



Decision Agriculture – Agriculture 5.0

Pros and Cons of Artificial Intelligence 2025/2050

Dr. Manfred J. Kern

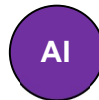
Director, AgriExcellence e.K.

55296 Lörzweiler, Germany

Manfred.Kern@agriexcellence.de

www.agriexcellence.com

March 2025



Global Symbols:



Technological Intervention
for Innovative Agriculture



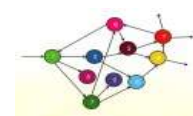
Internet
Agriculture



Digital
Agriculture



AI / Decision
Agriculture*



Socio-Economic
Evaluation

In 2015 “Digital Agriculture” (*IGREEN @evolution*) was the title of a paper from the author published by ISPSW: Strategy Series: Focus on Defense and International Security, Issue No. 331, 1-8, March 2015 (Kern, M., 3/2015; 9/2015). The abstract is quoted as follows:

Abstract, Anno 2015:

“Do more with fewer resources and with better results – and do it in time!” this should be a vision for all of us.

“Today, at the beginning of the 3rd Millennium, agriculture is confronted with a wide range of complex challenges. The task is to meet the growing demand for food, pet food, feed, fiber, fuel, industrial products and products based on ‘functional’ plants and improved agricultural production systems. By 2050, world food, feed, and biofuels requirements will more than double as a result of population growth and dramatically changing consumption patterns. Sustainable solutions are requested more and more.

By pressing the *IGREEN @evolution* forward in agriculture through implementation of digital systems such as smartphones, apps, global positioning systems (GPSs), sensors, robotics, drones, unmanned autonomous vehicles (ULVs) such as unmanned ground vehicles (UGVs) and unmanned aerial vehicles (UAVs), and others, the changing world will be able to address challenges in front of us.

Relevance and impact of digital systems on agriculture as well as data ownership, big data documentation and e-learning is addressed in order to improve sustainability of agriculture. Agriculture will become more like an exact science documenting and using data covering yield, energy uses, plant health status, biodiversity patterns, water use efficiency, nutrient use efficiency, GHG emissions, pollination, distribution of pest and diseases, welfare, soil qualities, soil fertility, water quality, water flow, profits, costs in real time.

The analog world in agriculture is becoming increasingly digitized, and last but not least: a digitized Ag-World and implementation of **IGREEN @evolution** will enable key resources to be preserved sustainably – more than 30 percent by 2050.”

10 Years Later

In 2025, “Decision Agriculture” using Artificial Intelligence (AI) (AIGREEN @evolution) will revolutionize the agricultural landscape directly or indirectly all over the world.

The focus of this paper is on an analysis of the current state of the art and an outlook to 2030/2040/2050, reflecting the pros and cons of AI in transforming agricultural practices, crop production and food production. State-of-the-art AI will enable autonomous production decisions by optimizing resource use, reducing risk and waste, increasing efficiency, effectiveness, food safety and sustainability.

Kumari, K. et al. (3/2025) are describing the evolution of agriculture and technology like that: *“There have been four major phases in the development of agricultural technology. Beginning around 10,000 BC, agriculture 1.0 relied on manual labor, animal power, and simple equipment, which resulted in ineffective operations with low productivity.*

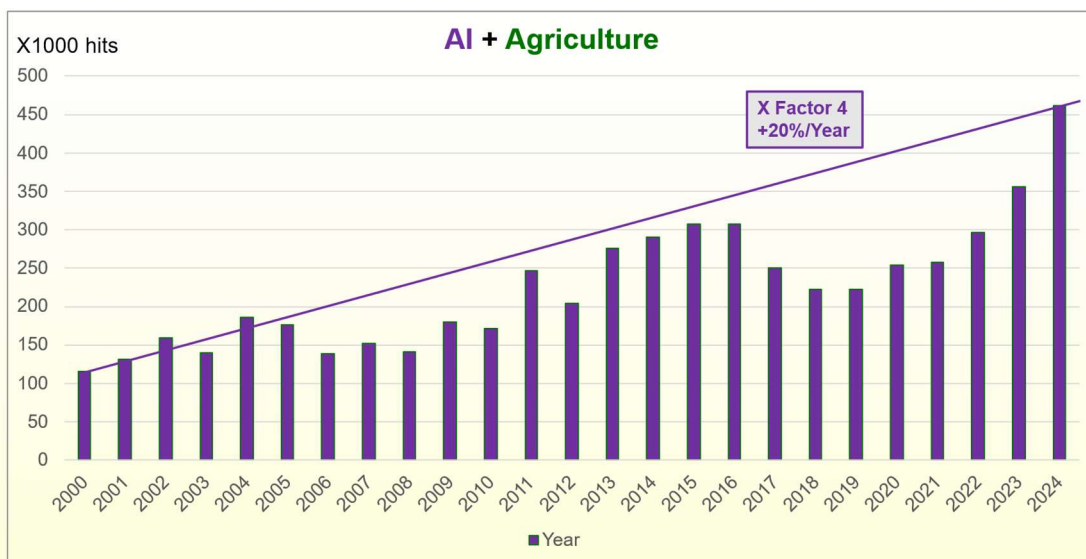
The 19th-century emergence of agriculture 2.0 included mechanical equipment like harvesters and tractors, as well as chemical inputs, which increased productivity but had drawbacks due to poor resource usage.

Through automation, robots, and computer-based systems, agriculture 3.0 improved farming throughout the 20th and 21st centuries. However, the comparatively low intelligence of these technologies resulted in limited precision.

To improve resource management and decision-making, agriculture 4.0 now emphasizes smart devices and systems that integrate technology like drones, the Internet of Things, and AI-driven analytics. However, this modern phase introduces additional concerns, particularly in terms of data security and privacy. This timeline highlights the evolution of agricultural methods, demonstrating the ongoing transition to intelligent and automated solutions while addressing the inefficiencies and difficulties of each stage.”

To get a global overview of the number of topics on AI and its advantages and disadvantages in agriculture, a GOOGLE search was conducted on March 30, 2025. The number of hits was determined by combining AI with 32 different keywords such as agriculture, crop production, crop protection, ... as well as advantages and disadvantages. In all areas, there were more hits for advantages than disadvantages! On average, there was a factor of 1.3 advantages/disadvantages. Interestingly, there are 10 relevant fields that were significantly higher than the average factor of 1.3: “agriculture” 1.4, “zero hunger” 1.4, “agricultural productivity” 1.5, “crop production” 1.6, “plant breeding” 1.6, “weed control”, 1.7, “sustainability” 1.7, “environment” 1.9, “costs” 2.0, “jobs” 2.2 (Fig. 1, 2). AI plus “climate change” plus advantages or disadvantages resulted in the most hits (>1 million), but the ratio was only 1.1 below average. From this simple overview, it can be concluded that AI brings more advantages than disadvantages in the area examined.

Hits via Google Recherche, 30th March, 2025
 “**AI + Agriculture**“, 2000-2024, 3/2025



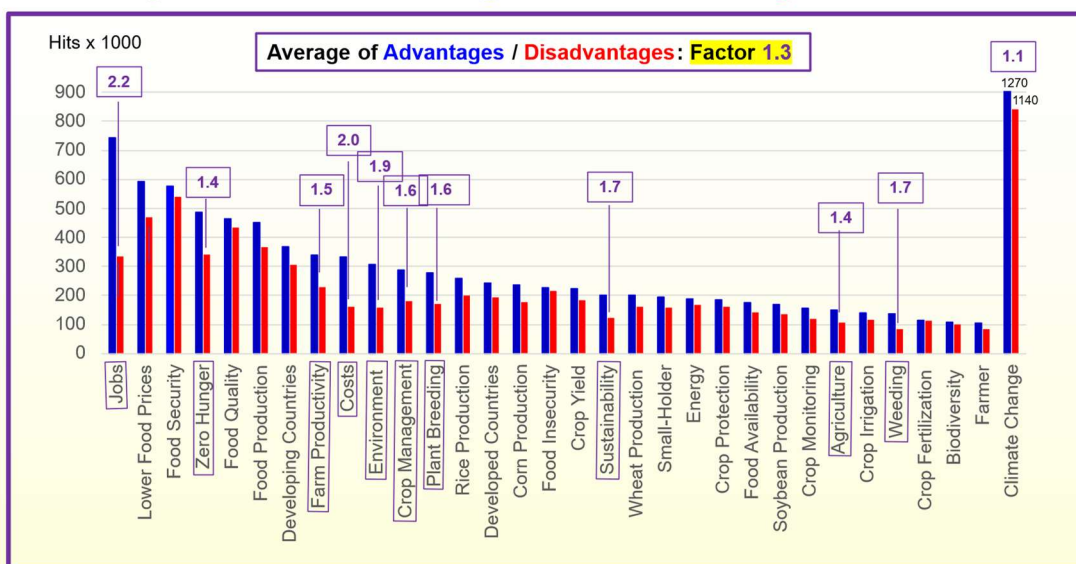
Source: Kern, M., 3/2025

Dr. Manfred Kern



Fig. 1: Hits via Google Recherche, 30th March 2025, “AI + Agriculture”, 2000-2024, 3/2025

