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Review

Management Information Systems for Tree Fruit—1: A Review

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Abstract: A farm management information system (MIS) entails record keeping based on a database management system, typically using a client-server architecture, i.e., an information system, IS, coupled with a variety of tools/methods/models for the support of operational management. The current review adopts a multivocal approach to consider academic and commercial developments in MISs for orchard management, based primarily on the refereed literature but extending to grey literature and interviews of Australian mango orchard managers. Drivers for orchard MIS development include increasing the orchard size and management complexity, including regulatory requirements around labour, chemical spray use and fertilisation. The enablers include improvements in within-orchard communications, distributed (web) delivery systems using desktop and mobile devices, and sensor systems and predictive models, e.g., for pest management. Most orchard MIS-related publications target the commodities of apple, grape, mango and olive in the context of management of plant health (pest and disease), plant development, irrigation and labour management. Harvest forecast and MIS modules are only now beginning to emerge, in contrast to a long history of use in grain production. The commercial systems trend towards an incorporation of financial information, an integration of data from multiple sources and a provision of dashboards that are tailored to the user. Requirements for industry adoption of a MIS are discussed in terms of technical and design features, with a focus on usability and scalability.

Keywords: adoption barriers; applications; data-driven; decision support; harvest forecast

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1. Introduction

1.1. MIS Definition and Need

An information system (IS) is comprised of hardware, software, people and procedures to manage the flow of information within an organisation, while a management information system (MIS) is an IS used to provide managers with information to make routine operational decisions. The MIS may be comprised of a dashboard or other reporting tools to present available data in an easily usable format and may also implement models to provide forecasts or other insights from the available data in support of the 'decision support' of day-to-day operations. The term decision support (DS) system has been differentiated from a MIS as providing tools and models in support of longer-term, strategic decision-making [1–3]. In practice, however, the term DS system is often used in the context of routine operational decision-making, e.g., in references [4–7]. For the current review, a stricter definition of a DS system has been adopted, with the term MIS adopted for operational management issues.

The development of a farm MIS requires the identification of management issues followed by the development of a conceptual model of a management approach to that problem [6]. A complete system will have capabilities of (i) data acquisition and management, (ii) integration of system components, e.g., of irrigation events and an accounting system to provide information on the cost of irrigation, (iii) decision-making based on data inputs and (iv) a communication system, e.g., for notifications and control actions.

Farm MISs were traditionally paper-based but are increasingly computer-based as the scale of operation per farm and the amount of data increases. For example, where once the yield of a broadacre field crop was recorded as one value for the entire block, it is now possible to map this character at a spatial resolution of several meters, enabling variable rate fertilisation and other management improvements.

A MIS developed for orchard management can be expected to address major tasks in commercial orchard operation, such as the management of irrigation [8,9], pests (weeds, insects and disease) [10,11], plant nutrition, manipulation of tree physiology and structure, e.g., through pruning and phytohormone applications [12,13], and harvest, e.g., planning harvest labour, packing and marketing needs [14]. Many farm MIS technical features and adoption drivers and barriers will be common across all agricultural production systems, with greater commonality expected within the plant production systems of perennial and annual horticultural production and broadacre cropping than with intensive and extensive animal production systems. For example, a report on the use of system analysis methods to define the design requirements of a farm MIS [6], explanations for the lack of success in the adoption of a computer-based MIS in farming systems [15], and a review of irrigation MISs [16], all have relevance to tree-fruit production systems.

While many issues are common to annual cropping operations, the management of tree-fruit operations differs from cropping operations in the perennialty of the production system, the relative lack of monitoring systems and tools for spatially localised actions and the extent of manual operations, with a need for large seasonal workforces involved in pruning and harvest operations. For example, in broadacre cropping, predictive (pre-harvest) yield estimates based on a crop's normalised difference vegetation index (NDVI) mapping and/or actual (at-harvest) yield measurements from harvester yield monitors are now regularly used to inform management operations such as fertilisation, harvest planning and marketing [17]. In tree-fruit production systems, however, harvest load information has, until recently, required tedious manual data collection and thus was rarely done rigorously. Technical advances in machine vision and other areas are now allowing for the preharvest count and sizing of fruit on-tree [18].

Past reviews of farm MISs have given little consideration to orchard management. Indeed, the use of more sophisticated MISs in commercial orchard management is relatively new relative to its use in broadacre cropping. For example, Fountas et al. [19] reviewed 141 commercially available FMIS products from 75 software vendors in the context of functionalities and academic concepts but limited this consideration to open-field crop production, with none of the reviewed work specifically targeted to orchard use. In another example, Tummers et al. [1] reviewed 38 FMIS-related papers and pointed out 53 obstacles to the adoption of FMIS but incorporated only two papers dealing with tree fruit. Zhai et al. [20] reviewed 13 'representative' decision support systems, but none specifically addressed tree-fruit production.

1.2. Review Motivation

The motivation was provided by the recent progress in systems for the in-orchard assessment of tree-fruit numbers and the size profile based on machine vision and for a forecast of optimum harvest dates from enhanced heat unit calculations and estimates of dry matter content of fruit-on-tree using NIR spectroscopy—as reviewed by Anderson et al. [18], Neupane et al. [21], Amaral et al. [22] and Walsh et al. [23], respectively. In our own experience in developing these technologies and prompting their use by growers, it became obvious that the output of the new technologies needed to be delivered into a MIS to be used by the orchard manager. We were, therefore, motivated to understand the state-of-the-art in-orchard MISs in context of the adoption of technologies for the estimation of harvest loads and timing. The deficiency in the documented development of an orchard MIS provided motivation for the current review.

1.3. Structure

This current study presents a multivocal literature review, a form of systematic review that includes both peer-reviewed publications and grey literature supplemented by a survey. The primary method was the review of peer-reviewed publications, as identified based on the foundation of the search string used in the review of farm MISs by Tummers et al. [1]. The grey literature review and survey were undertaken to provide a 'users' insight on the adoption of orchard MIS products.

The following sections cover: (i) methods employed in the data collection; (ii) an evaluation of published work in terms of topic categorisation, barriers and drivers to MIS adoption, system evaluation, system design features and technical capacities, and orchard management issues; (iii) a survey of technology providers and potential users in the context of barriers and drivers for MIS adoption; (iv) an assessment of a selection of current commercial systems; and (v) a conclusion on the trends of in-orchard MIS development and areas for future attention.

