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Review: Field crop production: Scientific foundations, global trends, and opportunities for sustainably increasing productivity

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ABSTRACT

Field crop production is central to food security, nutrition, and the rural economy. However, increasing production is no longer simply a matter of increasing input; it has become a multidimensional challenge encompassing improved yields, soil and water conservation, climate change adaptation, and reduced post-harvest losses. This article reviews the scientific basis for wheat, maize, rice, pulses, and oilseed production, and discusses the determinants of productivity from the variety and seed level to field management and the value chain. The latest FAO data shows that global cereal production reached 3.1 billion tons in 2024, a 27% increase compared to 2010, while the harvested area for major primary crops reached 1.5 billion hectares. Improved yields were the main driver of cereal production growth, while oilseed production growth was more closely linked to expanded acreage. [1, 2] The review concludes that the greatest opportunities for improvement arise from an integrated package that includes suitable varieties, careful nutrient management, plant-specific irrigation scheduling, diversified crop rotations, integrated pest management, and improved storage. It also warns that extreme climate change scenarios, if not met with adaptation, could reduce staple grain yields by simulated rates ranging from 7 to 23% (Eyshi Rezaei *et al.*, 2023) [3].

Keywords: Field crops, Crop productivity, Cereals, Pulses, Oilseed crops, Soil fertility, Water use efficiency, Climate change, Post-harvest losses, Sustainable intensification

1. Introduction

Field crops are defined as crops that are often grown in large areas and with production systems that rely on mechanized or semi-mechanized processes. They include cereals such as wheat, maize, rice, and barley; legumes such as lentils, chickpeas, beans, and peas; and oilseed crops such as soybeans, sunflowers, canola, and peanuts. These crops differ in their physiological pathways; wheat and rice are C₃ plants, while maize, millet, and sorghum are C₄ plants, a difference that affects their responses to heat, carbon dioxide, and water [3, 4].

Crop success should not be reduced to the total yield; yield is the product of harvested area and yield, and yield is the quantity of produce per unit area. Therefore, yield can increase due to horizontal expansion even with constant yields, or due to vertical improvement that increases production from the same land. According to the latest FAO statistics, the harvested area of major primary crops increased by 197 million hectares from 2010 to 2024, reaching 1.5 billion hectares, while cereal production rose by 27% to 3.1 billion tons. Improved yields were a key factor in this increase (FAO, 2025) [2].

2. Article methodology and data sources

This article was prepared as a synthetic scientific review combining official databases, international reports, peer-reviewed studies, and meta-analyses. FAOSTAT was used as the primary source for comparative statistics between countries and commodities, utilizing the official summary of crop production 2010–2024. Quantitative data were then linked to published evidence on soil, water, climate change, pests, and post-harvest losses [1, 2]. Furthermore, production in tons, area in hectares, and yield in tons per hectare were separated, as were observed figures and simulated estimates.

3. Global trends in field crop production

Statistical data shows that global crop production growth has been driven by a combination of acreage expansion and improved yields, but the contribution of each factor varies by crop and region. For cereals, global production rose to 3.1 billion tons in 2024 compared to 2010, with increased yields being the dominant factor. Oilseed production increased by 50% to 1.2 billion tons, with acreage expansion playing a more

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significant role, particularly for soybeans and oil palm fruit (FAO, 2025) [2]. This suggests that assessing sustainability should not solely focus on increased production but should also consider whether the increase stemmed from improved efficiency or the conversion of new land. Cereals remain the cornerstone of the global food supply, but they alone do not provide all nutritional requirements. Pulses add protein,

fiber and minerals, and their inclusion in crop rotations can support bio-nitrogen fixation and break the cycles of some pests, while oilseed crops provide edible oils and feed protein, but in some areas, they may be associated with agricultural expansion that puts pressure on forests and biodiversity [4, 5, 6, 7].