Hits via Google Recherche, 30th March, 2025
 “**AI + ‘Keywords’ + Advantages / Disadvantages**“, 3/2025



Source: Kern, M., 30.03.2025

Dr. Manfred Kern



Fig. 2: Hits via Google Recherche, 30th March 2025, “AI + ‘Keywords’ + Advantages/Disadvantages”, 3/2025

However, it is more relevant and important to assess the value of AI and “decision agriculture” and to evaluate the advantages and disadvantages in relation to various indications, e.g. for farmers, smallholders, the environment, food security, developing countries, consumers, societies, crops etc. and the enormous dynamics and consequences of implementation.

Key Factors Leading to the Adoption and Implementation of ‘Decision Agriculture’ in Agricultural Farming Systems

A. Advantages of AI in ‘Decision Agriculture’:

1. Data-driven ‘decision agriculture’

- Improving the range of agricultural production methods (De Oliveira, R.C. and De Souza e Silva, R.D., 6/2023).
- Combining AI with Industry 4.0 technologies in agriculture
- Optimising of multiple objectives simulatiously
- Operating faster and enabling more precise work
- Enabling autonomous predictive decision-making
- Making decision-making processes more efficient, resilient and profitable
- Improving calculation and monitoring of resource efficiency and resource saving potentials in agriculture
- Covering all agricultural systems
- Contributing to global sustainable development
- Leaveraging to achieve political goals – SDGs (Mac Pherson, J. et al., 7/2022), whith most of the 17 SDGs are not on track to be achieved by 2030 (Kern, M., 4/2025)

2. Improvements in Plant Breeding

- Improving the range of plant breeding methods
- Accelerating and streamlining plant breeding and genetic improvements
- Shortening steamlining the breeding cycles and improving accuracy in varietal selection
- Contributing to the development of beneficial traits and reducing off-target effects
- Predicting correlations between phenotypes and geneotypes under different environment conditions
- Providing machine learning programs enabling breeders to develop new crops/varieties
- Improving seed quality throught AI-driven learning platforms for machine learning, computer vision and data analysis, less time-consuming, improved accuracy, efficiency, and cost-effectiveness (Sairone, 2/2025)

3. Improvements in Crop Management

- Fine-tuning all aspects from seeds to harvest
- Improving the safty of agricultural production
- Improving the efficient use of nutrients, saving on fertilizers
- Reducing the risks of errors
- Eliminativg inefficiencies
- Increasing the profitability of crop production

4. Improvements in Crop Rotation Planing (Sairone 2/2025)

- Optimizing of crop rotations
- Selecting the most suitable crops on farms
- Facilitating ultra-multicropping, permaculture, and the growing of hedgerows (Daum, T., 2021)

5. Improvements in Pest and Disease Management

- Improving the monitoring and prediction of pest and disease outbreaks (De Oliveira, R.C. and De Souza e Silva, R.D., 6/2023)
- Providing real-time information on crop growth and health (Escriba-Gelonch, M. et al., 5/2024)
- Reducing the need for manual labour, and lowering operational costs (Raksha, 4/2025)
- Reducing pesticide use by 30% through AI-based insect monitoring (Tamanna, Y., 3/2025)
- Improving the effectiveness of pest and disease control, 50% less pest-caused losses (Tamanna, Y., 3/2025)
- Through the global use of 3000,000 commercial drones on more than 500 million hectares of farmland drones have helped to save over 210 million metric tonnes of water, and 47,000 metric tones of pesticides, and reduce emissions by over 25 million metric tons (DJI Agriculture Drone Industry Insight Report 2023/2024)
- Enabling optimal combinations of agronomic measure
- Enabling alternative weed control
- Enabling chemical-free farming by robots using lasers (Knutsson, K., 3/2025)
- Reducing the use of chemicals and runoff
- Diagnosing and curing plant diseases – new *'farm doctor'*
- Designing peptides (APP3-14) that can block *'cancer of citrus'* (Zhao, P. et al., 4/2025)

6. Improvements of Precision and Resilience of Agriculture

- Detecting biotic and abiotic stress
- Utilising real-time data
- Assessing the yield and quality potential
- Using nanotechnology in agriculture (nanoertilizers, nanopesticides, nanosensors, plant sensors)
- Improving the classification and sorting of products
- Predicting harvest potentials
- Prediction of agricultural production
- Avoiding overproduction or shortages
- Reducing post-harvest losses (Zadok, A.O., 7/2025)
- Optimizing transportation routes to ensure product quality
- Enabling market prediction analysis
- Improving connection with markets and buyers
- Contributing to economic, environmental and social sustainability (Mana, A.A. et al., 2/2024)
- Enabling weather-indexed crop insurance products for accurate farmer compensation (Gautam, L., 1/2025)

7. Improvements in Resource Management

- Reducing waste/input waste (De Oliveira, R.C. and De Souza e Silva, R.D., 6/2023)
- Reducing pollution
- Reducing the demand of natural resources (Kern, M., 2010, 2011)
- Reducing the environmental costs of conventional practices (Zürner, S. et al., 1/2023)
- Enabling more harvests with fewer resources
- Improving resource efficiency (Tamanna, Y., 3/2025)
- Enabling the monitoring of incorrect use of more nitrogen (N) fertilizers
- Enabling the detection and monitoring of micro- and nanoplastics, an invisible and neglected epidemic pollution in crops, soils, water, environment and all ecosystems (Kern, M., 4/2025)

- Maintaining healthier ecosystems
- Reducing compaction of topsoil in agriculture (Sparrow, R. and Howard, M., 10/2020)
- Improving soil quality by automated identification of nematodes
- Improving water management through AI-powered irrigation schedules (Mana, A.A. et al., 2/2024)
- Improving biodiversity
- Providing systems to identify, monitor and track endangered species (Gautam, L., 17/025)
- Enabling a balance between agribusiness and environmental ecosystems (Mana, A.A. et al., 2/2024; Zeddies, H.H. et al., 7/2024)

8. Improvements in Climate Change Adaptation

- Providing improvements in monitoring and forecasting the impacts of climate change
- Contributing to the protection of the environment and the planet (Perch Energy, 9/2024)
- Enabling predictions of regional and global disasters (flood, storms, droughts, locusts) and environmental changes
- Providing improvements in monitoring and managing water use efficiency
- Mitigating the adverse effects of climate change and socio-economic impacts in agriculture (Gautam, L., 1/2025)
- Offering recommendations to address climate change and crisis management
- Enabling fossil fuel free agro-systems
- Contributing to the reduction of greenhouse gas emissions and carbon footprint (Kern, M., 4/2011; Mana, A.A. et al., 2/2024)
- Supporting farmers to participate in carbon credit markets by verifying carbon sequestration in soils
- Enabling more accurate and reliable climate models (Gautam, L., 1/2025)

9. Improvements in Food Security/Safety

- Helping to ensure food security/safety (Ahmad, A. et al., 2024; Mana, A.A. et al., 2/2024; Mmbando, G.S., 1/2025)
- Providing a tool to increase the stagnating crop yields in sub-Saharan Africa (Wollburg, P.T. et al., 5/2024)
- Enabling the production of cost-effective and affordable food
- Improving agricultural logistics
- Helping to reduce food insecurity for two billion people (Kern, M., 4/2011)
- Recommending measures before hunger escalates into a human crisis
- Supporting the monitoring of safety standards
- Ensuring compliance with environmental and health regulations
- Providing specific programs to reduce fraud and corruption in agricultural systems

