Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 3, Issue 9, 2025

ENHANCING SUSTAINABILITY AND PROFITABILITY IN AGRICULTURE THROUGH AI-POWERED CROP PROTECTION

Muhammad Hammad u Salam[*1], **Shujaat Ali Rathore**[2], **Muhammad Irfan**[3]

[*1,2]*Department of Computer Science & Information Technology, University of Kotli, Azad Jammu and Kashmir.*
[3]*Department of Computer Science, NCBA&E, Sub-Campus Multan, 60000, Pakistan*

[*1]hammad.salam@uokajk.edu.pk

DOI: https://doi.org/10.5281/zenodo.17163792

Keywords

Article History
Received: 11 June 2025
Accepted: 06 September 2025
Published: 20 September 2025

Corresponding Author: *
Muhammad Hammad u Salam

Abstract

This paper presents selected features of the xarvio Field Manager solution that enhance agricultural sustainability. Conventional farming still relies heavily on agrochemicals to ensure a safe and sufficient food supply for our growing population. However, this work proposes new methods to reduce chemical use, benefiting both the environment and the farmer's profitability. The tools introduced follow the 4R principles: applying the right products at the right time, with the right dosage, and only on the required places. In the 2019 European cereal season, these solutions were used across 340,000 hectares. By optimizing fungicide use through precise timing or by skipping unnecessary applications, field trials showed an average savings of up to 30% compared to standard practices. The system also reduced tank leftovers by 72% by calculating the exact amount of ingredients needed for each field. In Brazil, targeting only the areas with weeds led to a 61% average savings in herbicide use. With the fully automated buffer zone solution in Germany, adherence to regulations and the conservation of protected areas became both effective and convenient. The solutions detailed here are highly scalable and can be implemented on a much larger scale, making them strong candidates for significantly reducing the environmental impact of crop protection products on land and water, thereby making farming more sustainable without jeopardizing food security. As a result, these solutions contribute directly to specific UN Sustainable Development Goals (SDGs), including target 2.4, which calls for resilient, sustainable agricultural practices, and target 12.4, which aims for the environmentally sound management of chemicals and their reduced release into the environment. While there is still much work to be done to fully achieve these goals, we believe the tools presented here are a significant step in the right direction.

Index Terms—Deep Learning, Precision Agriculture, Digital Farming, Sustainable Agriculture, Agronomic modelling, Responsible Pesticide Usage, Machine Learning, Computer Vision, Crop Health Monitoring, Robotics, AI-Powered Crop Protection

INTRODUCTION

The agricultural sector faces significant challenges in the 21st century [1]. By 2050, the global population is projected to reach 10 billion, necessitating a shift toward more sustainable farming practices to meet the increased demand for food [2]. While there is a clear need to boost productivity, it is crucial to minimize the environmental impact of agriculture and protect biodiversity. This is essential to ensure that future generations can continue to farm the same land. By adopting these sustainable practices, agriculture can contribute to achieving several United Nations Sustainable Development Goals (SDG), including Zero Hunger (SDG 2), Responsible Consumption and Production (SDG 12), and Life on Land (SDG 15).

Sustainable farming practices require a range of actions, including diversifying land use, improving soil management, and using agrochemicals like fertilizers and pesticides more selectively [3], [4]. These chemicals are essential for controlling diseases, pests, and weeds, which can significantly reduce crop yields. For example, the FAO estimates that plant pests and diseases cause a global reduction of up to 40% in crop yields each year. Similarly, uncontrolled weeds can lead to billions of dollars in economic losses [5], [6] and up to a 50% decrease in yield. While agrochemicals are vital for ensuring food production by managing these threats [7], a large portion of them are applied unnecessarily. This is because they're often spread uniformly across a field, even though the distribution of pests, diseases, and weeds is highly variable [8]. By targeting the use of these inputs, farmers can achieve efficient crop production while using these chemicals more responsibly.

To address this issue, the 4R nutrient stewardship can be applied to all agrochemicals, ensuring they are used correctly. This approach involves applying chemicals at the:

1. Right time
2. Right rate
3. Right place
4. Right source

However, implementing the 4Rs is difficult for farmers, particularly those managing large areas of land (hundreds or thousands of hectares), as they often lack detailed knowledge of their fields' specific conditions at a small scale. As a result, farmers need new technologies to provide them with the necessary information to make these precise decisions.

In recent years, farmers have increasingly adopted digital technologies to apply crop inputs more precisely. In this paper, we present solutions from xarvio that leverage Artificial Intelligence (AI) and other technologies to provide insights and recommendations. These tools help farmers apply pesticides according to the 4R principles, thereby reducing overall input usage. We illustrate our digital offerings' contribution to sustainable farming through two detailed case studies from Europe and Brazil.