Index	Operational definition	Common unit	Its importance in evaluation
Production	Quantity of crops produced during a season or year	tons or million tons	Measures the total supply volume
Harvested area	The area from which the crop was taken	Hectare	Reveals the impact of horizontal expansion
Yield	Production divided by harvested area	ton/hectare	It measures the productive efficiency of the land.
Water use efficiency	Production of dry matter per unit of water consumed	kg/m ³ or ton/m ³	Important in arid and irrigated environments
Nitrogen utilization efficiency	Increase or agricultural output relative to nitrogen used	kg crop/kg N	Production is linked to the risk of loss and pollution.

crop group	Key examples	Nutritional or economic function	Productivity and sustainability note
Grains	Wheat, corn, rice, barley, millet, sorghum	Energy, food, food, food, food, food, food, feed, and starch	Sensitive to planting dates, temperature and water
legumes	Lentils, chickpeas, beans, peas	Plant protein and fiber	Crop rotation is beneficial, but nitrogen fixation depends on the variety, bacteria, and environment.
oilseed crops	Soybeans, canola, sunflower seeds, peanuts	Oils, protein and feed	It has experienced rapid global growth, with significant variations in the impact of land expansion.
sugar crops	Sugarcane, sugar beet	sugar and ethanol	They consume large amounts of water and land in some systems.

4. Quantitative data on the production of major crops

4.1 Global production in 2010 and 2024

The following table shows global production data for wheat, maize, rice, and soybeans in 2010 and 2024. The values were extracted from downloadable data files in the Our World in Data Explorer, which dis-

plays FAO/FAOSTAT data after processing and standardization. The values are measured in metric tons, while the relative change was calculated using the equation: $\frac{\text{production}_{2024} - \text{production}_{2010}}{\text{production}_{2010}} \times 100$ [1, 4].

Figure 1. Global production of wheat, maize, rice, and soybeans in 2010 and 2024. The numbers above the 2024 bars represent the percentage change over the period. Source: Data files extracted from the crop indices in Our World in Data/FAOSTAT [1, 4].

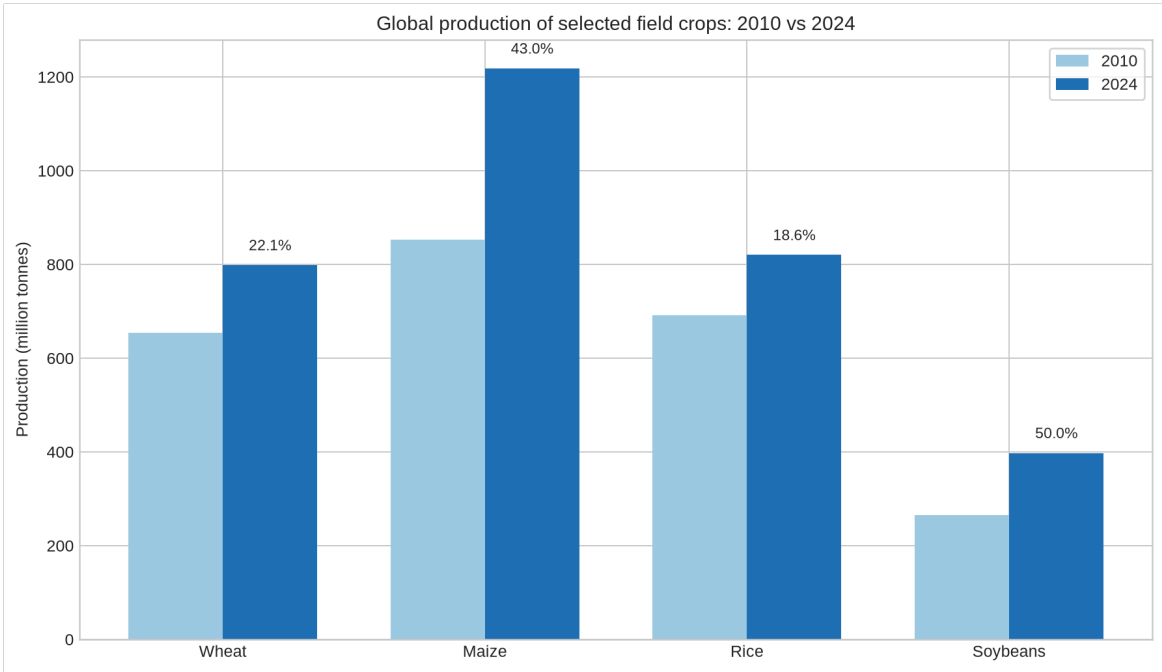


Figure 1. Comparison Production Global For crops Home between the years 2010 and 2024.