10. Automation of Labor-Intensive Tasks

- Replacing jobs that are "*dull, dirty, and dangerous*" (Sparrow, R. and Howard, M., 10/2020)
- Reducing the need for low-skilled labor
- Compensating labour shortages (Rose, D.C. et al., 5/2021)
- Improving the speed of operations/processes
- Enabling round-the-clock work without breaks
- Improving the quality and accuracy of the harvest
- Reducing labor costs

11. Autonomous Farming Systems

- Streaming the agricultural operations (planting, irrigating, monitoring, weeding, harvesting)
- Increasing the efficiency of crop production (De Oliveira, R.C. and De Souza e Silva, R.D., 6/2023)
- Replacing chemical pest control
- Sowing crops by drones (Sairone, 8/2024)
- Focusing on fossil fuel free systems
- Triggering robot functions to ensure day and night operations
- Providing multifunctional robots, drones, driverless tractors
- Acting like a personal 'human' agronomist and empowering farmers with precise data-controlled systems (Gautam, L., 1/2025)
- Minimising human interventions
- Reducing accidents and improving the safety of farm workers

12. Machine Learning Models

- Predicting of optimal planting and harvesting time
- Enabling combinations with other technologies
- Providing advanced functions for spraying, planting and harvesting
- Using "Digital Twins" offers the possibility to replicate the functionalities of objects and plants in real time and can support decision making in farm management (Escriba-Gelonch, M. et al., 5/2024)
- Improving yield predictions
- Improving the detection of pests, nematodes (Marston, J., 4/2025) and diseases
- Optimizing resource allocation (soil, water, pesticides, fertilizers)
- Enabling deep learning models, trained on huge datasets of seed images combined with quality data (Sairone, 2/2025)
- Democratizing access to expert-level diagnostic tools (Gautam, L., 1/2025)
- Providing enormous potential to analyze the small farm sector (Michelson, M., 4/2025)

13. Fossil Fuel Free Farming

- Contributing to a "Fossil Fuel Free Farming Future" (Kern, M., 2011, 2018, 2023)
- Enabling field operations without the use of fossil fuels (Mana, A.A. et al., 2/2024)
- Using renewable energy provided by agriculture itself (biomass, biogas, photovoltaics, solar panels, wind turbines, etc.) can provide energy for electricity and data processing as well as for data centers
- Encouraging innovators to develop environmentally friendly data processing (Harvard International Review 1/2020)
- Improving the fight against climate change

14. Improvements in Developed Countries

- Improving agricultural productivity in a significantly more sustainable way
- Contributing to safeguard food security and food safety by more sustainable crop yields
- Improving the profitability of agricultural production systems
- Transforming agriculture in an revolutionary way
- Improving the live of farmers and rural communities
- Minimizing the risk of crop failiures
- Reducing the environmental impact (Zeddies, H.H. et al., 7/2024)
- Reducing the gap of labor shortage
- Offering qualifyied jobs
- Enabling new agri-business segments
- Opening a new agro-based commercial industry
- Enabling to combat climate change

15. Improvements in Developing Countries

- Reducing the risk of crop production
- Improving yields (+25%) and farmers' income (Tamanna, Y., 3/2025)
- Improving logistics
- Reducing costs, increasing profitability, adapting to climate change, improving food security in agriculture (Farming in Kenya Consultancy, 9/2024)
- Overcoming outdated agricultural practices
- Revolutionizing floriculture in Kenya (Toolify.ai, 2/2024)
- Enabling 'decision-making systems' in agricultural administrations

16. Reduction of Production Costs

- Saving significant costs (AJ, 3/2024, Agriline, 3/2024)
- Increasing operational efficiency and effectiveness
- Enabling the use of autonomous agricultural equipment to reduce labor costs
- Using drones to replace large tractors, conventional agricultural engineering and many human workers (DJI Agriculture Drone Industry Insight Report 2023/2024)
- Reducing production and environmental costs by not compacting soil and burying diesel (DJI Agriculture Drone Industry Insight Report 2023/2024)
- Achieving environmental and social goals in a cost-effective way (Lowenberg-De-Boer, J. et al., 5/2019)

17. Education, New Jobs, Start-Ups, Entrepreneurship

- Making farmers to be '*Agents of Change*' (Mana, A.A. et al., 2/2024)
- Creating new types of jobs, because work does not disappear due to technology, its nature changes skilling (Modi, N., Prime Minister of India 2/2025)
- Requiring urgent investment in skilling and re-skilling (Modi, N., Prime Minister of India 2/2025)
- Leading to re-skilling and up-skilling (Marinoudi, V. et al., 11/2021); Daum, T., 4/2025)
- Revolutionising the education system in farming systems as well
- Improving the education tools for farmers living in developing countries
- Involving women in new forms of agricultural work
- Demanding hybrid, interdisciplinary teams (Shah, N., 12/2024)
- Offering high-tech careers for young people
- Addressing a bottleneck as access to expertise e.g. in nematodes, becomes increasingly difficult (Marston, J., 4/2025)
- Using drones in agriculture, implicates the creation of more than 100,000 new jobs in the U.S. by 2025 (DJI Agriculture Drone Industry Insight Report 2023/2024)
- Enabling young entrepreneurs to develop and sell innovative agritech solutions (Kern, 2018, Farming in Kenya Consultancy, 9/2024)
- Providing opportunities for investors/investments and partnerships (Kern, M., 2/2001, 4/2011)

18. Rise of Attractiveness of Farming

- Bridging the gap to the cutting-edge world of Big Data and universal AI
- Triggering the transformation of agriculture to a new level
- Encouraging young people to work in agriculture (Kern, M., 2013, 2014; Farming in Kenya Consultancy, 9/2024)
- Empowering young people to adapt, develop and implement appropriate agritech solutions (Kern, M., 2018, 2019)
- Increases the image of agriculture in societies

19. New Business

- Paving the way for farmers to enter agribusiness
- Opening up an attractive field for entrepreneurs

- Establishing new information and education centers
- Setting up advisory services for 'Decision Agriculture'
- Establishing contractors for 'Decision Agriculture'
- Developing a global AI market in agriculture that will reach USD 4.7 by 2028 (CAGR: 23.1), and USD 11.14 by 2032 (Market.Us Report, 2/2024; Tamanna, Y., 3/2025)
- Providing AI-technologies for 21% of farmers by 2025 (Tamanna, Y., 3/2025)
- Addressing the readiness among farmers to adopt AI-based technologies by large scale farms (>5000 acres) 81%, medium farms (2000-5000 acres) 76%, small farms (<2000 acres) 36% (Tamanna, Y., 3/2025)
- Enabling a return on investment (ROI) of 120% for small farmers and 150% for large-scale farmers (Tamanna, Y., 3/2025)
- Developing a global market for agricultural robots to reach USD 34.0 by 2028 (CAGR: 20.5%) and USD 86.5 by 2033 (Market US Report, Robot Market, 11/2023)
- Developing a global market for controlled environment agricultural (CEA) robots (hydroponics, aeroponics, aquaponics, other growing methods) to grow from USD 125.1 in 2025 to USD 194.0 by 2028 (CAGR: 18.1%) and USD 377.6 by 2032 (Market US Report, CEA Market, 3/2025)

B. Disadvantages of AI in 'Decision Agriculture':

1. Lack of Familiarity and Experience with AI-Driven Technologies

- Lack of established modern agricultural education systems and infrastructure
- Unequal access to necessary resources and appropriate solutions
- Culturally unadapted solutions
- No linkage with traditional knowledge and technology (Mmbando, G.S., 1/2025)

2. Investment Costs

- High investment costs
- Unequal access to finance
- Incentives, subsidies or low-interest loans to offset high costs are rare
- Not affordable for many farmers
- Discrimination against certain types of farms or crops

3. Specific Job Displacement in Agriculture

- Lack of skills
- Lack of skills to work with AI-driven technologies - "*digital literacy*" (Zscheitschler, J. et al., 4/2022)
- Aversions to cutting-edge technologies - "*technology phobia*"
- Leads to job losses in agricultural labor
- Impacts rural communities and livelihoods (Meghwanshi, S., 4/2024)
- Increased competition between farmers and agribusiness - "*winner and losers*"
- Widening gap between commercial and subsistence farmers

4. Dependence on Technology and Expertise

- High dependency on internal and external experts and expertise
- No absolute substitute for human expertise, there is no all-or-nothing decision (Lelech, K., 2/2025)
- Loss of autonomy and identity (Mana, A.A. et al., 2/2024)
- Increase in '*technostress*' (Mana, A.A. et al., 2/2024)
- The need for special protection of data centers and satellites, networks, energy supply - because agricultural production is part of the vital critical infrastructure