2. Review Protocol

2.1. Literature Survey

Tummers et al. [1] reviewed the 2008–2018 literature on farm MISs within the digital libraries of IEE Xplore, ACM Digital Library, Wiley Interscience, Science Direct, Springer and the ISI Web of Knowledge. Using the following search string and augmented with manual input, 1028 papers were identified:

> *"(farm OR agri*) AND (manage* OR information) AND (software OR system* OR tool OR platform)"*

These papers were screened by Tummers et al. [1] on a reading of the title and abstract, with 78 papers selected. A further screening was based on a reading of the complete article, resulting in a selection of 43 papers. The 43 reports were further assessed for their quality, with five studies excluded.

In an attempt to replicate this result, the ISI Web of Knowledge was searched using this search string for the same period, with 36,535 papers identified (doa 2023-06-16). The reason for the difference in the number of identified records is not known. Using the same search string and period for a Scopus database search of the combined field TITLE–ABS–KEY returned 68,727 (doa 2023-06-16) records. A search of the separate fields of TITLE, ABS and KEY returned 61,743 records in total, with the reduced number due to the requirement for all search terms to be in each field.

The relative volume of orchard MIS literature for the same time period was assessed by the inclusion of additional keywords (shown in italics) in the Scopus search string in a search of TITLE–ABS–KEY, which resulted in the identification of 3346 records, i.e., approximately 5% of the farm MIS results:

> *"(orchard OR (fruit AND tree)) AND (manage* OR information) AND (software OR system* OR tool OR platform)"*

The search string was refined to the following query, with a yield of 2340 records for the period 1960 to 2023 and 1069 records for the period 2008–2018 on a TITLE–ABS–KEY search (doa 2023-05-31):

> *"(orchard OR (fruit* AND tree*)) AND ("decision support" OR "information system*" OR software or platform)"*

Consideration was also given to the recently released review tool 'Elicit'. Elicit is a recently developed product using language models such as GPT-3 that responds to a research question by searching for the 400 most semantically related papers in the Semantic Scholar dataset, returning the top seven papers along with a summary of claims (specific to the question asked) based on information in the abstracts of papers (Elicit: The AI Research Assistant; https://elicit.com; accessed on 11 January 2024). The claimed benefits are the identification of relevant papers that do not match keywords, given the use of semantic similarity. The developers assert the use of features to avoid model 'hallucination'. The tool is geared towards a review of medical studies with the inclusion of summary fields such as the number of participants and dose rate, but fields such as 'outcomes measured' are generically useful.

A simple entry of the search string, as used above, returned three papers relevant to tree fruit within the top seven identified papers, with these three papers also identified by Scopus. However, Elicit is designed for the entry of a question rather than the entry of a Boolean string of keywords. The two queries, "What (farm management information systems) or (decision support systems) have been developed for orchard use?" each returned one paper not specific to orchard management in the top seven references, with one paper common to the two searches. Of the top 49 papers identified by Elicit, 14 were not common to the Scopus search. This result reflects the limitations of the 'literal' keyword relative to semantic searches. For example, papers using the terms 'A farm configuration system' [24], orchard 'information query service system [25], and 'digital orchard management system' [26] were not identified on the search string used for Scopus. We concluded the tool is a useful review aid, with the semantic search capturing relevant papers missed in a keyword search, as undertaken when using tools such as the ISI Web of Knowledge.

These records were filtered by three reviewers, with the inclusion of a record if approved by any of the reviewers. Records were first filtered on the title, followed by a reading of the abstract (to 175 records, of which the full text was available for 153), and then on a reading of the full text (to 130 records). The high exclusion rate for the screening of titles and abstracts was due to the number of papers that did not report on the development or assessment of a management system, despite the mention of these terms in the title, keywords or abstract. Papers describing the development of 'Decision Support Systems' were re-categorised as developing MISs, given that they were addressing day-to-day operational management, following the definition provided in Section 1.1.

After a preliminary reading of the papers, the topics and categories were defined (Table 1). A data extraction form (Appendix A) was then used to capture relevant information from each paper. The database of categorised publications is presented in Appendix B.

Table 1. Definition of topic and categories as used in the current review.

Topic	Category	Definition
System type	method	A tool/app, method or model to support decision-making
	MIS	as above, with the associated information database and graphical user interface
Application	plant health	Pest, disease and weed management
	plant development	related to cultivar selection, management of plant growth, including flowering, fruiting, thinning and harvesting
	irrigation and water stress	Irrigation management
	nutrition	Plant nutritional status and fertilisation
Aim	design	Design of a solution or software system
	development	Development of a software system
	implementation	Operationalisation of a software system
	use	Farm use of a software system
Platform	desktop	Software or app operated on a desktop PC
	web	Software or app accessed via web browsers
	mobile	Application operated on mobile devices
Technological features	capabilities	Features such as data acquisition, data management, analysis and visualisation

Table 1. *Cont.*

Topic	Category	Definition
Development tools	front-end	Tools for front-end developments, e.g., HTML/CSS, JavaScript, TypeScript or Bootstrap
	backend	Development tools for the backend, e.g., programming languages (PHP, Folium/Django python, .Net, RStudio, Ruby on Rails), DBMS (MySQL, PostgreSQL/PostGIS, MS SQL Server, Oracle) and geospatial (ArcGIS server, Geoserver/OpenLayers, Google Maps/API) Desktop (Pascal, Delphi, Visual Basic, Java, C++, .net)
Operational challenges	connectivity + continuity	connectivity of networks (3G, Wi-Fi, internet) and service continuity
	integration	Integration of different services from other vendors or upgrading with new technologies
	scalability	Ability of the system to handle an increased volume
	affordability	Cost of the service and the user's willingness to pay
Evaluation	efficacy	ability of software to produce an intended result satisfactorily
	usability	Ease of use of software or app feature
Accessibility	availability of software	Distribution channels

2.2. Orchard MIS Provider and User Survey

Commercially available orchard MIS products were identified through the grey literature (industry magazine articles and advertising), their presence at industry events (workshops, exhibitions, conferences), and referrals from tree-fruit farms using an orchard MIS product. Given the authors' location, this search resulted in the consideration of MIS products used in the Australian tree-fruit industry. Products were characterised based on publicly available information, discussions with providers and feedback from orchard managers.