METHODOLOGY

Agriculture is still heavily focused on a single objective: to maximize output (yield) while minimizing inputs (land, resources). This focus is central to the global effort to produce more food efficiently.

Significant progress has been made in agriculture through innovations in tools, machinery, and crop variety selection. However, the last two decades have brought a major shift in focus towards a more sustainable way of life. It's challenging to increase production and become sustainable simultaneously by finding "win-win" solutions. A key advantage in tackling these modern problems is that many technologies have become widely accessible due to the first phase of the technological revolution. In agriculture, there is a strong trend toward **digitization**. Today's farmers already use their own weather stations and are experimenting with new technologies like farming robots and UAVs. The data they generate is growing rapidly, which, when combined with **big data** and **cloud computing**, unlocks new possibilities. The solutions presented in this paper use these modern digital tools to achieve "win-win"

Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 3, Issue 9, 2025

scenarios for farmers by providing transparent, field-zone-specific crop production support.

xarvio Field Manager is a prime example of this approach. It is an app and web-based solution that proactively recommends crop production decisions throughout the growing cycle. The platform includes crop models, agronomic rules, and algorithms to provide automated recommendations. As a **Vertical Software as a Service** provider, Field Manager is dedicated to serving the specific needs of the agriculture industry by integrating a wide range of data inputs with various models. The technical structure of Field Manager can be described by four components (as shown in Figure 1):

- **Vertical Enabler:** Consumes raw data from internal or external sources and makes it usable for other parts of the system.
- **Vertical:** Provides a distinct value to the farmer based on data from vertical enablers or raw data.
- **Application:** Addresses specific user needs by using multiple verticals and vertical enablers.
- **Platform:** Manages, facilitates, and orchestrates the vertical enablers, verticals, applications, and the data exchange between them.

Within this paper, we demonstrate how specific features of Field Manager enable farmers to achieve the 4R Stewardship metrics:

- **xarvio Spray Timer** and **Spray Weather** are used to determine the **right time** for application.
- **xarvio Zone Spray** helps apply the **right rate** of product across the field.
- **xarvio Zone Spray (Weed Maps)** and **Buffer Zones** ensure products are applied in the **right place** within the field.
- **xarvio Product Recommendation** assists in selecting the **right product** for the specific application.

Using satellite imagery, the **xarvio Zone Spray** vertical saves fungicide by applying only the required amount in a highly scalable manner. The **Buffer Zone** solution also uses high-resolution satellite imagery to automatically establish application buffers around protected areas.

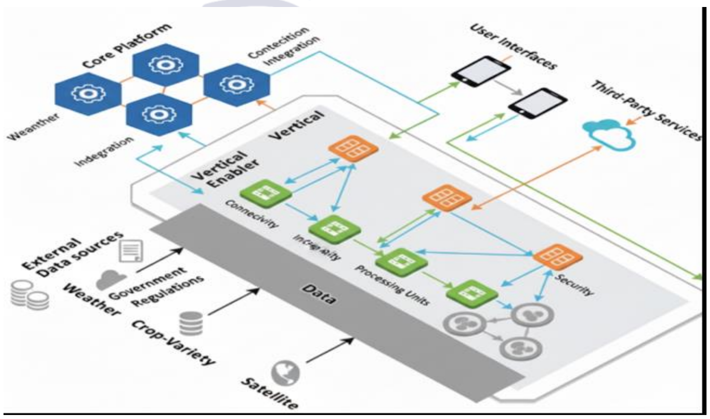

Fig. 1. Field Manager Technical Setup

For a more granular approach, the **Weed Maps** solution leverages readily available UAVs to locate weeds across large fields, which helps save herbicide. Additionally, on-farm weather stations connected to Field Manager provide next-level, in-field weather data.

The following sections of the paper will delve deeper into the **xarvio Field Manager** platform, providing specific details on how its features contribute to achieving the Sustainable Development Goals (SDGs).

REAL WORLD CASE STUDIES

This section presents two case studies that demonstrate how AI-powered features support more efficient and sustainable crop management: one on disease management in

Europe and another on weed management in South America.

Europe: Tackling diseases with AI

Europe is a significant contributor to global food production, with major crops including wheat, maize, barley, oats, and vegetables like potatoes and sugar beet. Cereals make up a large portion of this output [9]. In 2018, Europe was the second-largest wheat producer after Asia, accounting for 32.9% of the world's production. That year, Europe produced over 242.5 million tonnes of wheat, a figure expected to reach 269.6 million tonnes in 2019 [1].