5. Over-Reliance on AI-Predictions

- Inconsistencies, biases, errors, failures, no crop fails due to downtime (Shalwa, 9/2024)
- Bias, i.e. AI-driven systems learn what they have been taught, judgements should be strictly impartial (perch energy, 9/2024)

6. Uncertainty of Data Sets and Interpretability

- Data limitations and quality issues
- Calibration of data models
- Measurements errors
- Temporal inconsistencies (storms, earthquakes), unobservable variables (Wuepper, D. et al., 3/2025)
- Inconsistent, insufficient and outdated data
- Inherent complexity of agricultural operations
- Lack of user-friendly tools and interfaces (Sairone, 1/2025)

7. Loss of Traditional Knowledge

- Traditional knowledge is not sufficient to double crop production by 2050
- Over-reliance on cutting-edge technologies is causing traditional knowledge to be forgotten in some cases
- Triggering the erosion of traditional farming knowledge and practices accumulated over generations (Meghwanshi, S., 4/2024)
- Traditional knowledge and skills are necessary when digital systems fail
- Traditional knowledge is a prerequisite for the development and implementation of decision agriculture

8. Limited Access for Small-Scale Farmers, especially in Developing Countries

- Development and adoption in developing countries is delayed and varies by region
- High initial costs and lack of access to capital
- Lack of valid data sets and infrastructure (Michelson, H., 4/2025)
- Most traditional farmers are overwhelmed to understand data, use and manage software, and solve problems (Farming in Kenya Consultancy, 9/2024)
- Lack of confidence in new technologies
- Resistance to change
- Lack of trained personnel, skills
- Limited access to good internet and electricity, e.g., only 30% of rural areas in Kenya have access to reliable internet,
- Sixty percent of young people in sub-Saharan Africa are not online, compared to only four percent in Europe (Vincent-Lancrin et al., 2022)

9. Regulatory Uncertainty

- Lack of coherent policies and legal frameworks concerning data ownership (Kern, M., 2015)
- Lack of data sharing policies
- Lack of trust between stakeholders
- Pace of regulation lags behind technological development and hinders adaptation of AI-powered agriculture

10. Data Privacy and Security Concerns

- Vulnerability to cyber attacks on sensitive agricultural information (Leech, K., 2/2025)
- Need for help from 'White Hat Hackers' (Tzachor, A. et al., 2/2022)
- High dependence on power, energy, electricity especially

11. Ethic Concerns

- Lack of transparency

- Programed hidden bias in decision making
- Potential risks and ethical objectives (Ayriss, K. et al., 2/2024) are often not considered from the beginning of technology development (Tzachor, A. et al., 2/2022)
- Changing landscapes
- Hindered by cultural and social barriers (Mmbando, G.S., 1/2025)
- Hindered by “*Scientific Apartheid*”
- Political unrest, war

12. Misuse (e.g. Drones, Apps)

- Data misuse
- Use as weapons
- Destruction of crops and agricultural production
- Destruction of agricultural resources
- Dissemination of fake news

Some farmers voices from Germany are quoted here from a recent report (6/2024) titled: “**This is how digital agriculture is**” published by Rohleder, B. (Bitkom) and Meinel, T. (DLG) in June 2024. Results were based on a computer-assisted telephone interview (CATI) and online survey of 500 farmers in Germany. Some answers from farmers are the following:

- AI is a challenge for agricultural businesses (54%)
- The majority of farmers see digitalization and AI as an opportunity (79%) rather than a risk (15%)
- Confirming to save fertilizer, crop protection products and other resources (91%)
- Confirming a more environmentally friendly agricultural production (80%)
- Convinced that their farms can reduce costs in the long term (67%)
- Convinced to improve the quality of agricultural products (60%)
- Confirming to use at least one digital technology on their farm (90%) - mostly GPS-controlled agricultural machinery
- Confirming the use of AI technologies (9%), and field robots (5%)
- Explaining that the biggest advantages at farm level are time savings (69%), higher production efficiency (61%) and physical relief (57%)
- Explaining that they are very interested in AI training, many have already taken part in further training (34%), many have not yet but are interested, (43%), or are not interested in further training (24%)
- Mentioning that agricultural businesses (45%) have problems finding employees with digital know-how
- Worrying about loss of data sovereignty (49%) and IT-security (47%)
- Declaring to invest in digital / AI technologies after 2025 (33%).

“The use of AI is not a trend, but rather a necessity due to the many increasing burdens on farm management.” in Germany was summerized by Meinel, T. (Rohleder, B. and Meinel, T., 6/2024).

C. Conclusions:

Back to the beginning and the GOOGLE research where only the quantitative number of hits on AI and 32 different keywords were registered. The average ratio of advantages and disadvantages was 1.3. It was found that AI brings more advantages than disadvantages when looking only at the number of hits but not reflecting the content and value of the hits.

Advantages and disadvantages of AI-supported ‘decision agriculture’

In the 32 selected clusters in the advantages of AI section, 171 advantages were found from various publications - mostly scientific papers and reviews. Of the 12 selected clusters in the area of disadvantages of AI, only 63 disadvantages were identified. The ratio between advantages and disadvantages based on qualitative parameters is 2.7, showing that AI will bring immense benefits and sustainable innovations to the world's agricultural systems.

Nevertheless, it is important not to neglect the disadvantages. There are still significant barriers and challenges (limited digital literacy, inadequate infrastructure, insufficient government support and regulation) to the adoption of AI in agriculture to catch up with cutting-edge technologies in developing countries, especially in Africa. Most of these obstacles can/must be overcome, otherwise the gap between Africa and Europe will widen and inequalities in Africa and towards Europe or the industrialized countries will increase.

In February 2025, a World AI Action Summit was held in Paris on the safety of AI in general and did not specifically address agriculture. Some key priorities were: "Promoting accessibility to AI to reduce the digital divide; avoiding market concentration; ensuring that AI is open, inclusive, transparent, ethically safe and trustworthy, taking into account international frameworks for all; **making AI sustainable for people and the planet**" (Service de Presse de la Présidence de la République, France, 2/2025). End of 2025, Prime Minister N. Modi will host the next AI Action Summit in India, a country of 1.4 billion people that has built a low-cost digital infrastructure and is the world's largest talent hub. One focus will be to address the needs of countries in the Global South. Another focus should be a high priority: AI and agriculture.

The up-and-coming youth in many African countries are looking for work, and if the young people can't get it, they go to the cities or emigrate abroad. Africa needs more jobs, and Europe needs more workers. The introduction of artificial intelligence can drive economic growth and innovation, but it can also lead to high unemployment rates (Marinoudi, V. et al., 11/2021), and social unrest (El Louadi, M., 3/2024).

An UN statement by the World Population Fund on inequalities in Africa and Europe was in 2023: "*Too many young people? Destabilizing. Too many old people? A burden. Too many migrants? A threat*" (UNFPA, 2023).

All in all, there are no real knock-out factors that speak against the use of AI; all disadvantages can be eliminated if the necessary measures are taken.

AI in agriculture has the unique characteristic of enabling leapfrogging, which means that AI can skip several generations and stages of technological development in all countries and societies. A broad spectrum of practical AI based applications worldwide is given by the company Farmonaut® (2025).

The most important building blocks of AI application in the respective clusters are presented and summarized here:

Ad Advantages: More efficient, resilient and profitable decision-making processes; provide machine learning programs that enable breeders to develop new crops/varieties; increase profitability of crop production; select the most suitable crops on farms; improve effectiveness of pest and disease control, predict agricultural production; reduce demand on natural resources; enable balance between agribusiness and ecological ecosystems "*Industrial Ecology*"; provide recommendations to respond to climate change and crisis management issues; helping to ensure food safety; reducing labor costs; using robots to ensure 24/7 operations; optimizing resource allocation; using renewable energy "*Fossil Fuel Free Farming Future*"; improving the living conditions of farmers and rural communities; improving farmers' yields and income; reducing production and environmental costs; encouraging young people to work in agriculture, become entrepreneurs and find better jobs; preparing farmers to enter agribusiness.