The feedback activity involved semi-structured interviews based on the questions outlined in Appendix C, occurring over the period 2020–22. The interviews occurred on farms or at industry workshop events. The activity included 43 managers of mango orchards and value chains in tropical Australia, with the orchard managers selected from farms of a range of production sizes, from small 'family farms' to large 'corporate farms'. Some of these managers were also involved in the production of other commodities, principally avocado and citrus. In total, these managers accounted for over 65% of Australian mango production tonnage. While this interviewee base is 'narrow' in terms of the commodity (mango) and geographic base (Australia), it is 'deep' in terms of the proportion of industry covered and the level of interaction. The level of interaction was high, as our research team has a long history of research and development work in this industry with an established level of trust with industry players. This interviewee base is expected to hold similar views to that of other Australian tree-fruit managers, with the caveat that some mango production occurs in more remote areas than other Australian tree-fruit production. This remoteness historically involved poor internet connectivity, thus limiting the use of online resources.

3. Literature Evaluation

3.1. Literature Trends

The journals with the greatest number of papers were Acta Horticulture (21%), a conference proceedings series, followed by Computers and Electronics in Agriculture (9%), Agronomy (4%), Sensors (2%) and HortTechnology (2%) (Table 2). We hypothesise that many researchers develop hardware to address farm management issues and then realise the need for a MIS to utilise the technology. A bespoke MIS is then created, with peer input sought through conference presentations and subsequent publication in conference proceedings. Publication in the referred journal space requires an additional step, adding novelty in terms of the design, implementation or evaluation of the MIS.

Table 2. Orchard MIS publications by the topics of country of origin, crop, MIS type, aim of study and software type (as a % of the total number of publications, %Pub). A given publication can be assigned to more than one category within a topic. Tree-fruit production is given by topics of country and crop (as a % of total production on a weight basis). The ratio of country refers to the ratio of the % of publications to the % of global tree-fruit production for each country. The ratio on crop refers to the ratio of the % of publications to the % of global fruit production (on a weight basis) for each commodity. M-IS refers to a MIS incorporating a model as well as an information system, and M refers to the development of a model/tool without a supporting information system. Data are sourced from [27].

Country	Pub%	Prod (%)	Ratio
United States	18	3	7
China	18	27	1
Spain	10	2	5
Italy	8	2	4
Australia	6	0	15
Greece	4	1	8
India	3	12	0
Portugal	2	0	10
New Zealand	2	0	11
Argentina	2	1	3
Canada	2	0	22
Germany	2	0	8
Israel	2	0	14
Chile	2	1	2
Netherlands	2	0	18
Switzerland	2	0	37
Malaysia	2	0	12
France	2	1	2
Belgium	2	0	22
Taiwan	1	0	3
Czech Republic	1	0	29
Malawi	1	0	2
Pakistan	1	1	1
Japan	1	0	2
UK	1	0	9
Brazil	0.8	4	0
Indonesia	0.8	3	0
Iran	0.8	2	0
Russia	0.8	1	1
Colombia	0.8	1	1
Denmark	0.8	0	118
Romania	0.8	0	2

Crop	Pub%	Prod (%)	Ratio
Apple	27	9	3
Gen. orchard	22	-	-
Citrus	9	28	0
Olive	8	2	4
Cherry	6	0	15
Peach	5	2	2
Mango	5	5	1
Pear	4	2	2
Grape	3	7	0
Kiwi	3	0	7
Nut	2	-	-
Berry	2	1	1
Plum	2	1	1
Almond	2	-	-
Banana	1	12	0
Cecropia spp.	1	-	-
Jujube	1	1	1
Litchi	1	0	2

MIS Type	Pub%
Web	41
Desktop	32
Mobile	22
Web/Mobile	12
Desktop/Mobile	4
Desktop/Web	3
Desktop/Web/Mobile	1

Aim	Pub%
Development	75
Design	23
Implementation	14
Use	10
Other	2

Type	Pub%
M-IS	62
M	38

The highest number of papers per country originated from the United States and China; however, Denmark was notable for its publication rate relative to its production base [27–30]. India and Brazil are likely sources of future activity, as BRICS economies with large fruit production bases, but currently, little research activity is available on this topic.

The published papers targeted twenty different fruit commodities, with apple (27%) being the dominant application (Table 2). This result is expected, as the apple is the tree fruit with the highest global production (by weight) [31], and many apple production systems implement intensive management to achieve high production rates per hectare, e.g., through high-density plantings and operations such as trellising, flower and fruitlet thinning, with some operations now occurring at a tree level, e.g., machine vision-based flower thinning. The commodity with the greatest publication activity relative to the value of the crop was cherry, while research on citrus and banana was under-represented in the context of production value. This observation is consistent with most work originating from temperate climates and advanced economy countries.

The most employed platform was web-based, followed by mobile phones and desktops (Table 2). This observation result mirrors that seen in other services, with the initial deployment of stand-alone desktop systems superseded by web and mobile/web delivery systems [5]. In the field, orchard management requires the use of a mobile device for data collection and task messaging, with a web-based system allowing multiple-use accessibility.

Most publications dealt with the design and development of an MIS targeted to a specific orchard management issue (Table 2)—relatively few papers reported on the use of the MIS in commercial orchard operations, i.e., operating alongside or coupled into an existing farm management system. In our experience, managers of large orchard operations (the likely adopters of MIS) are time-poor and resistant to the use of secondary software platforms outside of their main management system. While such trials are essential to technology adoption, they are therefore, difficult to implement.

While the screening process removed papers reporting the development of a measurement method rather than a management system, a number of the included papers nonetheless were weighted heavily toward method development, e.g., 'a protocol based on thermal imagery for variable rate drip irrigation' [32] (Table 2).

Publications were classified by their management aim into five themes and 20 sub-themes (Table 3). Most studies addressed plant health (55%) and plant development (49%), while at the sub-theme level, more studies addressed pest management (15%), irrigation management (6%) and yield estimation (6%) than other topics. The publication rate has increased markedly over the last 5 years for the applications of irrigation management and yield estimation (Figure 1). Over half of the papers on forward estimation of fruit loads and harvest management described the development of an algorithm or model as well as an information system, i.e., a MIS rather than an IS (Table 3).