Given these figures, protecting crops from pests and diseases and boosting productivity are crucial for global food security. To do this effectively, farmers need detailed knowledge of the 4Rs of nutrient stewardship. The solution detailed in this paper provides this knowledge, guiding farmers to plan their fungicide applications for maximum benefit using only the necessary amount of product. This approach not only saves money but also protects

xarvio Spray Timer and Spray Weather

Fig. 2. Illustration of xarvio Zone Spray and Spray Timer

The **xarvio Spray Timer** tool identifies relevant diseases for a specific field by considering factors such as the crop variety's susceptibility, the previous crop grown, and the tillage method used. Since each disease thrives under different conditions and has a unique life cycle, the tool employs rule-based and process-based models. These models, developed from extensive research, calculate the disease risk for a field by determining when the specific weather conditions required for a disease to flourish are met.

To provide accurate recommendations, the following data is needed:

- **Field-specific information**, including location, previous crop, tillage methods, and seeding date.
- **Weather data**, both historical and forecast,
- which includes air and soil temperature, humidity, rainfall, wind speed, and sunshine index.
- **Crop growth stage**, which is a calculated value based on the seeding date and weather conditions throughout the growing season.
- Any available **observed infestation data**.

Based Based on the collected data, an expert model is used to assess the individual disease risk for each field. First, the model determines a field's **basic risk** by analyzing specific parameters like the current crop growth stage and variety.

This risk assessment is then expanded by checking for known patterns of infestation. The model also analyzes both current and historical weather data to see if conditions are conducive to a high risk of infestation. If available, observed infestation levels can be used to either correct the estimations or act as a starting point for new calculations.

For fields with at least one high-risk disease, a **treatment window** is calculated. This window is determined by considering the protective effects of previous applications, the recommended dose rate, and the list of high-risk diseases. An application is recommended if the previous protection is expiring or if conditions are favorable for a new infection. To provide flexibility, the model recommends a period (with a first and last date) during which the farmer can apply the treatment

Within the recommended spray timing window, the **Spray Weather** module analyzes weather conditions to suggest specific dates with favorable weather for application. By providing these customized fungicide and insecticide spray recommendations based on current, in-season risk and weather, the system helps farmers apply the correct dose at the optimal time, and only when necessary.

2. xarvio Zone Spray (VRA)

When it's essential to use fungicides due to a high risk of disease, it's still possible to reduce chemical input by adjusting the dosage to match the variations within a field. One key factor that determines the amount of fungicide needed is the **specific leaf area**. This means that less fungicide is required in parts of the field with lower biomass and, consequently, less leaf area. While farmers can generally identify these lower-performing areas, accurately assessing the entire field using time use traditional methods is too time-consuming for a one-time use.maps provide farmers with the precise fungicide rates to apply across their fields. These maps are created using remote sensing—specifically, satellite or UAV imagery—to identify variations with in a field. Artificial Intelligence (AI) is then used to process this imagery. Machine learning algorithms convert raw images from various sources into maps thatshow the distribution of leaf area within a field.Based on the varying leaf area, distinct zones with similar characteristics are identified. For each zone, agronomic expert models determine the optimal fungicide dose for a more targeted application. These digital VRA application maps bundle all this information and make it accessible to farm machinery. Sprayers can then use these maps to automatically adjust the fungicide dose rate as they move through the field.

BUFFER ZONES

In many European countries, government regulations prohibit the use of pesticides in **buffer zones**—field areas near sensitive structures like water bodies or forests. These zones are designed to protect surrounding ecosystems from chemical runoff.

Currently, Field Manager offers a fully automated solution for managing these buffer zones specifically in Germany, where regulations are particularly complex [10]. In Germany, the required buffer zone size varies for over 3,000 crop protection products and depends on factors such as the type of sensitive landscape, product characteristics, and the sprayer type used.

