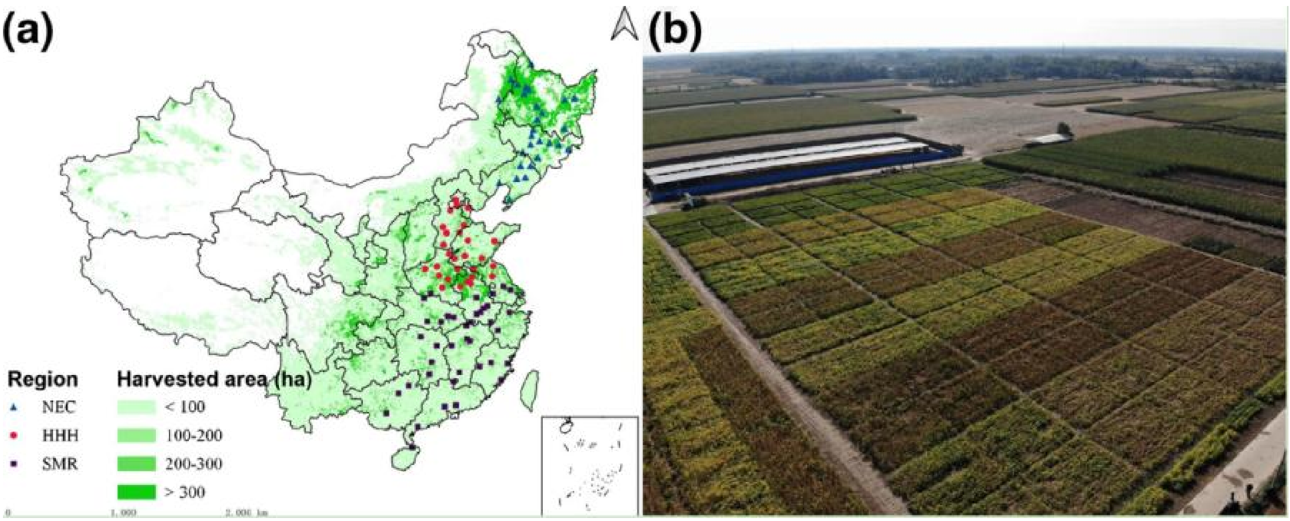

Figure 2 Spatial distribution of the national unified soybean variety testing (NUSVT) sites between the period of 2006 and 2020 across China (a). Effects of the interactions of cultivars, sowing dates and nitrogen inputs on soybean performance in the field experiment (b, photograph by the authors). NEC, HHH, and SMR represent Northeast China, Huang-Huai-Hai Plain, and Southern Multi-cropping Region, respectively. The background image represents the harvested soybean area in 2010, which was obtained from the Spatial Productional Allocation Model provided by International Food Policy Research Institute (https://www.mapspam.info/). The field experiment represented the interactions of 2 cultivars, 3 sowing dates, and 4 nitrogen managements (Adopted from Zhang et al., 2023)

6.2 Quality improvements in Huang-Huai-Hai Plain with moderate substitution

In the Huanghuaihai Plain, planting soybeans in rotation or intercropping systems has a good effect. Yields have increased, soil organic carbon has increased, and overall carbon emissions have decreased. For example, when wheat and corn are planted together with soybeans, annual grain production has increased by 3.6% and energy production has increased by 6.7%. Moreover, more money can be made and planting is more sustainable (Yang et al., 2025).

Field trials have also been conducted in this area, combining straw mulch with fertilization, which has increased soybean yields by an average of 17.2%. The structure of roots and leaves has improved, which has also improved seed quality and protein content. Compared with the old wheat-corn rotation system, wheat-soybean rotation produces more protein, higher returns, and is more environmentally friendly.

6.3 Soil improvement and fertilizer efficiency enhancement in southern hilly regions

In the southern hilly areas and similar southwestern mountainous areas, planting soybeans and corn together (intercropping) is more effective than planting only one crop, and the total yield can be increased by about 12%. By adjusting the planting method, such as wider strips and appropriate row spacing, soybean yields and fertilizer use can be more effective. Studies in these regions also show that soybeans have many benefits when used in rotation or intercropping: they can make the soil structure softer, increase organic matter, and improve nutrient cycling. These changes make the land more fertile and more conducive to long-term planting in the future (Yang et al., 2024b).

7 Concluding Remarks

In many planting methods, replacing part of chemical fertilizers with organic fertilizers can continuously improve crop yields, soil fertility and the quality of agricultural products. Generally speaking, the replacement ratio is between 30% and 50%. This practice can not only improve yields and water use efficiency, but also bring better economic benefits. It can also increase organic carbon in the soil, making nutrients more easily absorbed by plants and increasing the number of microbial species in the soil. These changes are all related to a more reasonable nutrient supply time, that is, fertilizers can better meet the growth needs of crops, thereby improving yields and quality.