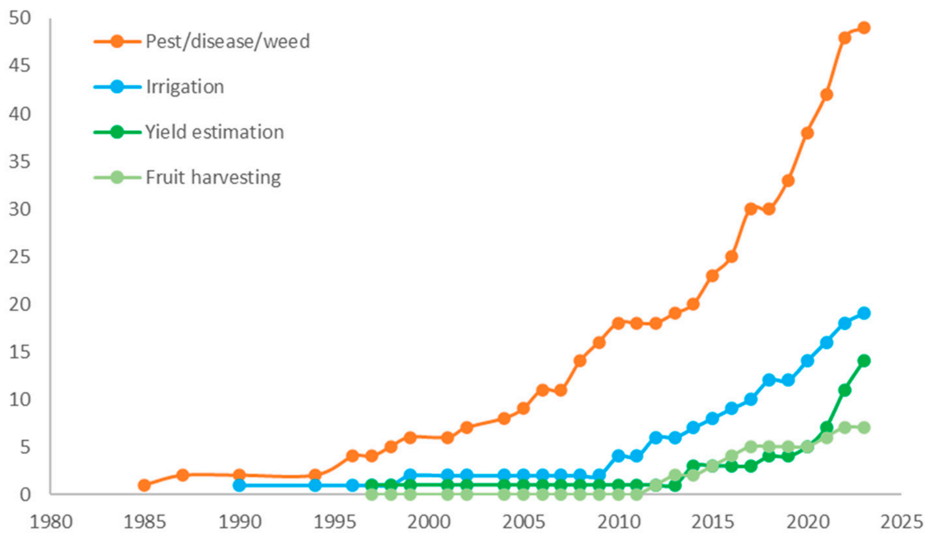

Figure 1. Cumulative count (1985–2023) of reports (of majority sub-themes) by application area.

Similar trends were noted for the sub-set of reports reporting the use or implementation of an orchard MIS, with the dominant commodities being apple and olive/cherry/citrus, and the dominant applications being irrigation and plant health.

Of the management application topics, pest and irrigation management enjoyed the greatest level of reporting across fruit commodities, while of the fruit types, pome fruit (apple and pear) and cherry enjoyed the greatest diversity of management applications (Figure 2). These results reflect the development of hardware and methodologies in the respective management areas, the value of these crops, and the concentration of research in economically advanced countries with temperate climates.

Table 3. Categorisation of publications by management aim, in terms of the number of reports by sub-theme and theme, and as a % of all publications, and the % of papers within a sub-theme that described a predictive function coupled with an information system (M-IS) rather than primarily a description of a tool/predictive function.

Theme	Sub-Theme	#	∑	%	M-IS (%)
Plant health (pest/disease/weed)	Pest management	29	55	42	48
	Pest/disease/weed management	13			85
	Disease management	7			57
	Environment monitoring	5			100
	Activity monitoring	1			100
Plant development (germplasm/breed/growth/yield)	Yield estimation	14	49	38	57
	Fruit harvesting	7			71
	Germplasm/cultivar/breeding management	6			83
	Growth and planting	6			33
	Orchard (spray/logger/fruit size/thinning/etc.) management	3			67
	Fruit maturity	3			33
	Production management	3			67
	Flower initiation/detection	2			50
	Labour management	2			100
	Carbon emission	2			50
	Financial analysis	1			100
Irrigation	Irrigation management	19	20	15	68
	Water stress assessment	1			0
Nutrition	Nutritional management	3	5	4	0
	Fertiliser calculator	2			100
Other	Review of DSS	1	1	1	0

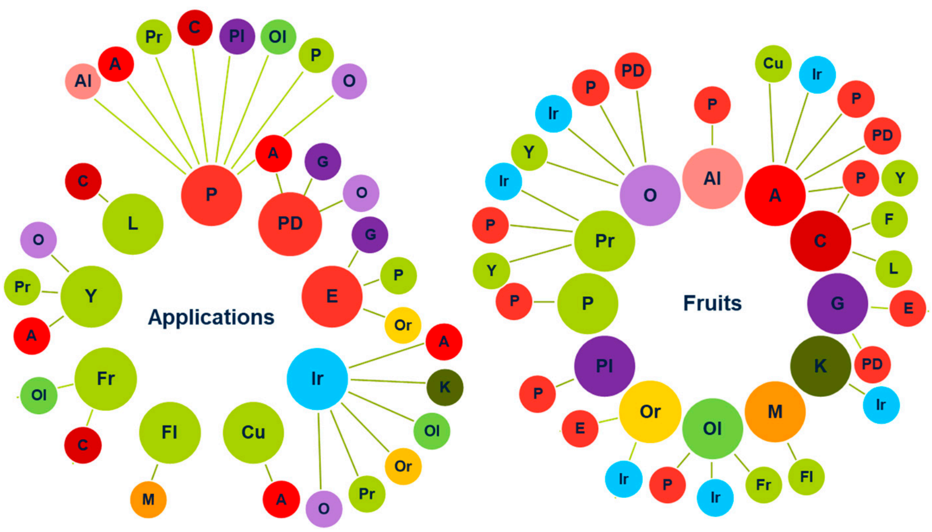

Figure 2. Categorisation of MIS-related publications in terms of management aim and fruit type. Right panel, papers are classified by management aim, then fruit type. Left panel, classification by fruit type, then management aim. Applications: P: pest, PD: pest/disease/weed, E: environmental monitoring, Ir: irrigation, Cu: germplasm/cultivar/breeding, Fl: flower initiation/detection, Fr: fruit harvesting, Y: yield estimation, L: labour management; Fruits: Al: almond, A: apple, C: cherry, G: grape, K: kiwi, M: mango, Ol: olive, Or: orange, Pl: plum, P: peach, Pr: pear, O: orchard/fruit.

3.2. Adoption Barriers and Drivers

Despite their promise to increase the efficiency of farm operations, farm MIS adoption has been less than expected, with MIS technology described as 'under-utilized' in agricultural production [1,33]. The major barriers to farm MIS adoption identified in previous studies [1,19,33–37] include:

(i) 'Internal' operational issues, including system 'bugs', feature incompleteness, poor user experience through poor wording of logic flow, the effort required for data entry, and poor system value as manifested in a low integration of system output into decision-making;
(ii) 'External' operational issues, including poor system reactivity caused by limited internet connection, poor input data quality and poor lack of system integration and interoperability through failure to use standardised data formats;
(iii) System maintenance issues, including low adaptation rates, high costs and poor user support resources;
(iv) Lack of trust in system reliability and data security;
(v) Affordability.

Similar operational challenges were reported in the reviewed orchard MIS papers, including:

(i) 'Internal' operational issues, including e-device or platform compatibility, scalability and performance/efficiency [38–40];
(ii) 'External' operational issues, including connectivity and adequacy of bandwidths [40] and poor integration of third-party services and new technologies [41];
(iii) System maintenance issues, such as software features and poor support services and training [42];
(iv) Data privacy and trust [38–40];
(v) Affordability and user willingness to pay for the services [43–46].

