What evidence exists on the effectiveness of sensing technologies as field vegetable crop water stress-detecting tools?: A Systematic Map Protocol.

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Systematic Map Protocol

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Crop health monitoring, field phenotyping, imaging techniques, plant water relations, remote sensing.

Background
Drought stress is among the abiotic factors restricting crop yield and quality [1]. It causes water deficits when transpiration exceeds water uptake in plants, triggering responses at the cell, tissue/organ, and whole-plant levels [2]. This includes detrimental physiological changes like increased leaf temperature, osmotic adjustments and reduced photosynthesis [2], relative water content, leaf size, and chlorophyll [3]. These changes may be subtle and not observable to the naked eye for drought-sensitive field vegetable crops such as potatoes, brassicas, beans, carrots, and lettuce with shallow and sparse root systems. Identifying water stress earlier during critical growth phases could enable timely interventions, such as targeted irrigation, that might help mitigate yield loss and quality issues. Traditional methods such as photosynthetic rate [4], gas exchange [5], and chlorophyll content [6] have been used for water stress detection. While these methods are useful for scientists, they are labour-intensive and time-consuming for farmers and agronomists. Sensing technologies such as thermal imaging, hyperspectral, visible, near- and short-wave infrared reflectance (VNIR/SWIR), and chlorophyll fluorescence may be more appropriate for farmers and agronomists, and considerable research has been done on these technologies for detecting water stress in crops. However, these interventions need to be assessed for their effectiveness in terms of accuracy and reliability. Therefore, using an accurate, comprehensive, and repeatable search, our systematic map will investigate the current knowledge of sensing techniques for detecting water stress on field vegetables. This systematic map examines the feasibility of sensing technology to enhance the accuracy of early water stress detection. This work will contribute to the academic field by advancing phenotyping methods and providing new insights into the interaction between drought stress and crop physiological responses.

Theory of change or causal model
The proposed intervention explores the potential of various sensing technologies, e.g. thermal imaging [7], hyperspectral ([8], and chlorophyll fluorescence [9], for detecting crop water stress. The hypothesised link is that farmers and researchers can more accurately monitor crop water status by validating these sensing methods, resulting in timely interventions that reduce drought-induced physiological disorders and yield loss. This approach is expected to enhance drought

resilience in cultivation, contributing to sustainable agricultural practices. The outcome will be evidence-based recommendations for the most effective sensing technology.

Stakeholder engagement

This protocol was developed as part of a research project funded by the Biotechnology and Biological Sciences Research Council (BBSRC) and the Douglas Bomford Trust (DBT). The BBSRC's interest is to deliver innovative, world-class research across the life sciences in the UK. The DBT objective is to advance knowledge, understanding, practice, and competence in applying engineering and technology to achieve sustainable agriculture and food systems. The project research questions were presented to the Cambridge University Potato Growers Research Association (CUPGRA) at a conference. The research progress will be updated to stakeholders during regular meetings, where they will provide interpretations of the results and recommendations if needed.

Objectives and review question

This systematic map aims to identify, collate and categorise available relevant evidence on the effectiveness of sensing technologies in detecting field vegetable water stress. This includes peer-reviewed and grey literature that describes studies performed in natural environments and greenhouses. The main objective addresses the following primary research question: What evidence exists on the effectiveness of sensing techniques that detect field vegetable water stress? A secondary question is designed specifically to inform further research on measuring water stress in potatoes as follows: What evidence exists on the effectiveness of sensing techniques that detect water stress in potato plants?

Definitions of the question components

Components of the primary question • Population (P): Drought-stressed field vegetable crops, which experience physiological changes due to water deprivation, negatively affecting their growth, yield, and quality. • Intervention: Sensing techniques that use sensors to collect crop information under various conditions. • Comparator. Conventional methods of detecting crop water stress, e.g. destructive techniques (relative water content (RWC) measurement and water potential using a pressure bomb), and non-destructive but indirect and time-consuming methods like stomatal conductance. • Outcome: High predictive capability of sensing techniques, providing reliable and repeatable data for accurately measuring crop water stress