Crop	2010 production (million tons)	Production in 2024 (million tons)	Absolute increase (million tons)	relative change
wheat	653.7	798.5	144.8	22.1%
maize	852.0	1,218.2	366.2	43.0%
rice	691.5	820.2	128.7	18.6%
soybean	265.1	397.7	132.6	50.0%

The data shows that maize saw the largest absolute increase, with production rising by approximately 366.2 million tons, while soybeans recorded the highest relative increase at 50.0%. However, these percentages do not necessarily imply that the increase was solely due to improved yields. Overall FAO data indicates that cereal growth was primarily linked to improved yields, while a significant portion of oilseed crop growth was attributed to expanded acreage (FAO, 2025) [2]. Therefore, a detailed causal analysis should consider both the harvested area and yield chains for each crop, rather than interpreting production alone as an improvement in efficiency.

4.2 Unit auditing and limitations of comparability

The figures above represent annual global production in metric tons, not yield or area. Furthermore, the definition of a crop can vary across databases; rice production may be reported in some statistics as paddy rice, while other sources may report milled rice or its processed products. For this reason, figures from different databases should not be combined before a standardized definition of the commodity and its unit of measurement is established. The FAO confirms that the field of crop and livestock production includes data on production and harvested area, with data on processed products available in a separate section (FAO, 2025) [2].

4.3 Practical reading of data

These figures convey three agricultural messages. First, maize, wheat, and rice remain the base of grain supply, but their growth rates are not uniform; maize has grown faster than wheat and rice over the same period. Second, the 50% growth in soybean production highlights the expanding demand for oils, protein, and animal feed, and necessitates an analysis of the impact of land expansion and trade on forests and biodiversity. Third, the global increase alone is insufficient to demonstrate improved local food security, as the global average masks differences between countries in yields, water resources, storage capacity, and access to inputs and markets.

5. Scientific determinants of productivity

5.1 Variety and seed

Variety determines a significant portion of yield potential through its growth period, light interception efficiency, drought, heat, and disease resistance, and market suitability. However, an improved variety cannot reach its full potential without genetically sound and healthy seeds, appropriate cultivation practices, suitable plant density, and optimal planting time. Yield gap studies indicate that the difference between realized and potential yields is influenced by soil, water, management, and pests, not solely by genetics (Mueller *et al.*, 2012; van Ittersum *et al.*, 2013; Cassman, 1999) [8, 9, 10]. Therefore, genetic improvement programs should treat variety as part of a management system, not as a product isolated from its environment.

5.2 Soil and its fertility

Soil is a vital medium for root anchoring, water storage, nutrient exchange, and support microorganisms. FAO guidelines for sustainable soil management emphasize that organic matter conservation, erosion reduction, improved soil structure, and salinity and acidity management are interconnected elements of sustainable production [11]. Evidence also shows that nitrogen- and organic matter-rich soils can support higher yields, but nutrient use efficiency is not uniform globally, necessitating local management based on soil analysis and crop requirements (Silver *et al.*, 2021) [12].

Practical soil management includes using plant residues or compost where appropriate, minimizing unnecessary tillage, mulching the soil surface, implementing crop rotations that combine cereals and legumes, adjusting machinery movement to prevent compaction, and improving drainage in waterlogged areas. There is no single approach for all fields; the response varies depending on soil texture, climate, depth, organic matter content, and irrigation water quality.