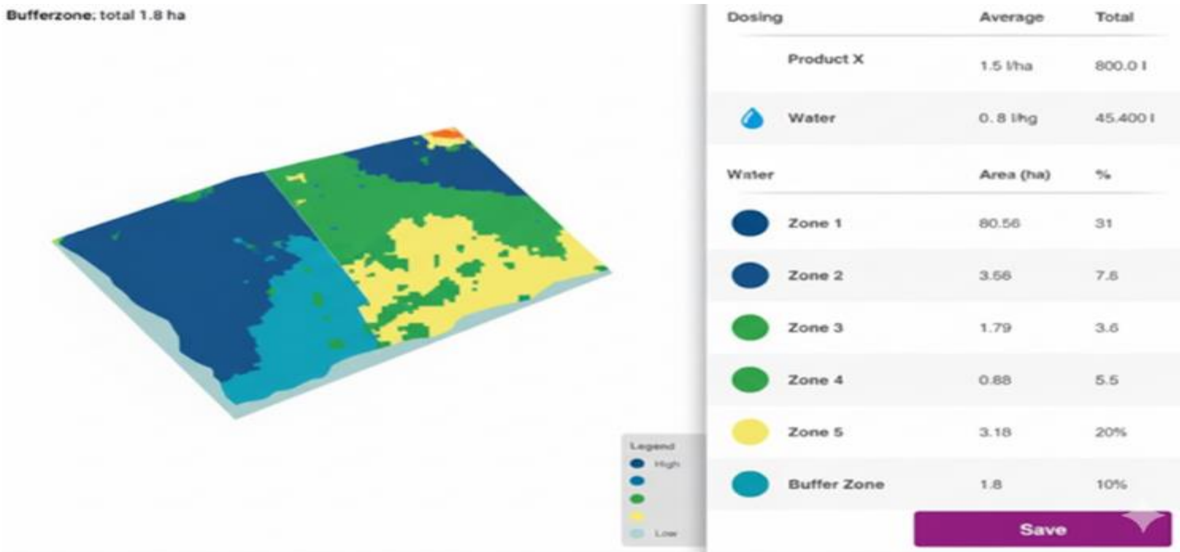

Fig. 3. Illustration of Buffer Zones in a fieldVariable Rate Application (VRA)

Our solution employs a **machine learning model** to identify different sensitive areas using high-resolution satellite imagery. This data is then combined with regulatory information and other details—like pesticide product data and farm machinery type—to generate digital

application maps with integrated buffer zones. These maps, as shown in Figure 3, can be loaded into a sprayer, which automatically considers the buffer zones during application.

PRODUCT RECOMMENDATION

The solutions mentioned earlier help farmers identify the best time for a spray application with **Spray Timer** and calculate precise dosage and field-specific maps with **Zone Spray**. However, the farmer is still responsible for choosing the product. The decisions about which fungicide to use, when to apply it, and in what dose are critical [11]–[13]. Farmers must also adhere to legal regulations and good farming practices. If a farmer selects an unsuitable product, it could negatively affect future disease pressure.

To address this, our solution collects data on the efficacy of various products and the criteria for selecting them. This information is not limited to a single brand. By providing suitable product options, farmers can more easily plan their pest control and application strategies. Farmersreceive a list of recommendations but are free to accept or reject them based on their experience. Once a farmer chooses a product, the recommended spray window is adjusted a final time to ensure maximum application effectiveness.

BRAZIL: TACKLING WEEDS WITH AI

Brazil has a highly developed agricultural industry, ranking fifth globally with 78 million hectares of cultivated land. It's unique for its large farms; over 100,000 farms are larger than 500 hectares, collectively covering more than half of the country's cultivated area [14].

As the world's largest soybean exporter, Brazil produced 33% of the global supply in 2018 on 34 million hectares of land. To protect these vast fields, the country uses over 1 billion liters of pesticides annually, with herbicides accounting for 45% of that total [15]. More than a third of this is applied to soybean fields, at an average rate of 12 liters per hectare. Weeds are a major challenge for the soybean industry, as they compete for soil resources and cause an average yield reduction of 37% [16]. For Brazilian farmers, effective weed management is therefore a crucial part of the production cycle.

xarvio Zone Spray To combat weeds on large Brazilian farms, recent advances in **AI** and **Cloud Computing** are combined with the rise of **Unmanned Aerial Vehicles (UAVs)** to help farmers reduce herbicide use in soybean production. This solution focuses on large-scale operations to have the biggest impact on pesticide usage.

In the primary growing season, called **Safra**, herbicides are typically applied at a flat rate across the entire field up to five times, including pre-sowing burndowns and one or two post-emergence controls. This approach is used even though weeds are rarely distributed uniformly; some areas may have dense weed patches while others have none. Additionally, weed tolerance can vary depending on the time of year, weather (e.g., dry vs. wet years), and management strategies. Traditional farming methods would spray all parts of the field regardless of the presence of weeds.

This solution specifically targets the second burndown (especially when expensive, resistant weeds are present) and post-emergence applications. We organize UAV flights to identify the precise locations of weeds. Within a few days, we provide the farmer with a digital map. The final step is for the farmer to load this map into their sprayer, which then applies herbicide only where weeds are present, resulting in significant product savings.The process of how this was achieved during the season is as follows:

The process of achieving this during the season is as follows:Before the season begins, we contact interested farms to identify which fields have known weed resistance or low weed pressure, making them ideal candidates for this solution.

Throughout the season, farm employees monitor the fields while preparing for sowing. They report any weed incidents to their managers, who also monitor the weather, as rain accelerates weed growth.

When a farmer decides to apply herbicide, they can request the Zone Spray service with a few taps in the Field Manager app. This request, typically made 2-5 days in advance, sets the window for us to produce the application map.

Within 1-2 days of receiving the farmer's confirmation, a trained drone operator flies over the requested fields. The resulting images have a ground sampling distance of 2.5–2.8 cm/px.