Search strategy

A methodology for environmental sciences that consists of gathering and collating evidence and answering the research questions will follow the [10], Collaboration for Environmental Evidence Guidelines [11] and ROSES reporting standard [12]. The ROSES report can be found in Additional File A1. We will gather evidence and identify knowledge clusters in sensing technologies and crop water stress, and in this way contribute towards mapping articles that identify the most effective sensing technologies. To explore the literature thoroughly, a predefined search strategy was trialled and developed on Web of Science as illustrated in Additional File A2. The search terms were identified using the PICO analysis, and the search strategy includes two items: (a) the key search terms and (b) the inclusion and exclusion criteria. The final search string that will be used is presented below: ((field* OR vegetable*) OR root* OR carrot* OR Daucus carota OR Solanum tuberosum OR potato* OR parsnip OR Pastinaca sativa OR radish OR Raphanus sativus OR salad* OR lettuce OR Lactuca sativa OR spinach OR Spinacia oleracea OR celery OR Apium graveolens OR leaf green* OR cabbage OR broccoli OR cauliflower OR kale OR Brassica oleracea OR pea* OR Lathyrus oleraceus OR bean* OR Phaseolus vulgaris)) AND (drought OR arid OR "abiotic stress" OR "water use efficiency" OR "water deficiency" OR "water stress" OR "deficit irrigation") AND (proximal OR remote OR sens* OR tech* OR satellite OR imag* OR drone OR aerial OR mapping OR GIS OR geospatial OR spectral OR unmanned OR survey*).

Bibliographic databases

The following bibliographic search platforms will be searched using Harper Adams University, University of Warwick subscriptions for relevant articles to the research question: 1. Web of Science (WoS) All Databases (conducted as a topic search) 2. CAB abstracts. 3. Scopus conducted on the article title, abstract, and keywords.

Web-based search engines

The web-based search engines CORDIS, and Open Science Framework (OSF), will be used to identify additional literature that cannot be found in the bibliographic database. Due to the languages, the systematic map team understands, all searches and only studies published in or translated into English using Google Translate will be included.

Organisational websites

The search string defined above will be used to search in the Food and Agriculture Organization (FAO) David Lubin Memorial Library [13], the Department for Environment Food and Rural Affairs (DEFRA, UK government) [14], the Agriculture and Horticulture Development Board (AHDB) knowledge library [15], the International Water Management Institute (IWMI) [16], and China Water Risk [17]. Due to the word limit on the United States Department of Agriculture (USDA) website [18], the search base was reduced to the following search string: (field* OR vegetable*) AND (drought OR "abiotic stress" OR "water deficiency" OR "water stress") AND (proximal OR remote OR sens* OR tech* OR satellite OR imag* OR drone OR aerial OR mapping OR GIS OR geospatial OR spectral OR unmanned OR survey*).

Comprehensiveness of the search

Using the search terms and ten known relevant articles shown in Additional File A3, a preliminary pilot search was conducted using the Web of Science (WoS) for search comprehensiveness. When articles were not found using the initial search strings, the search terms were modified to include relevant keywords. When the articles were still not found on WoS, alternative databases such as Scopus and Google Scholar were used for the search. Four articles were found on WoS, three on Google Scholar, and the remainder on Scopus. The inclusion of grey literature (non-commercial publications) and other databases was done to ensure the comprehensiveness of the search.

Search update

Search update is not planned.

Screening strategy

The results from each search will be exported into reference software (RIS) files and imported to EPPI-reviewer software where the screening will be done in three stages. That is, identifying duplicates using the EPPI-reviewer automated deduplication function. The title and abstract will include EPPI-reviewer machine learning algorithms where the system learns from previous decisions (included/excluded) initially made by the reviewer and suggests the likelihood of relevance for unscreened studies. The last stage will comprise the manual full-text screening. Where necessary, full-text versions of non-open-source articles will be accessed using the Harper Adams University, Warwick University, Birmingham University, Aston University, and Leicester University Online Libraries. This is due to the collaboration the BBSRC has with the mentioned Universities. If the full text is unavailable, and the abstract satisfies the inclusion criteria the article will be included in the systematic map.