The issues noted above are often inherent in system design, resulting from a mismatch of designer and developer focus and the requirements of the ultimate users of the system. As with any technology adoption, there exists a scale-up problem between the proof-of-principle stage and the offer of a user-friendly, cost-effective product to a large user base.

MIS adoption is also a function of the client base. For example, a relationship was noted between the 'technical efficiency' of Brazilian citrus farms and their adoption of a MIS, with MIS users producing greater output using the same level of inputs [47]. The perceived benefits of orchard MIS use are related to increased efficiency in planning and the coordination and monitoring of production, particularly in larger-scale enterprises.

3.3. Orchard MIS Evaluation

An orchard MIS is a software artefact. While some quantitative performance metrics can be reported, e.g., the speed of data rendering and accuracy of forecasts based on models, the value of such a system is 'in the eye of the beholder', i.e., the user. User evaluation is, therefore, required. Many studies reporting evaluation use a survey tool. However, attention is required to the goal of the survey goal. Questions such as 'which of the following features were most useful?' may help guide developer efforts but do not provide information on the product's usability and, thus, likely uptake. For example, a web-based agro-ecological monitoring system was evaluated through a user survey to check the satisfaction of registered users, with 95.8% of the users reported agreeing that "the pest density forecasting service helped to prevent pest outbreak" [46]. The willingness of users to adopt (and pay) for the use of the system is a separate question.

To assess the likely uptake, questions can probe the relative performance of the orchard MIS to an existing management approach or probe the economic value achieved in the use of the MIS. For example, a quantitative approach was described for a user satisfaction survey on a decision support system for integrated pest management in an apple orchard, involving a comparison of the decision support recommendation to that of a domain expert [48]. The decision support system agreed with the domain expert in all 100 cases of spray recommendations and in 95% of 283 cases of disease diagnosis. In another example, the Washington State University-Decision Aid System (WSU-DAS) was evaluated using a web-based user survey [40]. It was reported that the tool had achieved a high market penetration in the area of integrated pest management (IPM) due to the provision of time-sensitive information, e.g., recommendations on the timing of insecticide application to achieve disruption on insect mating with fewer applications. Users were asked to estimate the economic value gained in the use of WSU-DAS from a reduction in the number of chemical sprays [11]. Adoption of such questions in the evaluation of future orchard MIS developments is recommended.

3.4. Technological Features

Technological features, including development tools (as defined in Table 1), were described in 31% of all papers (Tables 4 and 5), with a useful review provided by Kaloxylos et al. [49] on the architecture of an FMIS and the use of generic software modules in building farm-specialised systems. Decadal progression in technical features can be summarised in terms of (i) the use of personal computers from the 1990s, (ii) the use of WebGIS mapping and remote sensing from the 2000s, (iii) the use of mobile phones for data entry and LoRa-enabled sensors from the 2010s, and (iv) the use of IoT sensors, Lidar, UAVs and machine learning in image analysis in the 2020s. Twelve features were identified within the MISs (Tables 4 and 5). Less common features, such as a search engine, location-based services (LBS), WebGIS-based mapping, notification and alert messaging systems, e.g., web/email/SMS, add to the farm usability of a MIS. These features can be expected to be added to commercial products intended for orchard management use, as opposed to the systems reported in publications, which tend to focus on the demonstration of proof-of-concept for the management of a particular task. Likewise, software features such as RESTful APIs, which allow for the progressive development of an application, are more important in a commercial product than a proof-of-concept project.

Table 4. Technological features utilised within orchard MISs: code key (for use with Table 5).

Code	Features
1	IoT/Sensor
2	Data acquisition
3	Data management
4	Data analysis/processing
5	Search engine
6	Prediction/computational model
7	Location-based service
8	Visualisation (charts/graphs)
9	Map visualisation/WebGIS
10	Notification/alert system (e.g., web/email/SMS)
11	Reporting
12	RESTful API/web services

In concert with the evolution from static to dynamic and onto progressive web app delivery of the orchard MIS, there has been an evolution in the development tools used (Table 6). Of the publications reporting on an orchard MIS as a web application, the majority used HTML/CSS and JavaScript for the development of a front-end graphical user interface (GUI) (Table 6). PHP was popular for backend development (including RESTful APIs) along with Java, .Net and Folium/Django (Python). Most developers used MySQL for database management, followed by PostgreSQL/PostGIS, MS SQL Server and Oracle. Google and ESRI platforms were predominantly used for web mapping and WebGIS app development, with some use of other platforms, e.g., GeoServer/OpenLayers and OpenStreetMap.

Table 5. Technological features utilised within orchard MISs: categorisation of research papers.

#	Study	Crop	Technological Features											
			1	2	3	4	5	6	7	8	9	10	11	12
1	Miranda et al. [50]	apple		√	√	√				√				
2	Bazzi et al. [51]	apple		√	√	√				√	√			
3	Buhrdel et al. [52]	apple		√	√	√				√	√			
4	Padma et al. [48]	apple			√	√						√		
5	Xia et al. [53]	apple		√	√	√				√				
6	Tsiropoulos et al. [54]	apple		√	√	√				√	√	√	√	
7	Xiang et al. [55]	apple		√	√	√				√	√			√
8	Osman et al. [56]	apple, orange and pumpkin		√		√				√	√			
9	Shuen et al. [57]	banana			√			√						
10	Ren et al. [58]	bayberry			√		√							
11	González et al. [59]	cherry		√		√				√				
12	Tan et al. [60]	cherry		√	√	√				√	√			
13	Ampatzidis et al. [61]	cherry, apple		√	√	√				√	√			
14	Ampatzidis et al. [62]	cherry, blueberry and apple		√		√				√	√			
15	Zhang et al. [63]	citrus		√		√								
16	Perondi et al. [64]	citrus		√	√	√				√		√		√
17	Porto et al. [65]	citrus		√	√	√				√	√			
18	Cohen et al. [66]	citrus		√		√				√				
19	Yang et al. [67]	fruit			√	√				√	√			
20	Kun et al. [68]	jujube	√	√		√				√		√		
21	Dhonju et al. [69]	mango	√	√	√	√				√	√	√		√
22	Walsh et al. [70]	mango		√		√				√				
23	Iquebal et al. [71]	mango			√		√							
24	Gkisakis et al. [72]	olive		√	√	√								
25	Capraro et al. [73]	olive	√	√	√					√				
26	Capraro et al. [74]	olive		√	√	√				√				
27	Pontikakos et al. [75]	olive	√	√	√	√			√	√	√			√
28	Li et al. [76]	orange			√			√						
29	Flores et al. [77]	orange		√	√	√				√				
30	Forcén-Muñoz et al. [9]	orchard	√	√	√	√								
31	Stöcklin et al. [41]	orchard	√	√	√	√				√		√		√
32	Tan [78]	orchard		√		√								
33	Tan et al. [44]	orchard		√	√	√				√	√			
34	Tan et al. [79]	orchard		√	√	√				√	√			
35	Jiang et al. [46]	orchard		√	√	√						√		
36	Zapata et al. [8]	orchard		√	√	√				√				
37	Jones et al. [40]	orchard			√	√		√		√				
38	Liu et al. [80]	orchard			√	√		√						
39	Damos et al. [81]	peach	√	√		√				√				
40	Todorovic et al. [82]	peach, olive		√	√	√						√		
	Total count		7	32	31	35	2	4	1	28	14	8	1	5