5.3 Nutrients and nitrogen use efficiency

Crops require nitrogen, phosphorus, and potassium, as well as sulfur and micronutrients, but increased fertilizer application does not necessarily lead to increased yield. Excess nitrogen may be lost through leaching, volatilization, or denitrification, and may increase nitrous oxide emissions and lead to water pollution (Roy *et al.*, 2006; Hou *et al.*, 2023; Cassman, 1999) [13, 14, 10]. Integrated nutrient management is based on four practical principles: the right source, the right rate, the right time, and the right place, incorporating mineral and organic fertilizers and biostabilization when conditions are suitable (Roy *et al.*, 2006; Hou *et al.*, 2023) [13, 14].

5.4 Water and irrigation

Water affects germination, leaf expansion, flowering, and grain filling; therefore, crop sensitivity varies according to the growth stage. Reviews of water productivity show that improving irrigation scheduling, field leveling, irrigation method selection, reducing evaporation from the soil surface, and improving root structure can increase yield per unit of water more than focusing solely on increasing the amount of water used [15, 16, 17, 18]. In water-scarce regions, supplemental irrigation at critical stages may be more efficient than undirected over-irrigation.

5.5 Pest and disease management

Insects, diseases, and weeds cause both pre-harvest and post-harvest losses, which vary depending on the crop, climate, and farming system. Global estimates suggest that pests and diseases can undermine a significant portion of potential production, but assessing the loss requires distinguishing between actual damage and excessive chemical protection (Oerke, 2006; Savary *et al.*, 2019) [19, 20]. Integrated pest management combines monitoring, economic thresholds, crop rotation, resistant varieties, biological control, agricultural practices, and the controlled use of pesticides when necessary [21, 22].

6. Climate change and production risks

Climate change impacts crops through rising temperatures, altered rainfall, increased droughts and heat waves, changing pest pressure, soil salinity, and disruption of planting schedules. A Nature Reviews Earth & Environment review shows that increased carbon dioxide may offset some of the climate impact on wheat and rice, but heat and drought can negate this offset, while C₄ crops benefit less from the fertilizing effect of carbon dioxide (Eyshi Rezaei *et al.*, 2023) [3]. In a severe, non-adaptive scenario, simulated yield losses for staple cereals ranged from 7% to 23% (Eyshi Rezaei *et al.*, 2023) [3].

Global modeling studies have also shown that maize, wheat, and rice do not respond to the same degree, and that outcomes depend on the climate scenario, water and nutrient management, planting date, variety, and the assumed impact of carbon dioxide (IPCC, 2022; Jägermeyr *et al.*, 2021; Lobell *et al.*, 2008; Ortiz-Bobea *et al.*, 2021; Asseng *et al.*, 2015; Zhao *et al.*, 2017; Challinor *et al.*, 2014) [23, 24, 25, 26, 27, 28, 29]. Therefore, presenting a single climate figure as a definitive prediction should be avoided; it is more appropriate to present ranges and explain the sources of uncertainty.

Danger Path	Potential impact on crop	Adaptation options
high temperature	Shortening the gestation period and increasing infertility or heat stress	Early or heat-tolerant varieties, and adjusting the planting date
Drought	Reduced leaf area and full grains	Supplemental irrigation, soil moisture retention, tolerant varieties
heavy rains	Excessive rainfall, erosion, and delays in planting and harvesting	Improved drainage, terraces, and process timing management
Change in pest pressure	The range of some pests and diseases has expanded	Early detection, genetic resistance, integrated management
High salinity	Poor water absorption and ionic imbalance	Calculated drainage and washing, tolerant varieties, irrigation water management

7. Towards sustainable agricultural intensification

Sustainable intensification aims to produce more food from the same land while reducing environmental damage and improving farmers' resilience. Extensive reviews have concluded that the performance of sustainable technologies varies depending on the context; conservation agriculture, integrated fertilization, or intercropping may succeed in one location but require modification in another due to soil, labor, and market characteristics (Pretty *et al.*, 2018; Tilman *et al.*, 2011; Foley *et al.*, 2011; Rockström *et al.*, 2017) [30, 31, 6, 32]. Therefore, scientific recommendation should not be a "one-size-fits-all" approach, but rather a decision package based on field-specific assessments.