After the data is collected, the operator uploads the images to our cloud solution. A proprietary **Convolutional Neural Network** automatically classifies the images and generates the Zone Spray map. The process from image upload to map creation is fully automated and highly scalable, delivering a map for even the largest fields (around 1,000 ha) in a maximum of 24 hours.

The process of achieving this during the season is as follows:

Before the season begins, we contact interested farms to identify which fields have known weed resistance or low weed pressure, making them ideal candidates for this solution.

Throughout the season, farm employees monitor the fields while preparing for sowing. They report any weed incidents to their managers, who also monitor the weather, as rain accelerates weed growth.

the weather, as rain accelerates weed growth.

When a farmer decides to apply herbicide, they can request the Zone Spray service with a few taps in the Field Manager app. This request, typically made 2-5 days in advance, sets the window for us to produce the application map.

The process of achieving this during the season is as follows:

Before the season begins, we contact interested farms to identify which fields have known weed resistance or low weed pressure, making them ideal candidates for this solution.

Throughout the season, farm employees monitor the fields while preparing for sowing. They report any weed incidents to their managers, who also monitor the weather, as rain accelerates weed growth.

When a farmer decides to apply herbicide, they can request the Zone Spray service with a few taps in the Field Manager app. This request, typically made 2-5 days in advance, sets the window for us to produce the application map.

Within 1-2 days of receiving the farmer's confirmation, a trained drone operator flies over the requested fields. The resulting images have a ground sampling distance of 2.5–2.8 cm/px.

After the data is collected, the operator uploads the images to our cloud solution. A proprietary **Convolutional Neural Network** automatically classifies the images and generates the Zone

Spray map. The process from image upload to map creation is fully automated and highly scalable, delivering a map for even the largest fields (around 1,000 ha) in a maximum of 24 hours.

Once the map is published in Field Manager, the farmer can view the weed pressure on the surveyed fields. They can then set a weed tolerance threshold based on factors like weed coverage, personal tolerance, time of season, region, and weather conditions. Higher thresholds lead to greater product savings, though even with a 0% tolerance, significant savings are achieved when the overall weed pressure is low.

Finally, an **ON/OFF application map** is created based on the classified UAV image and the farmer's chosen threshold. The map can be instantly downloaded in the required format and is ready for use during application.

Product Recommendation

Once After the farmer receives the UAV-based herbicide application map, they still need to choose the right products. To help with this, we've developed an automated tool for recommending tank mixes. This tool considers several parameters provided by the farmer, including the specific weed species present, any known resistance to active ingredients, the sowing date, and the traits of the soy been variety

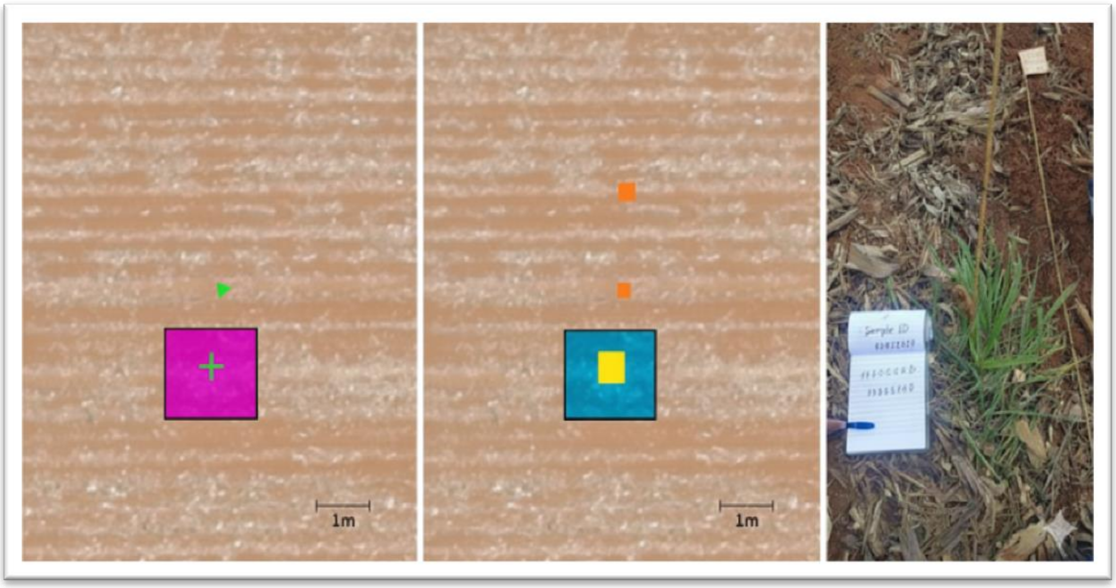

Fig. 4. An example of a weed detection. Here we have a weed inside of a black rectangle on a drone orthomosaic (left), followed by our weed classification in red (center) and a ground truth image of the same spot in the field taken by a smartphone (right). A light blue dot on images in left and center represents an accurate position of the weed showing a displacement which can occur in any direction when using GPS guided drones which is taken care of in post-processing spraying buffers.