This "partial replacement" method has many other benefits. It can prevent soil acidification, reduce nitrous oxide emissions and nutrient loss, and is more environmentally friendly. Moreover, it can help farmers make more money, and the income per unit area can be increased by up to 46%. This method is suitable for different regions and various crops, so it is a very practical and popular green planting method. At the same time, the use of organic fertilizers can also better recycle and utilize organic waste such as farmyard manure and straw, which also makes it more supported in policy and more popular in practice.

Looking ahead, partially replacing chemical fertilizers with organic fertilizers may become an important direction for achieving sustainable agricultural development. It can take into account both environmental protection and farmers' benefits without sacrificing yields. However, future research needs to continue to improve, such as finding the most suitable replacement ratio, controlling greenhouse gas emissions (such as carbon dioxide and methane), and making more specific plans for different regions, soils and crops. As soil management and microbial utilization technologies become more mature, combining organic fertilizers with chemical fertilizers will be a key step in achieving a high-yield, environmentally friendly and risk-resistant agricultural system.

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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

Assefa Y., Purcell L., Salmerón M., Naeve S., Casteel S., Kovács P., Archontoulis S., Licht M., Below F., Kandel H., Lindsey L., Gaska J., Conley S., Shapiro C., Orlowski J., Golden B., Kaur G., Singh M., Thelen K., Laurenz R., Davidson D., and Ciampitti I., 2019, Assessing variation in US soybean seed composition (protein and oil), Frontiers in Plant Science, 10: 298.
https://doi.org/10.3389/fpls.2019.00298

Bender R., Haegele J., and Below F., 2015, Nutrient uptake, partitioning, and remobilization in modern soybean varieties, Agronomy Journal, 107(2): 563-573.
https://doi.org/10.2134/AGRONJ14.0435

Digrado A., Montes C., Baxter I., and Ainsworth E., 2024, Seed quality under elevated CO_2 differs in soybean cultivars with contrasting yield responses, Global Change Biology, 30(2): e17170.
https://doi.org/10.1111/gcb.17170

Hou H., Liu X., Zhou W., Ji J., Lan X., Lv Z., Liu Y., Zhang J., and Müller C., 2022, N transformation mechanisms and N dynamics of organic fertilisers as partial substitutes for chemical fertilisers in paddy soils, Journal of Soils and Sediments, 22(9): 2516-2529.
https://doi.org/10.1007/s11368-022-03246-4

Hu M. and Wiatrak P., 2012, Effect of planting date on soybean growth, yield, and grain quality: review, Agronomy Journal, 104(3): 785-790.
https://doi.org/10.2134/AGRONJ2011.0382

Huynh K., Jolánkai M., Kassai M., Kovács G., Gyuricza C., and Balázs L., 2025, Influence of light intensity and nutrient concentration on soybean (*Glycine max* (L.) Merr.) seedling growth, Agronomy, 15(5): 1037.
https://doi.org/10.3390/agronomy15051037

Jumrani K., and Bhatia V., 2018, Impact of combined stress of high temperature and water deficit on growth and seed yield of soybean, Physiology and Molecular Biology of Plants, 24(1): 37-50.
https://doi.org/10.1007/s12298-017-0480-5

Kuntyastuti H., Sutrisno S., and Lestari S., 2020, Effect of application of organic and inorganic fertilizer on soybean yield in lowland Vertisols, Journal of Degraded and Mining Lands Management, 8(1): 2439-2450.
https://doi.org/10.15243/JDMLM.2020.081.2439

Lin S., Pi Y., Wang X., Zhu X., Long D., He J., Duan J., and Zhu Y., 2022, Impact of organic and chemical nitrogen fertilizers on the crop yield and fertilizer use efficiency of soybean-maize intercropping systems, Agriculture, 12(9): 1428.
https://doi.org/10.3390/agriculture12091428

Maity A., Paul D., Lamichaney A., Sarkar A., Mandal N., Babbar N., Dutta S., Maity P., and Chakrabarty S., 2023, Climate change impacts on seed production and quality: current knowledge, implications, and mitigation strategies, Seed Science and Technology, 51(1): 65-96.
https://doi.org/10.15258/sst.2023.51.1.07

Ngosong C., Tatah B., Olougou M., Suh C., Nkongho R., Ngone M., Achiri D., Tchakounté G., and Ruppel S., 2022, Inoculating plant growth-promoting bacteria and arbuscular mycorrhiza fungi modulates rhizosphere acid phosphatase and nodulation activities and enhance the productivity of soybean (*Glycine max*), Frontiers in Plant Science, 13: 934339.
https://doi.org/10.3389/fpls.2022.934339

Peng H., Xiong J., Zhang J., Zhu L., Wang G., Pacenka S., and Yang X., 2023, Water requirements and comprehensive benefit evaluation of diversified crop rotations in the Huang-Huai Plain, Sustainability, 15(13): 10229.
https://doi.org/10.3390/su151310229

Sandrakirana R., and Arifin Z., 2021, Effect of organic and chemical fertilizers on the growth and production of soybean (*Glycine max*) in dry land, Revista Facultad Nacional de Agronomía Medellín, 74(3): 9643-9653.
https://doi.org/10.15446/rfnam.v74n3.90967