Ad Disadvantages: Lack of established modern agricultural education systems and infrastructure; high investment costs that are not affordable for many farmers; lack of skills to work with AI-driven technologies; high dependence on internal and external experts and expertise; inconsistencies, biases, errors, failures, no crop left undone due to downtime; data limitations and quality issues; traditional knowledge is a prerequisite for the development and implementation of decision agriculture; most traditional farmers are overwhelmed when it comes to understanding data, using and managing software and solving problems; the pace of regulation lags behind technological development and hinders the adoption of AI-powered agriculture; vulnerability to cyber-attacks on sensitive information on farms; potential risks and ethical objectives are often not considered from the outset when developing technology.

14 Take Home Messages:

1. 'Decision Agriculture' will improve decision making in the field/on the farm and enable the goal of more efficient crop production.
2. The correct application of 'Decision Agriculture' can significantly improve agricultural adaptability, crop resilience, productivity, quality, food security/safety, resource management, carbon footprint, profitability and sustainability.
3. 'Decision Agriculture' will promote plant breeding and enabling the production of new crops and varieties, that are a prerequisite for future human life on Earth and on Mars.
4. 'Decision Agriculture' empowered by AI will make it possible to enable '*fossil fuel free*' production systems and reduce the carbon footprint of agriculture.
5. AI-enabled 'Decision Agriculture' will be a key tool for the necessary "*dematerialization, decarbonization and reorganization of resources*" in agriculture worldwide (Kern, M., 4/2011).
6. 'Decision Agriculture' will help to analyse, monitor and offer solutions concerning impacts of agriculture in different agricultural production systems as well as ecosystems worldwide.
7. If decision-makers in industrialized and developing countries do not recognize the value of 'Decision Agriculture' and do not ensure that appropriate guidelines, the necessary provision of the corresponding digital infrastructure and the promotion of local implementation are in place in good time, the use of this key technology will not benefit farming societies and will significantly hinder the modernization of more sustainable agriculture. "*No one will be left behind*" will then remain an ethical phrase and pure utopia.
8. Knowledge sharing, education and training to empower farmers, programs to support AI-supported 'Decision Agriculture', interdisciplinary collaboration, partnerships between the public and private sectors, and smart regulatory standards are important prerequisites for the introduction of 'Decision Agriculture'.
9. The development and implementation of 'Decision Agriculture' will revolutionize agriculture in more or less all countries worldwide and catapult agriculture to a top level, especially in those countries where the necessary skills for an appropriate and tailored use of AI are available, e.g. India, The Netherlands, Indonesia, China, Australia, USA, Canada, Argentina, Brazil, Europe, Ukraine and Kenya.
10. 'Decision Agriculture' will cause loss of autonomy and partial identity, can trigger technostress, cut jobs but also creates new ones, can lead to de-skilling, re-skilling, or up-skilling, need to be responsibly regulated in time and be protected from cyber-attacks, disinformations and abuse.
11. Areas of concern need to be addressed in a serious way, whereby the large amount of advantages of 'Decision Agriculture' need to be shown and communicated to the public at large.
12. 'Decision Agriculture' using Artificial Intelligence (AI) (AIGREEN @evolution) will transform the global landscape of agriculture.
13. 'Decision Agriculture' is expected to make it possible to sustainably conserve important resources worldwide by around 40 percent by 2050.

14. 'Decision Agriculture' / 'Agriculture 5.0' will become mainstream and help farmers to do more with less, better and - in less time.

D. Outlook: Controlled Environment Agriculture (CEA)

Controlled Environment Agriculture (CEA) is a farming technique that involves growing crops in a fully regulated environment using high tunnels, greenhouses, vertical farms, plant factories with fully autonomous and automated systems, or agri-technology parks to ensure crop production in a safe and sustainable manner. These systems are a beacon of hope, offering sustainable, stable, resilient and space-efficient alternatives to traditional agriculture.

Installed where fertile arable land is limited or unavailable, these farming systems are a valuable option to combat climate change, food insecurity, geopolitical tensions, and global supply chain disruptions by enabling year-round supply with consistent quality, lower transportation costs, and reliance on renewable energy sources ("*fossil fuel free*"). The integration of AI, machine learning, predictive analytics and automation technologies, as well as other cutting-edge technologies, will take crop production to a new and necessary level.

Controlled Environment Agriculture (CEA) is operational on Earth. CEA on Mars is in the research phase, partially under development, and is hampered by many unresolved challenges. Relevant activities and developments supported by AI will be presented and discussed by Kern, M. (2026, in preparation).

From:

- 1927: "*Hinsbergs Frühkultur*" ("*Hinsberg's Early Culture*"), Fa. Otto Hinsberg, Erste und älteste reine Pflanzenschutzmittelfabrik, Nackenheim am Rhein, Rheinhessen, Germany (Dr. Reichwein, 1927) via



- 2027: "*Vertical Farming*", "*Controlled Environmental Agriculture*" to



** Admin, 2023

- 2127: "*Mars Agriculture*" on Mars ...



*** Lorente, B. et al., 2018

E. References:

- ** Admin** (2023). Indoor Vertical Farming, <https://futuresoftech.com/indoor-vertical-farming-2/>, 2023.
- Agricline** (3/2024). Advantages and disadvantages of artificial intelligence in agriculture, <https://agricline.com/advantages-and-disadvantages-of-artificial-intelligence-in-agriculture/>, 2024.
- Ahmad, A., Liew, A.X.W., Venturini, F, Kalogeras, A., Candiani, A., Di Benedetto, G., Ajibola, S., Cartujo, P., Romero, P., Lykoudi, A, De Grandis, M.M., Xouris, C., Lo Bianco, R., Doddy, R., Elegbede, I., D'Urso Labate, G.F., García del Moral, L.F., Martos, V.** (4/2024). AI can empower agriculture for global food security: Challenges and prospects in developing nations. *Frontiers in Artificial Intelligence*, 7, 1328530, <https://www.frontiersin.org/journals/artificial-telligence/articles/10.3389/frai.2024.1328530/full>, 2024.
- AJ** (3/2024). Advantages and Disadvantages of artificial intelligence in agriculture, <https://agriplanting.com/advantages-and-disadvantages-of-artificial-intelligence-in-AJ>, 2024.**P**
- Assoualma, C.** (3/2025). The Role of AI in Sustainable Farming Practices: Promoting Environmental Conservation, Kenya, Blog, March 14, 2025, <https://www.amini.ai/blog-post/the-role-of-ai-in-sustainable-farming-practices-promoting-environmental-conservation>, 2025.
- Ayris, K., Jackman, A., Mauchline, A., Rose, D.C.** (2/2024). Exploring inclusion in UK agricultural robotics development: who, how, and why?, *Agriculture and Human Values*, 41/3, 1257-1275, February 2024, <https://pmc.ncbi.nlm.nih.gov/articles/PMC11341617/>, 2024.
- Daum, T.** (9/2021). Farm robots: ecological utopia or dystopia? *Science Direct*, 36/9, 774-777, <https://pubmed.ncbi.nlm.nih.gov/34272072/>, 2021.
- Daum, T.** (4/2025). Digitalization and skills in agriculture, *Outlook on Agriculture*, 4/2025, 1-11, <https://journals.sagepub.com/doi/pdf/10.1177/00307270251336474>, 2025.
- De Oliveira, R.C., and de Souza e Silva, R.D.** (6/2023). Artificial Intelligence in Agriculture: Benefits, Challenges and Trends, *Appl. Sci.*, 13, 7405, [file:///C:/Users/mk/Downloads/applsci-13-07405%20\(3\).pdf](file:///C:/Users/mk/Downloads/applsci-13-07405%20(3).pdf), 2023.
- DJI Agriculture** (2024). Agricultural Drone Industry Insight Report 2023/2024, https://www1.djicdn.com/cms_uploads/ckeditor/attachments/9171/03e81f9a23cf4df447b66c91c43d929a.pdf, 2023/2024.
- Dr. Reichwein** (1927). Versuche mit "Hinsbergs Fröhkultur" (D.R.P.a.) ausgeführt von Landwirtschaftsassessor Dr. Reichwein, Ober-Rosbach, im September 1927, Verlag Eugen Straub, Mainz, 1927.
- El Louadi, M.** (3/2024). Demographic Dynamics and Artificial Intelligence: Challenges and Opportunities in Europe and Africa for 2050. [file:///C:/Users/mk/Downloads/2403.03935%20\(4\).pdf](file:///C:/Users/mk/Downloads/2403.03935%20(4).pdf), 2024.
- Escriba-Gelonch, M., Liang, S., van Schalkwyk, P., Fisk, I., Van Duc Long, N., and Hessel, V.** (5/2024). Digital Twins in Agriculture: Orchestration and Applications, *J. Agric. Food Chem.*, 72, 10737-10752, 2024, https://pubs.acs.org/doi/epdf/10.1021/acs.jafc.4c01934?ref=article_openPDF, 2024.