The tool not only focuses on the efficacy of individual active ingredients but also how they interact with each other in a mixture, along with any desired additives. Its goal is to find tank mixes and additives with the highest effectiveness while using the fewest possible ingredients. In addition to efficacy, the recommended mixes are also ranked based on good agronomic practices, such as rotating active ingredients and their modes of action.

The farmer can view these proposed tank mixes and decide whether to select one or create a custom mix. It is important to note that the tool includes virtually all products on the market, and its rankings are based on efficacy and good agronomic practices rather than a specific product bran

ENVIRONMENTAL AND ECONOMICAL IMPLICATIONS

With As the global population steadily increases, a major challenge for farmers is to produce more food with the same amount of land. With **80% of arable land already in use**, food production must increase by **70%** to feed the predicted 9.1 billion people by 2050 [17]. To avoid further harm to biodiversity, converting forests, grasslands, or peatlands into farmland should be a last resort. This urgent need to increase yields while minimizing environmental impact is the primary challenge facing global agriculture. It's a concept known as "**sustainable intensification**" [18].

Adopting these sustainable farming practices helps mitigate issues such as increased pesticide resistance, environmental contamination, soil degradation, water shortages, and energy supply problems [19]. The advancement and adoption of **precision agriculture** techniques have made it possible to leverage new technologies to address this crucial challenge.For high-yield agriculture, farmers must strategically plan their disease management to ensure crop quality. This can be done with both proactive and reactive methods. Proactive measures include crop rotation, using disease-resistant crop varieties, and strategically planning planting dates to avoid conditions that favor disease outbreaks.

However, even with these precautions, diseases still inevitably occur due to changes in disease dynamics and adverse weather from climate change. Fungal diseases, in particular, are notorious for causing significant damage, leading to about **15–20% of yield loss** [20]. **Septoria tritici Blotch (STB)** is currently the main threat to wheat production in Europe, costing farmers **€280–€1,200 million** annually in direct losses and control costs, such as applying fungicides and insecticides [21]. Without a proper plan, farmers typically have to spray their fields three or four times per season, which can cost them about **€100 per hectare** [22].During During the 2019 European season, the solutions presented were used on over **340,000 hectares** of cereals, leading to a more efficient and targeted use of fungicides. This was achieved by applying the product at the right time or by skipping a standard application when disease pressure was low.

Our field trials demonstrated an average saving of **30%** compared to traditional disease management practices. Another significant benefit is the reduction of tank leftovers. Farmers typically mix water and chemicals in their sprayer tank, but they often have leftover mixture that must be disposed of, which is a source of environmental pollution. With the precise application information provided by xarvio, farmers know exactly how much product is needed, reducing leftovers by an average of **72%**.

In Brazil, weeds pose a major threat to soybean yields, leading farmers to use up to five herbicide treatments per season. This strategy results in a combined annual cost of **$1.2 billion** for chemical weed control in soybeans [16]. During the 2019/2020 **Safra** soybean season, the **Zone Spray** solution was used on over **178,000 hectares** (approximately 1,000 fields) for three of the five potential herbicide applications. In this initial test, farmers who used the map achieved an average savings of **61.1%**, cutting their use of both product and water by nearly two-thirds.

The Brazilian version of the **Product Recommendation** tool further enhances environmental benefits by suggesting tank mixes with the highest efficacy while also following sound agricultural practices, such as rotating active ingredients and their modes of action. Applying less product and using the right mixes not only improves efficiency but also acts as a preventive measure by delaying the development of herbicide resistance.As this paper demonstrates, these methods have a significant impact on both the farmer's profitability and the environmental footprint of agriculture. By combining **AI** with other technologies, datasets, and agronomic knowledge, it's possible to transform conventional farming practices for the better and achieve more responsible agriculture. The solutions strongly support the United Nations' **Sustainable Development Goals (SDGs)**, particularly in the agricultural sector. By optimizing chemical usage, the solutions reduce chemical release into the environment, which supports more responsible food production and consumption (SDG target 12.4). Additionally, we guide farmers to be more productive and better prepared for climate changes while protecting biodiversity and improving land quality (SDG target

OUTLOOK

This paper highlights the potential for scaling digital farming products, yet many challenges remain due to the scarcity of high-quality **spatio-temporal datasets** in agriculture.[1] We believe these datasets, which often consist of tabular sensor and trial data, have not been fully utilized, especially given the recent advancements in **Deep Learning**.