Sattar M., Raza M., Ali S., Bashir S., Kanwal F., Khan I., Raza A., Hussain S., and Shen F., 2023, Integrating by-products from bioenergy technology to improve the morpho-physiological growth and yield of soybean under acidic soil, Chemosphere, 327: 138424.
https://doi.org/10.1016/j.chemosphere.2023.138424

Si T., Wang X., Zhou Y., Zhang K., Xie W., Yuan H., Wang Y., and Sun Y., 2022, Seed yield and quality responses of oilseed crops to simulated nitrogen deposition: a meta-analysis of field studies, GCB Bioenergy, 14(8): 959-971.
https://doi.org/10.1111/gcbb.12977

Singh S., Saini P., Bhati J., Kumar D., Shukla S., and Yadav S., 2024, Management of nutrients in soybean (*Glycine max*) crops: a review, Journal of Advances in Biology & Biotechnology, 27(10): 820-833.
https://doi.org/10.9734/jabb/2024/v27i101505

Tang Q., Cotton A., Wei Z., Xia Y., Daniell T., and Yan X., 2021, How does partial substitution of chemical fertiliser with organic forms increase sustainability of agricultural production? Science of the Total Environment, 803: 149933.
https://doi.org/10.1016/j.scitotenv.2021.149933

Wang X., Zhang Y., Zhang J., Li X., Jiang Z., and Dong S., 2025, Effects of DA-6 and MC on the growth, physiology, and yield characteristics of soybean, BMC Plant Biology, 25(1): 304.
https://doi.org/10.1186/s12870-025-06310-6

Wu G., Huang H., Jia B., Hu L., Luan C., Wu Q., Wang X., Li X., Che Z., Dong Z., and Song H., 2024, Partial organic substitution increases soil quality and crop yields but promotes global warming potential in a wheat-maize rotation system in China, Soil and Tillage Research, 244: 106274.
https://doi.org/10.1016/j.still.2024.106274

Wu Z., Chen X., Lu X., Zhu Y., Han X., Yan J., Yan L., and Zou W., 2024, Impact of combined organic amendments and chemical fertilizers on soil microbial limitations, soil quality, and soybean yield, Plant and Soil, 507(1): 317-334.
https://doi.org/10.1007/s11104-024-06733-4

Xu X., Bi R., Song M., Dong Y., Jiao Y., Wang B., and Xiong Z., 2024, Organic substitutions enhanced soil carbon stabilization and reduced carbon footprint in a vegetable farm, Soil and Tillage Research, 236: 105955.
https://doi.org/10.1016/j.still.2023.105955

Yang L., Jin W., Chen X., Song W., Yang Y., Zhou J., Kong L., Huang Z., Liu R., and Du X., 2025, Effect of soybean inclusion in cropping systems on productivity, profitability, and carbon footprints: a case study from the Huang-Huai-Hai Plain, Energy, 316: 134422.
https://doi.org/10.1016/j.energy.2025.134422

Yang Q., Li J., Xu W., Wang J., Jiang Y., Ali W., and Liu W., 2024a, Substitution of inorganic fertilizer with organic fertilizer influences soil carbon and nitrogen content and enzyme activity under rubber plantation, Forests, 15(5): 756.
https://doi.org/10.3390/f15050756

Yang S., Zhao Y., Xu Y., Cui J., Li T., Hu Y., Qian X., Li Z., Sui P., and Chen Y., 2024b, Yield performance response to field configuration of maize and soybean intercropping in China: a meta-analysis, Field Crops Research, 306: 109235.
https://doi.org/10.1016/j.fcr.2023.109235

Zhai L., Wang Z., Zhai Y., Zhang L., Zheng M., Yao H., Lv L., Shen H., Zhang J., Yao Y., and Jia X., 2022, Partial substitution of chemical fertilizer by organic fertilizer benefits grain yield, water use efficiency, and economic return of summer maize, Soil and Tillage Research, 217: 105287.
https://doi.org/10.1016/j.still.2021.105287

Zhang L., Zheng H., Li W., Olesen J., Harrison M., Bai Z., Zou J., Zheng A., Bernacchi C., Xu X., Peng B., Liu K., Chen F., and Yin X., 2023, Genetic progress battles climate variability: drivers of soybean yield gains in China from 2006 to 2020, Agronomy for Sustainable Development, 43(4): 50.
https://doi.org/10.1007/s13593-023-00905-9

Zhao J., Wang Y., Zhao M., Wang K., Li S., Gao Z., Shi X., and Chu Q., 2023, Prospects for soybean production increase by closing yield gaps in the Northeast Farming Region, China, Field Crops Research, 293: 108843.
https://doi.org/10.1016/j.fcr.2023.108843

Zhao N., Wang X., He J., Yang S., Zheng Q., and Li M., 2024, Effects of replacing chemical nitrogen fertilizer with organic fertilizer on active organic carbon fractions, enzyme activities, and crop yield in yellow soil, Huanjing Kexue = Environmental Science, 45(7): 4196-4205.
https://doi.org/10.13227/j.hjkx.202307222