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SPEAKER BIODATA FORM

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Brief career highlights (less than 250 words):

Between 1992 and 2012, Dr Armin Werner was the scientific head of the *Department of Land Use Systems* at the Leibniz Centre for Agricultural Landscape Research (ZALF) in Germany. He initiated and conducted research on sustainable land use, including integrated cropping with Precision Agriculture.

From 2013 to 2023, Werner led the Precision Agriculture Group at Lincoln Agritech Ltd. (LAL), an independent, private science and engineering company, a subsidiary of Lincoln University in New Zealand.

Werner, the group, supported by other teams at LAL utilised digital technologies, including sensors, geospatial data, and satellite sensing, enabling primary industries to make better-informed decisions. They worked on assessing and utilising spatiotemporal data in arable and pasture-based agriculture, as well as in crop load management of high-value fruit crops such as grapes and apples. For this, they developed optical and microwave sensing technologies combined with machine learning models to analyse crop variability and predict yields for crops like grapes and apples.

Werner's project work also included developing automation and robotics to assist with manual labour in the primary industries. He led the six-year *National Robotic Spearhead*, part of New Zealand's Science for Technological Innovation Challenge, focusing on science for technologies to enable learning robots that operate in harsh environments. He co-led the subsequent "Ending-with-Impact" project, creating a controller for a *semi-autonomous forest-track maintenance robot*.

Currently, Werner is LAL's Principal Science Advisor. He holds an Adjunct Professor role at Lincoln University, where he taught precision agriculture courses in bachelor's and master's degree programs for six years.

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MEASURE, MODEL, MANAGE: THE UNFINISHED REVOLUTION IN AGRICULTURE

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ABSTRACT

Over the last 40 years, the paradigm *of Measure, Model, Manage* has promised an agricultural revolution through data-informed precision management. This shift remains largely incomplete, lagging concurrent innovations in genetics and pesticides.
Significant barriers persist in achieving breakthrough innovations for crop data collection and the development of data analysis/decision-making systems. These hurdles include a decades-old "*Sensor Crisis*" (a lack of appropriate tools), a "*Data Crisis*" (inconsistent and underutilised data), and deep-rooted challenges in the adoption of innovations.
Fundamentally, these innovation crises stem from globally uncoordinated research and development (R&D) combined with highly fragmented agrarian structures. This fragmentation results in numerous small, diverse markets that fail to justify the costly R&D, required for technological breakthroughs in the complex agricultural systems.
Finalising and maximising precision agriculture requires unprecedented global collaboration across R&D, industry, and governance. New transregional alliances should simultaneously focus on market-specific technology suites and on quickly establishing flexible, standardised tools for AI-based data extraction, analysis, and decision-making.

Keywords: Data-driven agriculture, sensor crisis, data crisis, adoption barriers, AI-based solutions.

INTRODUCTION

"Measure, Model, Manage" [0] - the core concept of data-driven, precision agriculture – has guided R&D for half a century, creating technologies ranging from sensors to satellite imagery aimed at boosting productivity and sustainability [1]. Yet, widespread adoption of "*smart*" practices remains elusive. Our paper explores that disconnect, identifying key challenges in digital agriculture, with a focus on crop data relevant to input management.

RESULTS & DISCUSSION

Sensors Crisis. For the past four decades, most crop data have relied on optical reflection sensors [2], which measure only the plant's surface (colour/morphology), not its internal state. Inefficiencies such as non-detection, saturation, and confounding with ambient conditions can easily skew the readings, leading sensors to report symptoms (e.g., chlorophyll loss) rather than causes (e.g., insufficient Nitrogen at a sensitive stage). High calibration demands render these sensors inadequate for use and make them difficult to adjust cross-regionally, resulting in very low adoption of commercial sensors or services, with probably less than 20,000 nitrogen sensors sitting idle globally on farms.

We lack both 'universal crop sensors' - capable of tuning into key plant processes - and the knowledge to utilise such data for crop management. Promising lab solutions, such as *Raman Spectroscopy* [3] or *Impedance Spectroscopy/Electrophysiology* [4], require substantial R&D efforts to become proximal, contactless and low-cost field tools. Remote sensing could become more objective with physics-based *Radiative Transfer Models* [5].

Data Crisis.
Modern farm equipment for one crop utilises 60 to 100 sensors for internal control, and some of this data can describe soil or crop features. Combining this with dedicated crop sensor readings, all geo-referenced, creates large data sets - effectively turning every square meter of a field into a trial plot - that should be used to train decision AI models.

Currently, such data is wasted due to proprietary data files and a lack of automated collection and analysis tools. Data analytics provides methods that can infer and profile metadata in 'data lakes' for automated data input, analysis, and decision support [6]. Making such tools available for agriculture requires substantial, combined R&D efforts.

Inadequate Markets.
Though the world's 608 million farms will continue to consolidate, they don't form a unified technology market. Instead, they are highly fragmented by factors such as size, farming system, training, age, history, environment, crops, market access, profitability and more. This fragmentation causes variability in already low adoption rates, driven by a low willingness to invest (30%) where returns are vague or long-term, compounded by the fact that 50% of farmers are unwilling to pay for new data services [8]. This ultimately results in markets being too small to justify R&D investment for breakthrough innovations.

CONCLUSIONS

The lack of innovative digital tools (sensors, analysis, management) negatively affects productivity, food security, profitability, rural development and the environment [9]. The stagnation and inability of extremely fragmented agrarian systems to overcome this challenge with current R&D concepts urgently require the commitment of all stakeholders to adopt novel approaches, R&D methodologies, and commercialisation paths.
Mastering these challenges requires a multi-actor effort, starting with transregional R&D alliances that develop a suite of market-specific sensor technologies, each suite designed for a particular farming intensity and region. Simultaneously, initiatives must develop self-learning AI tools for both data sharing and data-driven decision-making.

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