Farming in Kenya Consultancy (9/2024). Kenya's Agritech Revolution, September 16, 2024, <https://farminginkenya.co.ke/author/farming-in-kenya-consultancy/>, 2024.

Farmonaut® Company (2025). Empowering Farmers Across Every Continent, Satellite and Ai Based Personalized Farm Advisory Report, 2025.

Gautam, L. (1/2025). Making AI an ally for sustainable agriculture in the face of climate change, *SenseGrass, Field Actions Science Report*, Special Issue 27, 138-142, 2025, https://www.institut.veolia.org/sites/g/files/dvc2551/files/document/2025/01/23_VEOLIA_FAC_TS_27_2025_GB_WEB_L_Gautam.pdf, 2025.

Kern, M. (2001). New Partnerships – Partnerships in public and private sector agricultural research, *agriculture + rural development*, 2, 1-6, 2001.

Kern, M. (2010). Vision: Land Resources and Land Use Options – Challenges for Food Security to Climate Change, In: *Crop Science and Land Use for Food and Bioenergy*, Eds. R.K. Behl, W. Merbach, H. Meliczek & C. Kaetsch, (IFSDAA), Göttingen, Germany, Agrobios (International), Jodhpur, pp 3-7, 2010.

Kern, M. (4/2011). Fragenkatalog: persönliche Stellungnahme von Dr. Manfred Kern, 35. Sitzung des Ausschusses für Ernährung, Landwirtschaft und Verbraucherschutz des Deutschen Bundestags, 17. Wahlperiode, Öffentliche Anhörung zum Thema "Welternährung", Montag, den 04.04.2011, 13:00 Uhr Sitzungssaal: 3 101 Sitzungsort: Berlin, Marie-Elisabeth-Lüders-Haus, Adele-Schreiber-Krieger-Straße 1, https://webarchiv.bundestag.de/archive/2011/0603/bundestag/ausschuesse17/a10/anhoerung/A_04_4_2011_Welternaehrung/Stellungnahmen/A-Drs_451-C.pdf, 2011.

Kern, M. (2012). Food Security at the Crossroads – A Wake-up Call, *ISPSW Strategy Series: Focus on Defense and International Security*, No. 178, February 2012, https://www.files.ethz.ch/isn/136536/178_Kern_Food_Security.pdf, 2012.

Kern, M. (3/2013). Cutting Edge Science & Technologies towards Food, Environment and Health Focus: Encouraging Young Scientists, *ISPSW Strategy Series: Focus on Defense and International Security*, No. 231 1-8, March 2013, https://www.files.ethz.ch/isn/164345/231_Kern.pdf, 2013.

Kern, M. (2014). Vision Cutting-Edge Science and Technologies Towards Food, Environment and Health Focus: Encouraging Young Scientists, In: *Proceedings of the International Conference on Renewable Energy for Institutes and Communities in Urban and Rural Settings*, April, 27-29, 2012, Göttingen, Germany, Eds. R.K. Behl, A.R. Asif, and W. Merbach, Cutting Edge Science and Technologies for Food, Environment and Health, Agrobios (International) Publishers, Jodhpur, 2014, pp 1-6, 2014.

Kern, M. (2015). The DNA-@evolution of Agriculture, In: *Production and Processing of Food Crops for Value Addition: Technology and Genetic Options*, Eds: R.K. Behl, A.P. Singh, A.B. Lal, and G. Haesaert, Agrobios (International) Publishers, 2015, pp 1-6 , Book pages 1-347, ISBN: 978-93-81191-05-7, <https://www.agriexcellence.com/page.php?pid=aktuelles>, 2015.

Kern, M. (3/2015). Digital Agriculture, *ISPSW Strategy Series: Focus on Defense and International Security*, No. 331, 1-8, March 2015, https://www.zef.de/fileadmin/user_upload/4saengenendt_download_331%20Digit%202015_Kern%5B1%5D.pdf, 2015.

Kern, M. (9/2015). Vision: Do more with less, better and in time! Sustainable Value Creation in Agriculture by Implementing Digital Technologies. In: *Computer Application towards Agri-Biology and Engineering Streams*. Eds: R.K. Behl et al. Agrobios (International) Publishers, <https://www.agriexcellence.com/upload/pdf/2015-03-05-11-15-10.pdf>, 2015.

Kern, M. (2018). Changing Horizons: Renewable Energy for a "Fossil-Fuel-Free Farming" - Vision 2025/2050, <https://www.agriexcellence.com/upload/pdf/2018-05-18-17-04-08.pdf>, 2018.

Kern, M. (2018). Vision: From Agricultural Research to Agribusiness by Factor Cⁿ (CCCC CCCC CCCC CCCC CCCC CCCC C...) Capability, Capacity, Courage, Competence, Creativity, Context, Culture, Conscience, Conscientiousness, Commitment, Complexity, Clarity, Cutting-edge orientation, Communication, Consensus, Connectivity, Cooperation, Coherence, Coordination, Countability, Capital, Curiosity, Challenge-based, Climate change, Crop insurance, Climate resilience, Cellular agriculture, Customers, Consumer interests, in: Emerging Technologies towards Agriculture, Food and Environment, (eds.) R.K. Behl, M. Singh, A. Ibenthal and W. Merbach, Proceedings of International Seminar on "Harnessing Science and Technology Applications through Capacity Building and Economic Policies for Sustainable Development", September 13-15th, 2018, Mahatma Gandhi Haus, Göttingen, Germany, published by Agrobios (International), Jodhpur, India, 2019.

Kern, M. (2023). Keynote lecture: Climate Resilient Agriculture (2025/2050): Climate Resistant Crops + Fossil-Fuel-Free Farming presented at the International Conference on Climate Resilient Agriculture for Food Security and Sustainability, CCS Haryana Agricultural University, Hisar, India, February 17-19, 2023.

Kern, M. (2025). Food Security in 2030/2050 at Crossroads – A Wake-up Call in 2012! / An Emergency Call in 2025! in: International Webinar "Food Security at Crossroads", organized by IFSDAA, Göttingen, Germany and Department of Agriculture at MM (DU), Mullana, India, February 1, 2025, <https://www.agriexcellence.com/page.php?pid=aktuelles>, 2025.

Kern, M. (4/2025). Most of the 17 SDGs are not on track to be achieved by 2030!, International Knowledge Centre (IKnC) AASF, Magazine "Afro-Asian Spectrum", April 31, 2025, Göttingen, Germany, 12-17, <https://webmail-web136.alfahosting-server.de/?task=mail&frame=1&mbox=INBOX&uid=10307&part=2&action=get&extwin=1>, 2025.

Kern, M. (4/2025). A Critical Overview on Reviews about Micro- and Nanoplastics, 2025/2050: The Invisible and Neglected Epidemic Pollution That Threatens Food Security and Safety, The Environment, and Human Health, In: Sustainable Agriculture for Food Security und Climate Change, Eds. R.K. Behl, P.K. Sharma, R.K. Arya, S.S. Bagci and E. Morzog, Proceedings of the International Conference on "Sustainable Agriculture for Food Security und Climate Change", September 27-29th, 2023, Mahatma Gandhi Haus, Göttingen, Germany, published by Agrobios International, Jodhpur, India, 2025.

Kern, M. (2026). Controlled Environment Agriculture (CEA) on Earth, on Mars – Impact of AI 1927, 2027, 2127 (2026, in preparation).

Knutsson, K. (2025). Robot uses lasers to make chemical-free farming a reality, Fox News, March 12, 2025, <https://www.foxnews.com/tech/robot-uses-lasers-make-chemical-free-farming-reality>, 2025.

Kumari, K., Nafchi, A.M., Mirzaee, S. and Abdalla, A. (3/2025). AI-Drive Future Farming: Achieving Climate Smart and Sustainable Agriculture, *AgriEngineering*, 7, 1-31, 2025. https://www.researchgate.net/publication/390037198_AI-Driven_Future_Farming_Achieving_Climate-Smart_and_Sustainable_Agriculture, 2025.