Table 6. Development tools and technologies used in MIS-related publications.

Technology	Development Tools
Frontend	HTML, CSS, JavaScript, TypeScript, Angular.io, Bootstrap
Backend	Ruby on Rails, PHP, Folium/Django python, .Net, RStudio, Java
Database	NoSQL, SQLite, PostgreSQL/PostGIS, MySQL, MS SQL Server, Oracle
WebGIS	ArcGIS Server, GeoServer/OpenLayers, OpenStreetMap, Google Maps
Web services	RESTful API, PaaS, SaaS
Desktop	Pascal, Delphi, Visual Basic, Java, C++, .Net

The implementation of sensor and control networks on orchards has been constrained by communication capability. The most implemented orchard-wide management tool has been for irrigation management, involving soil moisture monitoring and irrigation valve control. This has typically involved proprietary radio communications. LoRa and related technologies such as LoRaWAN and SigFox have enabled low bandwidth applications, such as temperature monitoring across orchards, although line-of-sight requirements require the use of elevated aerials and repeater stations. To date, the coverage of high-bandwidth 4G and 5G networks across (Australian) orchards has been limited, given their location in low-population-density areas. The advent of lower-cost satellite-based communication systems such as StarLink^{TM} (Redmond, Washington, DC, USA), which operates in both the 2.4 GHz and 5 GHz frequency spectrums, opens possibilities for high-bandwidth orchard applications. Competitor systems are expected to expand during the next decade, potentially further lowering the cost. Another relatively recent development is the deployment of mesh-wifi across farms, based on 900 MHz, 2.4 GHz and 5 GHz frequencies in Australia. Which of these high-bandwidth applications will eventually dominate in-orchard use will reflect the reliability and cost of the technologies. It is clear, however, that their availability will lead to an increase in the use of control actuators and sensors, particularly cameras, across orchards operating through orchard MISs.

3.5. Management Aims

3.5.1. Plant Health

Publications in the 'Plant health' category commonly involved the monitoring of environmental parameters in the context of pest, disease and weed risks, e.g., the use of wireless sensor networks for near real-time environmental monitoring of environmental parameters in the context of disease risk, with data storage in a database system and visualisation through a web-based system [45,83]. Other work involved the development of models for the management of pests and disease [84,85] or weed invasion risks [86]. These management tools were generally intended for use at a farm level; however, some papers reported on tools intended for regional use, for use by a catchment or government agency.

3.5.2. Irrigation

Publications in the 'Irrigation' category dealt with the development of MISs around water stress assessment and irrigation management. For example, a multi-modal sensor system for plant water stress assessment was developed in the context of an irrigation decision support system for an apple orchard [7]. Several authors report on the design and development of a generic MIS for the irrigation management of tree crops [8,39]. Other examples of models that could be used within a farm MIS include the CropSyst model for the irrigation management of pear orchards [87], while apple-specific irrigation management systems were developed [7,54] and implemented [8,39]. Similarly, a system ('Irriman') was developed for use across an irrigation community based on input from a regional array of sensors [9,88].

3.5.3. Nutrition

Publications in the 'Nutrition' category dealt with the in-field assessment of nutritional status and fertiliser use. For example, a mobile application was developed for the assessment of the nutritional status of apple trees [89], a web-based fertiliser information system was developed for banana production [57], and a web-based expert system was developed for the fertilisation of orange trees [76].

3.5.4. Plant Development

Publications in the 'Plant development' category dealt with a selection of germplasm/cultivars, planting issues, prediction of growth, flowering or fruiting, and thinning requirements. Several publications did not target orchard management per se but rather the management tasks in the other areas of the value chain, e.g., bayberry breeding [58]. Examples of models that could be used within an orchard MIS include a method for yield estimation of apple trees [90], a carbon balance model for use in guiding apple tree thinning [13], a model for apple and pear growth [55,91], apple and orange yield estimations [14,56,87], an agent-based decision support system for mango flower initiation [92] and a tool for the forward estimation of mango harvest timing [93]. The most comprehensive management system was that of Jianwei et al. [94], who applied research on plant growth modelling within a framework to enable management decisions on, e.g., pruning, irrigation, fertilisation, yield prediction and cultivation.

Publications addressing harvest management were categorised as related to the estimation of fruit maturity for the timing of harvest, estimation of on-tree fruit load or the management activity during the harvest. These reports document the development of sensors and methods, with a number of studies also exploring the presentation of data to users. In particular, methods based on machine vision are rapidly developing for a direct assessment of tree-fruit attributes, underpinning the forecast of crop timing and loads. Indeed, a number of machine vision-based commercial systems have recently become available for in-orchard use, as reviewed by Anderson et al. [18].