Furthermore, integrating optical remote-sensing data with other sensor types, such as radar or ground sensors, is still a developing area. Progress in this **data fusion** could significantly enhance the scalability of precision agriculture solutionSUMMARThis paper demonstrates how specific features of the **xarvio Field Manager** solution can improve agricultural sustainability. While conventional agriculture still heavily relies on agrochemicals to produce a safe and sufficient food supply for a growing population, this research proposes new methods to reduce chemical usage.The tools detailed in this paper benefit both the environment and the farmer's profitability by following the **4R principles**: applying the right products at the right time, with the right dosage, and only on the required places.

- In the 2019 European cereal season, these solutions were used on over **340,000 hectares**. By optimizing fungicide usage through proper timing or by skipping unnecessary applications, field trials showed an average saving of up to **30%** compared to standard practices.
- The system also reduced tank leftovers by **72%** by calculating the exact amount of ingredients needed for each field.
- In Brazil, targeting only the areas with weeds led to a **61%** saving in herbicide use.
- The fully automated buffer zone solution in Germany makes it both effective and convenient for farmers to comply with regulations, helping to conserve protected areas.

The solutions presented here are highly scalable and can be implemented on a much larger scale. This makes them strong candidates for significantly reducing the environmental impact of crop protection products on land and water, thereby making farming more sustainable without compromising food security.

These tools directly support specific **UN Sustainable Development Goals (SDGs)**, particularly:

- **SDG Target 2.4:** "By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems..."
- **SDG Target 12.4:** "By 2020, achieve the environmentally sound management of chemicals...and significantly reduce their release to air, water and soil..."

While there is still much to be done to fully achieve these goals, we believe the tools presented here are a significant step in the right direction.

Acknowledgement

This work is the result of an extensive, five-year research effort. We would like to thank all the colleagues and research partners who contributed to the various solutions presented in this page

REFERENCES

Dieter Gerten, Vera Heck, Jonas Ja¨germeyr, Benjamin Leon Bodirsky Ingo Fetzer, Mika Jalava, Matti Kummu, Wolfgang Lucht, Johan Rock- stro¨m, Sibyll Schaphoff, and Hans Joachim Schellnhuber. Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nature Sustainability*, 2020.

Luigi Chiarappa, Huai C. Chiang, and Ray F. Smith. Plant pests and diseases: Assessment of crop losses. *Science*, 176(4036):769–773, 1972.

E.-C. OERKE. Crop losses to pests. *The Journal of Agricultural Science*, 144(1):31–43, 2006.

Ouzman J Walker S Mayfield A Llewellyn RS, Ronning D and Clarke

M. Impact of weeds on australian grain production: the cost of weeds to australian grain growers and the adoption of weed management and tillage practices.

Yogita Gharde, P.K. Singh, Rp Dubey, and P Gupta. Assessment of yield and economic losses in agriculture due to weeds in india. *Crop Protection*, 107, 01 2018.

Serge Savary, Laetitia Willocquet, Sarah Jane Pethybridge, Paul Esker, Neil McRoberts, and Andy Nelson. The global burden of pathogens and pests on major food crops. *Nature Ecology & Evolution*, 3(3):430–439, 2019.

Rebecca L. Whetton, Toby W. Waine, and Abdul M. Mouazen. Evalu- ating management zone maps for variable rate fungicide application and selective harvest. *Computers and Electronics in Agriculture*, 153:202 – 212, 2018.

Agricultural production - crops, Nov 2019.

Pamrobust – abstandsauflagen im pflanzenschutz.

Joseph P Lynch, Elizabeth Glynn, Steven Kildea, and John Spink. Yield and optimum fungicide dose rates for winter wheat (triticum aestivum l.) varieties with contrasting ratings for resistance to septoria tritici blotch. *Field Crops Research*, 204:89–100, 2017.

Lise N Jørgensen, F Van den Bosch, RP Oliver, TM Heick, and ND Paveley. Targeting fungicide inputs according to need. *Annual review of phytopathology*, 55:181–203, 2017.

Kamilla Knorr, Lise Nistrup Jørgensen, and Mogens Nicolaisen. Fungi- cides have complex effects on the wheat phyllosphere mycobiome. *PloS one*, 14(3), 2019.

Steven M. Helfand, Nicholas E. Rada, and Marcelo M. Magalha˜es. Brazilian agriculture: Is it all about the large farms? *EuroChoices*, 16(1):17–22, 2017.

Fernando Ferreira Carneiro, Lia Giraldo da Silva Augusto, Raquel Maria Rigotto, Karen Friedrich, and Burigo Andre Campos. *Dossie ABRASCO: um alerta sobre os impactos dos agrotoxicos na saude*. Escola Politec- nica de Saude Joaquim Venancio, 2015.