Distance	Index	Method of calculation or measurement	Significance
Productive	Yield	ton/hectare	land use efficiency
Water	Water productivity	kg crop/m ³ water consumed	The system's suitability for water scarcity
My food	Protein or energy produced	kg of protein or megajoules/hectare	Measuring mass alone goes beyond that
environmental	Net nitrogen or greenhouse emissions	kg N or kg CO ₂ e/ton	Input efficiency and climate impact
soil	Organic matter and drift	Periodic measurements and soil cover indicators	long-term flexibility
economic	Risk-adjusted profit margin	Revenue, less costs and losses	Adoptable and sustainable
Value chain	Loss after harvest	Percentage of quantity or quality lost	Efficiency of converting produce into food

10. Discussion

Evidence suggests that field crop production is determined by the interaction of four levels. The first level begins with genes and seeds, followed by the field level, which includes soil, water, nutrients, and pests. Next comes the farm level, encompassing crop rotation, labor, mechanization, and risk management. Finally, the value chain and policy level determines the producer's access to markets, storage, and financing. This interaction explains why the results of a successful experiment at a research station may not directly translate to farmers' fields.

Increased global production does not mean the end of food security problems; higher production may coexist with unequal access, food poverty, high losses, and environmental degradation. Crop diversifi-

The most generalizable package includes pre-fertilization soil analysis, certified and adapted seeds, a varied crop rotation, appropriate soil cover, water management based on soil moisture and physiological stage, regular pest monitoring, and the use of weather and remote sensing data when available. Effectiveness increases when these practices are supported by extension services, financing, insurance, and infrastructure, as limited access to inputs and markets may prevent farmers from implementing the correct technical recommendation (Pretty *et al.*, 2018; HLPE, 2014; FAO, 2016) [30, 33, 34].

8. Post-harvest and value chain

Crop production efficiency is not fully realized at harvest; threshing or grain loss can occur during drying, transport, storage, and marketing. Grain loss reviews have estimated that post-harvest losses can be substantial in some environments, varying widely depending on the crop, infrastructure, climate, and storage method (Affognon *et al.*, 2015; Kumar *et al.*, 2017; Hodges *et al.*, 2011) [35, 36, 37]. A review published in PMC, based on World Bank estimates, cited approximate ranges of grain losses of 7–10% in some field operations and 4–5% in the market stages, emphasizing that values vary considerably depending on the context (Affognon *et al.*, 2015) [35].

Priority interventions include determining appropriate harvesting and storage humidity, rapid and safe drying, using airtight containers or well-ventilated storage facilities, controlling rodents and insects, and improving sorting, packaging, and transportation. When evaluating these interventions, quantity, quality, and safety must be measured, as weight reduction alone does not account for mycotoxins or nutritional deficiencies.

9. Proposed indicators for measuring the success of a crop production system

Evaluating a system based solely on yield is not recommended. A farm might achieve high yields but consume excessive water or nitrogen, or experience significant post-harvest crop loss. The following table suggests an indicator board that combines production, efficiency, and resilience.

cation remains important for improving food diversity and resilience, but diversification should consider market conditions, consumer needs, and the risks of alternative crops [4, 38, 39, 40, 41]. In arid regions, increasing water productivity may be more important than maximizing yields, while protecting soil from erosion may be a priority on sloping lands.

11. Conclusion and recommendations

Analysis shows that the future of field crop production depends more on increasing yields from existing resources than on uncontrolled land expansion. Global cereal production reached 3.1 billion tons in 2024, with improved yields being a major driver of growth since 2010, while the expansion of oilseed crops has been more closely linked to increased acreage (FAO, 2025) [2]. Meanwhile, climate models reveal

that a lack of adaptation could lead to significant losses in staple cereal yields (Eyshi Rezaei *et al.*, 2023) [3].

Therefore, the article recommends adopting production programs based on soil diagnosis, suitable seeds, integrated fertilization, precise irrigation scheduling, varied crop rotations, integrated pest management, and improved storage. Public investment should focus on extension services, data, and post-harvest infrastructure, rather than simply subsidizing inputs regardless of their efficiency. Future research needs to link field trials with climatic and economic models and simultaneously measure food, nutritional, profitability, and environmental impacts.

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