The timing of the 'decision to pick' requires information on fruit maturation. This can be estimated based on the heat unit requirements between flowering and fruit harvest maturity, e.g., Sousa et al. [95] and Amaral et al. [22], given the measurements of orchard temperatures. Depending on the commodity, fruit maturity can also be assessed based on the level of storage reserves, fruit skin colour, flesh colour and/or fruit shape. For example, the classification of melon ripeness/maturity from field imagery of the fruit surface was reported to support the estimation of optimum harvest timing [14]. The development of portable, non-invasive assessment technologies has enabled the inclusion of internal attribute specifications into farm management systems. For example, a hand-held device for the assessment of the ratio of absorbances at two wavelengths was used to assess flesh pigment levels in fruit [96], and the use of hand-held near-infrared spectrometry has been recommended for the estimation of fruit storage reserve levels as a measure of fruit maturity [97], e.g., of olive fruit [98]. An online MIS was developed for the optimisation of olive orchard harvesting orders based on monitoring networks for environmental data and physio-chemical fruit analysis [99]. In other examples, a flower initiation model was adopted into a decision support system for mango production in a greenhouse environment [92], and a web-based MIS for mango harvest time forecasting, based on non-invasive in-field measurements of fruit dry matter, was implemented [70]. A MIS has also been developed that provides a financial assessment of the value of the use of sensor technologies in harvest timing [100].

The estimation of harvest loads, i.e., the fruit number per tree and the fruit size, can be based on manual assessments. Wulfsohn et al. (2018) report on sampling strategies that are appropriate for use in these applications, with commercial use exemplified by Pronofrut (San Fernando, Chile) (https://pronofrut.cl/en) (accessed on 18 December 2023) in which a yield estimation support service is provided for the bud, flower and fruit counts and sizing using multistage systematic sampling designs and manual measurements. In another example, the 'AKFruitData' software was used to acquire manual count data for the estimation of apple yields [50].

A number of researchers have explored the use of machine vision in fruit load assessment. For example, a deep learning model for an Android smartphone app, "KiwiDetector", was developed for the yield estimation of kiwifruit [101], a smartphone camera application was used in a client-server architecture for the estimation of apple yields [90], and the orange fruit count was estimated from UAV collected imagery, with results broadcast to an online map [102]. The use of depth cameras or LiDAR has enabled the estimation of size profiles of fruit on trees, with a coupling to a fruit growth model that allows a forecast of the fruit size distribution at harvest, as reviewed by Neupane et al. [21]. Moving beyond the provision of yield data per se to use in management, a system for estimation of the optimal number of harvest containers and their field placement for efficient logistics was developed based on apple yield mapping from orchard video images [56].

A number of systems also exist for recording fruit yields and quality at harvest. For example, a tree-fruit yield map was generated using labour time data collected from 'labor monitoring devices' [79], which was later developed into a cloud-based harvest management system for monitoring harvest labour [44]. Several cloud-based harvest information systems have been developed, e.g., involving real-time harvest data and the generation of yield maps for hand-harvested cherry, blueberry and apple fruits [62] or the recording of the in-orchard location of harvest field bins, enabling a postharvest association of fruit to a set of trees for the construction of a yield map [51]. In another example, a system was developed for the quality assessment of cherry fruit at harvest based on the use of a mobile device to upload pictures of harvested fruit, with a cloud image processing pipeline providing a report on the quality of the fruit [59].

4. Commercial Practice

4.1. Adoption Barriers and Drivers

As identified in semi-structured interviews, the requirement to provide documentation for external parties was a significant driver for record keeping by Australian mango orchard managers. This need existed in the context of chemical usage for major retailer certification, labour records for compliance with government regulations, practices relevant to organic certification and export markets requiring GlobalGAP [103] or other certifications (Table 7). Documentation of anticipated orchard yields was supplied to the national industry body and within closed marketing groups (using cultivars under Plant Breeders Rights). However, record keeping was predominately manual and paper-based. Some automated data recording and decision support occurred in the context of irrigation management, pest scouting and the estimation of fruit maturation, and this occurred only on large farms (with >50,000 trees). With farm managers being time-poor, it is not surprising that system usability was identified as a key adoption factor (Table 7).

Table 7. Responses by Australian mango orchard managers in the context of field production.

Issue	Prevalence (% of Respondents)
What is your primary recording need?	93% chemical records, 68% labour records
Do you share data with the value chain?	98%
Do you use automated processes in data acquisition and processing?	17%
Do you use a commercial orchard MIS product?	5%
What are the barriers to the use of a commercial MIS product?	71% difficulty of use, 44% cost

Examples of regulatory pressures in Australia that drive a need for documentation include (i) legislation requiring fertiliser use at or below the recommended levels in Great Barrier Reef catchment areas, with records to be available for audit for six years (Environmental Protection (Great Barrier Reef Protection Measures) and Other Legislation Amendment Act 2019) [104]; (ii) legislation requiring adherence to chemical use protocols, including withholding periods before harvest, with documentation within 48 h of use and maintenance of records for two years, e.g., Section 6 in Queensland Government [105], and (iii) retailer requirements, involving audited compliance to food safety and quality standards for suppliers to the major fruit retailers, e.g., HARPS [106]. While concerns around data privacy are strong, it is expected that the increasingly onerous reporting tasks will drive the use of automated reporting systems using data extracted from an orchard MIS—this conclusion, while based on Australian observations, is globally relevant.

The interviewed producers that were using commercial orchard MIS products were young (<40 years), large producers (>70,000 trees) and members of closed-loop value chains. The drivers for adoption in these factors are obvious, involving a generational change in IT familiarity and a willingness to adopt new technology, larger production units that have an operational complexity that requires record keeping and forecasting capability, and the requirement to supply forecast data to marketing groups.

Commercial FMISs were generally perceived as difficult to use. Decision-making is not trivial, given the complexity of orchard operations, with each season providing a different set of issues to the preceding seasons. A MIS will, therefore, become more complex as additional management needs are addressed. Farm managers also described themselves as extremely time-poor during the production season and resistant to running multiple software platforms to deliver different aspects of management. Orchard MIS implementation thus requires a staged approach, with the progressive introduction of features and complexity to the user under a common service umbrella, matched to the management needs of the moment. The organisation of software into a series of modules is recommended.

Connectivity, which had previously been a major constraint on many farms, did not feature as an issue to MIS adoption. Change factors include a rapid improvement in the available bandwidth and geographic availability, notably through satellite services.

4.2. Commercial Orchard MIS

The first generation of computer-based MISs used on farms involved the keeping of records for regulatory purposes, e.g., chemical usage, with later generations of products providing decision support functions [107]. Carrer et al. [47] categorised seven aspects of electronic MISs in Brazilian citrus production planning: (i) cost control spreadsheets; (ii) input stock records; (iii) records of production, productivity, and the incidence of pests per plot of land; (iv) use of integrated decision support systems; (v) online access of market information; (vi) adoption of precision agriculture techniques; and (vii) traceability and quality certifications.