Eligibility criteria

Eligible population: All drought-affected field vegetable crops will be eligible subjects. This includes crops cultivated in open fields and semi-controlled environments like polytunnels, greenhouses, and growth chambers. These crops are typically susceptible to environmental factors such as temperature and rainfall. Relative intervention: Any studies that use sensing techniques to detect water stress in eligible populations will be included. These articles will be accessed if the sensing technologies used meet the preferred checklist (Additional File A4). Relative outcome: Detected crop water stress. Eligible study designs: We will include field experiments that represent both small- and large-scale commercial farmers, e.g. pot experiments, they give a better scientific overview despite not meeting farmers' reality. Field, modelling studies and greenhouse experiments that have the potential to be expanded for large crop production will be included. To avoid a technological gap, only studies published from 2014-2024 were selected. Although there were no restrictions on publication status, only papers written in English or translated into English were included.

Consistency checking
We will include an assessment of the repeatability of our results in the systematic map. At least two reviewers will assess a random subset of 100 or 5% of article records (whichever is fewer). A Cohen's kappa coefficient relating to the assessments will be calculated to check for consistency ($\kappa > 0.6$) among reviewers. If inconsistency occurs ($\kappa < 0.6$), discrepancies will be discussed, clarified and the inclusion criteria/data coding strategy will be modified.

Reporting screening outcomes
The screening process outcomes will be reported through a ROSES flow chart diagram [12]. This diagram will consist of the articles' source (database), accepted, and rejected at each stage. Two files will be created, with one file consisting of a list of excluded articles using the title and abstract, while the other file will consist of excluded articles using full text with provided explanations.

Study validity assessment
The systematic map will compile and provide a structured overview of all the existing evidence relating to sensing techniques on field vegetable crops. Therefore, the assessment of study validity will not be performed.

Consistency checking
As this is a systematic map, no critical appraisal will take place.

Data coding strategy
A two-stage approach will be implemented where two sets of key information will be constructed based on the quantity of the articles. The first set of questions will consist of basic information on plant general water stress detection. This information will be checked at the abstract level and if there are too many articles the second set of questions will be used as a criterion. The article's eligibility will be based on specific information such as crop type, length of study, spatial area etc (demonstrated in Additional File A5).

Meta-data to be coded
All studies will record the following meta-data: bibliographic information, basic study details (including Population, Intervention, Comparator, and Outcome), study location, and background. The full coding strategy can be found in Additional File 5.

Consistency checking
The first author will code, and the other reviewer will check for consistency by sampling 5% of the articles. The coding criteria will be reviewed once there are substantial disagreements between the first author and the reviewer. When a new coding strategy is established, a further 5% of the articles will be subject to consistency checking. The process will be repeated until consistency is at least 90%.

Type of mapping
The methodology, data collected, meta-data, codes and the research outcome of comparative analysis will be documented for the systematic map database. The comparison analysis will be identified by analysing the meta-data representation based on effective sensing technology, and which will be visualised using tables or graphs.

Narrative synthesis methods
Descriptive statistics and geographical maps will be used to characterise the systematic map into a report format.

Knowledge gap identification strategy
The systematic map database will be used to identify knowledge clusters, by analysing the meta-data representation based on the effectiveness of the intervention in drought conditions. This will be reported in the final manuscript, and identifying these knowledge clusters and gaps will be of use for additional research.

Demonstrating procedural independence
ET does not have any previous publications. The random subset of articles PK will check for consistency will not include papers published by PK, JM, or NR.

Competing interests
The authors declare that they have no competing interests.

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The evidence synthesis upon which this article was based on BBSRC and DBT funding. Both parties played no role in the study design, collection, analysis, interpretation of data, writing of the report, or the decision to submit the paper for publication. They accept no responsibility for the contents.

Author's contributions
ET, PK, NR and JM conceptualised the primary question, PICO terms and search strategy. ET headed the development of search strings, while NR, PK, and JM reviewed the search strings and provided additional keywords to include. PK as the subject expert refined the data coding strategy, and NR as the methods expert guided and reviewed the study design and methodology. ET drafted the first protocol, performed the scoping study and wrote the final manuscript. All authors read and approved the final version of the manuscript.

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