Leech, K. (2/2025). The pros and cons of AI in resource management, Retain International Blog, 2/2025, <https://www.retaininternational.com/blog/pros-and-cons-ai-resource-management>, 2/2025.

*****Llorente, B., Williams, T.C., and Goold, H.G.** (7/2028). The Multiplanetary Future of Plant Synthetic Biology, *Genes* 2018, 9/348, 1-16, <https://www.mdpi.com/2073-4425/9/7/348>, 2018.

Lowenberg-DeBoer, J., Huang, I.Y., Grigoriadis, V., and Blackmore, S. (5/2019). Economics of robots and automation in field crop management, *Precision Agriculture*, 21, 278-299, 2020, https://link.springer.com/article/10.1007/s11119-019-09667-5?utm_source=getftr&utm_medium=getftr&utm_campaign=getftr_pilot&getft_integrator=sciencedirect_contenthosting, 2019.

Mac Pherson, J., Voglhuber-Slavinsky, A., Olbrisch, M., Schöbel, P., Dönitz, E., Mouratiadou, and Helming, K. (7/2022). Future agricultural systems and the role of digitalization for achieving sustainability goals. A review, *Agronomy for Sustainable Development*, July 06, 2022, <https://publica.fraunhofer.de/entities/publication/f5a7adba-48b7-405a-8934-c088b17a3da2>, 2022.

Macron, E. (2/2025). Statement on Inclusive and Sustainable Artificial Intelligence for People and the Planet, AI Action Summit, Co-chaired by France and India, 10-11 February, 2025, Paris, France, Service de Presse de la Présidence de la République, France, <https://www.elysee.fr/en/emmanuel-macron/2025/02/11/statement-on-inclusive-and-sustainable-artificial-intelligence-for-people-and-the-planet>, 2025.

Mana, A.A., Allouhi, A., Hamrani, A., Rehman, S., el Jamaoui, I. and Jayachandran, K. (2/2024). Sustainable AI-based production agriculture: exploring AI applications and implications in agricultural practices, *Smart Agricultural Technology*, 7, 1-15, 2024, <https://www.sciencedirect.com/science/article/pii/S2772375524000212>, 2024.

Market.U.S Report, Robot Market (11/2023). Global Agricultural Robot Market, <https://market.us/report/agricultural-robot-market/>, 2023.

Market.U.S Report, Artificial Intelligence Market (2/2024). AI in Agriculture Statistics: Transforming Farming Practices for Enhanced Efficiency and Sustainability, <https://www.globenewswire.com/news-release/2024/02/06/2824050/0/en/AI-in-Agriculture-Statistics-Transforming-Farming-Practices-for-Enhanced-Efficiency-and-Sustainability.html>, 2/2024.

Market.U.S Report, CEA Market (3/2025). Controlled Environment Agricultural Market, <https://market.us/report/controlled-environment-agriculture-market/>, 2025.

Marinoudi, V., Lampridi, M., Kateris, D., Pearson, S., Sorensen, C.G., and Bochtis, D. (11/2021). The Future of Agricultural Jobs in View of Robotization, *Sustainability*, 13, 12109, <https://www.mdpi.com/2071-1050/13/21/12109>, 2021.

Marston, J. (2025). Veridi pairs nematodes with machine learning to tackle Europe's \$55bn soil biodiversity problem. *AgFunderNewsletter*, April 9, 2025, <https://agfundernews.com/veridi-pairs-nematodes-with-machine-learning-to-tackle-europes-55bn-soil-biodiversity-problem>, 4/2025.

Meghwanshi, S. (4/2024). Review Paper: Disadvantages of Artificial Intelligence in Agriculture, [file:///C:/Users/mk/Downloads/disadvantagesofartificialintelligenceinagriculture%20\(1\).pdf](file:///C:/Users/mk/Downloads/disadvantagesofartificialintelligenceinagriculture%20(1).pdf), 2024.

Michelson, H. (4/2025). Navigating the Measurement Frontiers: New Insights into Small Farm Realities. *Agricultural Economics*, 2025, 1-17, <https://onlinelibrary.wiley.com/doi/full/10.1111/agec.70013>, 2025.

Mmbando, G.S. (1/2025). Harnessing artificial intelligence and remote sensing in climate-smart agriculture: the current strategies needed for enhancing food security, *Cogent Food & Agriculture*, 11/1, 1-21, 2025, <https://www.tandfonline.com/doi/epdf/10.1080/23311932.2025.2454354?needAccess=true>, 2025.

Modi, N., Prime Minister of India (2/2025). Key Highlights from PM Modi's Remarks at the AI Action Summit 2025, *Team MyGov*, February 13, 2025, <https://blog.mygov.in/editorial/key-highlights-from-pm-modis-remarks-at-the-ai-action-summit-2025/>, 2025.

Perch Energy (9/2024). How Artificial Intelligence Helps the Environment & Sustainability, Blog, September 30, 2024, <https://www.perchenergy.com/blog/innovation/artificial-intelligence-environment-sustainability>, 2024.

Raksha (4/2025). Drones Technology in Agriculture, International Knowledge Centre (IKnC) AASF, Magazine "*Afro-Asian Spectrum*", April 31, 2025, Göttingen, Germany, 66-69, <https://webmail-web136.alfahosting-server.de/?task=mail&frame=1&mbox=INBOX&uid=10307&part=2&action=get&extwin=1>, 2025.

Rohleder, B. (BitKom e.V.) and Meinel, T. (DLG), (6/2024). So digital ist die Landwirtschaft, Berlin, DLG, <https://www.bitkom.org/Presse/Presseinformation/Stall-bis-Feld-Agrarbetrieb-Kuenstliche-Intelligenz#>, 2024.

Rose, D.C., Lyon, J., de Boon, A., Hanheide, M., and Pearson, S. (5/2021). Responsible development of autonomous robotics in agriculture, *Nature Food*, 2, 306-309, May 2021, <https://www.nature.com/articles/s43016-021-00287-9>, 2021.

Sairone (2024). Drone Cover Crop Seeding / Comprehensive Guide, <https://saiwa.ai/sairone/blog/drone-cover-crop-seeding/>, 2024.

***Sairone** (1/2025). AI for Crop Rotation Planning / Transforming Sustainable Agriculture, <https://saiwa.ai/sairone/blog/ai-for-crop-rotation-planning/>, 2025.

Sairone (2/2025). AI for Seed Quality / Smarter Farming Solutions, <https://saiwa.ai/sairone/blog/ai-for-seed-quality/>, 2025.

Shah, N. (2024). Predictions for AI in 2025: Collaborative Agents, AI Skepticism, and New Risks, Stanford University News, December 23, 2024, <https://hai.stanford.edu/news/predictions-for-ai-in-2025-collaborative-agents-ai-skepticism-and-new-risks>, 2024.

Shalwa (9/2024). AI in Agriculture: Key Statistics and Trends for 2024, *Globe News Wire Blog*, September 5, 2024, <https://artsmart.ai/blog/ai-in-agriculture-statistics-trends-2024/>, 2024.

Sparrow, R. and Howard, M. (10/2020). Robots in agriculture: prospects, impacts, ethics, and policy, *Precision Agriculture*, 22, Online First, October 24, 2020, <https://robssparrow.com/wp-content/uploads/Agricultural-Robotics.pdf>, 2020.

Tamanna, Y. (3/2025). AI in Agriculture: A Strategic Guide for Industry Leaders [2025-2030], StartUS Insights, <https://www.startus-insights.com/innovators-guide/ai-in-agriculture-strategic-guide/>, 2025.

Toolify.ai (2/2024). Revolutionizing Flower Farming in Kenya: AI and Drones Combat Climate Change, <https://www.toolify.ai/ai-news/revolutionizing-flower-farming-in-kenya-ai-and-drones-combat-climate-change-1569951>, 2024.

Tzachor, A., Devare, M., King, B., and Ó hÉigeartaigh, S. (2/2022). Responsible Artificial Intelligence in Agriculture Requires Systemic Understanding of Risks and Externalities, *Nature Machine Intelligence*, February 2022, <https://www.nature.com/articles/s42256-022-00440-4>, 2022.

UNFPA, United Nations Population Fund (2023). State of the World Population in 2023 (8 Billion Lives, Infinite Possibilities – The Case for Fights and Choices); UNFPA Division for

Communications and Strategic Partnerships, United Nations Population Fund, <https://www.unfpa.org/sites/default/files/swop23/SWOP2023-ENGLISH-230329-web.pdf>, 2023.