E-C Oerke and H-W Dehne. Safeguarding production—losses in major crops and the role of crop protection. *Crop protection*, 23(4):275–285, 2004.

Jelle Bruinsma et al. The resource outlook to 2050: by how much do land, water and crop yields need to increase by 2050. In *Expert meeting on how to feed the world in*, volume 2050, pages 24–26, 2009.

David Baulcombe, Ian Crute, Bill Davies, Jim Dunwell, Mike Gale, Jonathan Jones, Jules Pretty, William Sutherland, and Camilla Toulmin. *Reaping the benefits: science and the sustainable intensification of global agriculture*. The Royal Society, 2009.

Tiziano Gomiero. Soil and crop management to save food and enhance food security. *Saving Food*, page 33–87, 2019.

Melania Figueroa, Kim E. Hammond-Kosack, and Peter S. Solomon. A review of wheat diseases-a field perspective. *Molecular Plant Pathology*, 19(6):1523–1536, 2017.

Helen Fones and Sarah Gurr. The impact of septoria tritici blotch disease on wheat: An eu perspective. *Fungal Genetics and Biology*, 79:3–7, Apr 2015.

Stefano F.f. Torriani, James P.e. Melichar, Colin Mills, Naomi Pain, Helge Sierotzki, and Mikae¨l Courbot. Zymoseptoria tritici: A major threat to wheat production, integrated approaches to control. *Fungal Genetics and Biology*, 79:8–12, May 2015.

T. Abbas, J. I. Janjua and M. Irfan, "Proposed Agricultural Internet of Things (AIoT) Based Intelligent System of Disease Forecaster for Agri-Domain," *2023 International Conference on Computer and Applications (ICCA)*, Cairo, Egypt, 2023, pp. 1-6, doi: 10.1109/ICCA59364.2023.10401794.

Khan, T. (2023). AN AGRICULTURAL INTERNET OF THINGS (A-IOT) BASED INTELLIGENT SYSTEM FOR DISEASE PREDICTION USING TRANSFER LEARNING, A CASE STUDY. *Lahore Garrison University Research Journal of Computer Science and Information Technology*, 7(3).

Rehman, A., Noor, F., Janjua, J. I., Ihsan, A., Saeed, A. Q., & Abbas, T. (2024, December). Classification of Lung Diseases Using Machine Learning Technique. In *2024 International Conference on Decision Aid Sciences and Applications (DASA)* (pp. 1-7). IEEE.

Almansour, B. Y., Almansour, A. Y., Janjua, J. I., Zahid, M., & Abbas, T. (2024, December). Application of Machine Learning and Rule Induction in Various Sectors. In *2024 International Conference on Decision Aid Sciences and Applications (DASA)* (pp. 1-8). IEEE.

Janjua, J. I., Ahmad, R., Abbas, S., Mohammed, A. S., Khan, M. S., Daud, A., ... & Khan, M. A. (2024). Enhancing smart grid electricity prediction with the fusion of intelligent modeling and XAI integration. *International Journal of Advanced and Applied Sciences*, *11*(5), 230-248.

Abbas, T., Khan, A. H., Kanwal, K., Daud, A., Irfan, M., Bukhari, A., & Alharbey, R. (2024). IoMT-Based Healthcare Systems: A Review. *Computer Systems Science & Engineering*, *48*(4).

Abbas, T., Fatima, A., Shahzad, T., Alharbi, M., Khan, M. A., & Ahmed, A. (2024). Multidisciplinary cancer disease classification using adaptive FL in healthcare industry 5.0. *Scientific Reports*, *14*(1), 18643.

Janjua, J. I., Nadeem, M., Khan, Z. A., & Khan, T. A. (2022, April). Computational Intelligence Driven Prognostics for Remaining Service Life of Power Equipment. In *2022 IEEE Technology and Engineering Management Conference (TEMSCON EUROPE)* (pp. 1-6). IEEE.

Al-Tarawneh, A. M., AlOmoush, R. A., ul Islam, T., Janjua, J. I., Abbas, T., & Ihsan, A. (2024, December). Current Trends in Artificial Intelligence for Educational Advancements. In *2024 International Conference on Decision Aid Sciences and Applications (DASA)* (pp. 1-6). IEEE.

Alqarafi, A., Batool, H., Abbas, T., Janjua, J. I., Ramay, S. A., & Ahmed, M. (2024, December). Estimating Uncertainty in Deep Learning Methods and Applications. In *2024 International Conference on Computer and Applications (ICCA)* (pp. 1-6). IEEE.

Ramay, S. A., Kanwal, K., Javid, H. A., Abbas, T., Ansari, G. J., & Irfan, M. (2023). Enhancing Fruit Quality Detection with Deep Learning Models. *Journal of Computing & Biomedical Informatics*, 6(01), 28-40.