Vinvent-Lancrin, S., Romani, C.C., and Reimers, F. (2022). In: Louadi, M. (3/2024), Demographic Dynamics and Artificial Intelligence: Challenges and Opportunities in Europe and Africa for 2050, [file:///C:/Users/mk/Downloads/2403.03935%20\(4\).pdf](file:///C:/Users/mk/Downloads/2403.03935%20(4).pdf), 2024.

Wollburg, P.T., Bentze, Y., Lu, Y., Udry, C., and Collin, D. (5/2024). Crop Yields Fail to Rise in Smallholder Farming Systems in Sub-Saharan Africa, *Proceedings of the National Academy of Sciences*, 121/21, 2024, <https://pubmed.ncbi.nlm.nih.gov/38739799/>, 2024.

Wuepper, D., Oluoch, W.A., and Hadi, H. (3/2025). Satellite in Agricultural and Environmental Economics: Theory and Practice, *Agricultural Economics, ICAE 2024 Special Issue Article*, <https://onlinelibrary.wiley.com/doi/10.1111/agec.70006>, 2024.

Young, S. (1/2020). The Future of Farming: Artificial Intelligence and Agriculture, *Harvard International Review (HIR)*, (1/2020), <https://hir.harvard.edu/the-future-of-farming-artificial-intelligence-and-agriculture/>, 2020.

Zadok, A.O. (7/2025). Using AI to forecast food demand and reduce post-harvest losses, London Daily News, July 03, 2025, <https://www.londondaily.news/using-ai-to-forecast-food-demand-and-reduce-post-harvest-losses/>, 2025.

Zeddies, H.H., Busch, G. and Qaim, M. (7/2024). Positive public attitudes towards agricultural robots, *Scientific Reports*, 14, 15607 (2024), <https://doi.org/10.1038/s41598-024-66198-4>, 2024.

Zhao, P., Yang, H., (...), and Ye, J. (4/2025). Targeted MYC2 stabilization confers citrus Huanglongbing resistance, *Science*, 388, 6743, 2025, <https://www.science.org/doi/10.1126/science.adq7203>, 2025.

Zscheischler, J., Brunsch, R., Rogga, S., and Scholz, R.W. (7/2022). Perceived risks and vulnerabilities of employing digitalization and digital data in agriculture – Socially robust orientations from a transdisciplinary process, *J. Cleaner Production*, 358, 132034, https://www.sciencedirect.com/science/article/pii/S0959652622016419?ref=pdf_download&fr=RR-2&rr=93cfa3576e6fa043, 2022.

Zürner, S. Deutschländer, L.P., Schieck, M., and Franczyk, B. (1/2023). Sustainable Development of AI Applications in Agriculture: A Review, *Procedia Computer Science* 225, 3546-3553, 2023, <https://www.sciencedirect.com/science/article/pii/S1877050923015089>, 2023.

F. Further Recommended Reviews:

Ahmad, A., Liew, A.X.W., Venturini, F., Kalogeras, A., Candiani, A., Di Benedetto, G., Ajibola, S., Cartujo, P., Romero, P., Lykoudi, A, De Grandis, M.M., Xouris, C., Lo Bianco, R., Doddy, R., Elegbede, I., D'Urso Labate, G.F., García del Moral, L.F., Martos, V. (4/2024). AI can empower agriculture for global food security: Challenges and prospects in developing nations. *Frontiers in Artificial Intelligence*, 7, 1328530, <https://www.frontiersin.org/journals/artificial-intelligence/articles/10.3389/frai.2024.1328530/full>, 2024.

AI & Blockchain Canada (1/2025). Are AI Real – Exploring the Validity and Impact of Artificial Intelligence, AI & Blockchain Canada, January 29, 2025, <https://theasu.ca/blog/are-ai-real-exploring-the-validity-and-impact-of-artificial-intelligence>, 2025.

Daum, T. (4/2025). Digitalization and skills in agriculture, *Outlook on Agriculture*, 4/2025, 1-11, <https://journals.sagepub.com/doi/pdf/10.1177/00307270251336474>, 2025.

De Oliveira, R.C., and de Souza e Silva, R.D. (6/2023). Artificial Intelligence in Agriculture: Benefits, Challenges and Trends, *Appl. Sci.* 13, 7405, [file:///C:/Users/mk/Downloads/applsci-13-07405%20\(3\).pdf](file:///C:/Users/mk/Downloads/applsci-13-07405%20(3).pdf), 2023.

Escriba-Gelonch, M., Liang, S., van Schalkwyk, P., Fisk, I., Van Duc Long, N., and Hessel, V. (5/2024). Digital Twins in Agriculture: Orchestration and Applications, *J. Agric. Food Chem.*, 72, 10737-10752, 2024, https://pubs.acs.org/doi/epdf/10.1021/acs.jafc.4c01934?ref=article_openPDF, 2024.

Kern, M. (3/2025). Most of the 17 SDGs are not on track to be achieved by 2030!, International Knowledge Centre (IKnC) AASF, Magazine "Afro-Asian Spectrum", March 31, 2025, Göttingen, Germany, <https://webmail-web136.alfahosting-server.de/?task=mail&frame=1&mbox=INBOX&uid=10307&part=2&action=get&extwin=1>, 2025.

Kern, M. (4/2025). A Critical Overview on Reviews about Micro- and Nanoplastics, 2025/2050: The Invisible and Neglected Epidemic Pollution That Threatens Food Security and Safety, The Environment, and Human Health, In: Sustainable Agriculture for Food Security und Climate Change, Eds. R.K. Behl, P.K. Sharma, R.K. Arya, S.S. Bagci and E. Morzog, Proceedings of the International Conference on "Sustainable Agriculture for Food Security und Climate Change", September 27-29th, 2023, Mahatma Gandhi Haus, Göttingen, Germany, published by Agrobios International, Jodhpur, India, 2025.

Lowenberg-DeBoer, J., Huang, I.Y., Grigoriadis, V., and Blackmore, S. (5/2019). Economics of robots and automation in field crop management, *Precision Agriculture*, 21, 278-299, 2020, https://link.springer.com/article/10.1007/s11119-019-09667-5?utm_source=getftr&utm_medium=getftr&utm_campaign=getftr_pilot&getft_integrator=sciencedirect_contenthosting, 2019.

Mac Pherson, J., Voglhuber-Slavinsky, A., Olbrisch, M., Schöbel, P., Dönitz, E., Mouratiadou, and Helming, K. (7/2022). Future agricultural systems and the role of digitalization for achieving sustainability goals. A review, *Agronomy for Sustainable Development*, July 06, 2022, <https://publica.fraunhofer.de/entities/publication/f5a7adba-48b7-405a-8934-c088b17a3da2>, 2022.

Mana, A.A., Allouhi, A., Hamrani, A., Rehman, S., el Jamaoui, I. and Jayachandran, K. (2/2024). Sustainable AI-based production agriculture: exploring AI applications and implications in agricultural practices, *Smart Agricultural Technology*, 7, 1-15, 2024, <https://www.sciencedirect.com/science/article/pii/S2772375524000212>, 2024.

Mmbando, G.S. (1/2025). Harnessing artificial intelligence and remote sensing in climate-smart agriculture: the current strategies needed for enhancing food security, *Cogent Food & Agriculture* 11/1, 1-21, 2025, <https://www.tandfonline.com/doi/epdf/10.1080/23311932.2025.2454354?needAccess=true>, 2025.

Raiman, A. (12/2024). A Review of Artificial Intelligence (AI) for Sustainable Agriculture, [file:///C:/Users/mk/Downloads/AReviewofArtificialIntelligenceforSustainableAgriculture%20\(2\).pdf](file:///C:/Users/mk/Downloads/AReviewofArtificialIntelligenceforSustainableAgriculture%20(2).pdf), 2024.

Tamanna, Y. (3/2025). AI in Agriculture: A Strategic Guide for Industry Leaders [2025-2030], StartUS Insights, <https://www.startus-insights.com/innovators-guide/ai-in-agriculture-strategic-guide/>, 2025.

Zürner, S. Deutschländer, L.P., Schieck, M., and Franczyk, B. (1/2023). Sustainable Development of AI applications in Agriculture: A Review, *Procedia Computer Science* 225, 3546-3553, 2023, <https://www.sciencedirect.com/science/article/pii/S1877050923015089>,

In press