Many research studies employ commercially available tools/sensors that are also in commercial use in farm management systems, e.g., the use of a commercially available orchard imaging system in research on harvest timing decisions [108]. However, academic papers rarely report the use of a commercial orchard MIS, with a few exceptions involving MISs in pest, disease, and irrigation management. This situation is expected to change as orchard MISs become more prevalent.

Academic reports generally involve the development of a tool for the management of a specific farm issue, with 45 of the reviewed papers giving a name to the developed tool (Table 8). Some of these tools have been distributed for grower use, but most remain as a research tool for the support of the development of measurement instrumentation and management protocols. For example, Rodriguez et al. [109] developed an interactive economic decision support tool in a Microsoft (Redmond, CA, USA) Excel environment for organic apple production. This tool facilitates the analysis of a breakeven point, sensitivity analysis and net present value estimates over the life of an orchard on 'what if scenarios' and the given inputs of costs, yield and price. These tools are potentially useful for integration into a broader orchard MIS. In the current era of open data and source code, to encourage further R&D and adoption, it is recommended that researchers make the software of such tools available through repositories such as GitHub or via a commercial release.

Table 8. Named software tools in reviewed papers and their intended management task.

#	Study	Crop	Name	Description
1	Gkisakis et al. [72]	olive	CO_2 Mputoliv	Carbon emission
2	Perondi et al. [64]	citrus	CAS	Disease management
3	Gouk et al. [110]	apple	Firework	Disease management
4	Gouk [111]	apple, pear	HortPlus MetWatch	Disease management
5	Lightner [112]	orchard	Maryblyt	Disease management
6	Ghaemi et al. [113]	peach, orange	FrostPro	Environment monitoring
7	García et al. [114]	fruit	PRAPPIS	Financial analysis
8	Toldam-Andersen et al. [115]	apple	Apple Key	Germplasm/cultivar/breeding
9	Paprštein et al. [116]	cherry	ISGOD	Germplasm/cultivar/breeding
10	Gómez-Ollé et al. [117]	mango	MangoBase	Germplasm/cultivar/breeding
11	Iquebal et al. [71]	mango	MiSNPDb	Germplasm/cultivar/breeding
12	Guo et al. [91]	pear	Pie-Landscape	Growth and planting
13	Lang [118]	cherry	Vcherry	Growth and planting
14	Buono et al. [42]	kiwi	Blueaf	Irrigation management
15	Marsal et al. [87]	pear	CropSyst	Irrigation management
16	Todorovic et al. [82]	peach, olive	Hydro-Tech	Irrigation management
17	Flores et al. [77]	orange	Innova Riego	Irrigation management

Table 8. *Cont.*

#	Study	Crop	Name	Description
18	Forcén-Muñoz et al. [9]	orchard	Irriman	Irrigation management
19	Boshuizen et al. [119]	orchard	Irry	Irrigation management
20	Capraro et al. [73]	olive	PISys	Irrigation management
21	Zapata et al. [8]	orchard	Rideco	Irrigation management
22	Maul et al. [120]	apple, peach	FruitSim	Orchard (spray//fruit size/ thinning/etc.)
23	Lakso et al. [13]	apple	MaluSim	Orchard (spray//fruit size/ thinning/etc.)
24	Laurenson et al. [121]	apple, kiwi	Orchard 2000	Orchard (spray/fruit size/ thinning/etc.)
25	Pissonnier et al. [84]	apple	CoHort	Pest management
26	Miranda et al. [122]	olive	C-Plas	Pest management
27	Röpke et al. [123]	orchard	Drips	Pest management
28	Goul et al. [124]	pear	IPMA	Pest management
29	Cohen et al. [66]	citrus	MedCila	Pest management
30	Solomon et al. [125]	orchard	Pest-Man	Pest management
31	Samietz et al. [126]	apple, pear, cherry, plum	SOPRA	Pest management
32	Graf et al. [127]	apple	SOPRA	Pest management
33	Cristian et al. [128]	orchard	Specware	Pest management
34	Tan [78]	orchard	Agrilaxy	Pest/disease/weed management
35	Stöcklin et al. [41]	orchard	Agrimeteo	Pest/disease/weed management
36	Román et al. [10]	grape	DOSA3D	Pest/disease/weed management
37	Kalamatianos et al. [129]	olive	Olivenia	Pest/disease/weed management
38	Chambers et al. [11]	orchard, apple	WSU-DAS	Pest/disease/weed management
39	Cittadini et al. [130]	fruit	Frupat	Production management
40	Kim et al. [7]	apple	MMDAQ	Water stress assessment
41	Rodriguez et al. [109]	apple	AIEDST	Yield estimation
42	Miranda et al. [50]	apple	AKFruitData	Yield estimation
43	Zheng et al. [102]	citrus	Fly4Citrus	Yield estimation
44	Scalisi et al. [131]	apple, pear	Green Atlas Cartographer	Yield estimation
45	Zhou et al. [101]	kiwi	KiwiDetector	Yield estimation

Commercially available orchard MISs are relatively new to the market compared to farm MISs for cropping and, thus, are at an early stage of developing market share. These products address the orchard activities of irrigation control, harvest labour management, chemical spray records and fertiliser use (Table 9). Some are 'simple' record-keeping systems, e.g., labour timekeeping or chemical usage, while others provide decision support, e.g., on when to spray based on weather and pest pressure inputs. Recognising the difficulty of working with multiple platforms, some providers offer a 'dashboard' service, which integrates output from other systems, e.g., Pairtree [132]. Recognising the bespoke needs of individual tree-fruit producers, several providers also offer the creation of a dashboard tailored to the client's needs.

Table 9. Functions of commercial cloud-based electronic management in use in Australia.

OFMIS	Tree Crop	Function	Company Headquarters
eOrchard [133]	Any	Activity tracking, pesticide use, irrigation, production cost, harvest labour management	Gronja Radgona, Germany
Farmable [134]	Any	Activity tracking, scout, pesticide and fertiliser use, labour management, sales management	Oslo, Norway
Growdata [135]	Any	Labour management, pesticide and fertiliser use, irrigation, production cost, harvest tracking	Shepperton, Australia
FarmInOne [136]	Any	Irrigation, pesticide and fertiliser use	Atherton, Australia

Table 9. *Cont.*

OFMIS	Tree Crop	Function	Company Headquarters
TieUpFarming [137]	Any	Spray diary, reporting, scout, harvest tracking, labour management with payroll integration, machinery check and tracking, cost per task	Cremorne, Australia
Tatou [138]	Vineyard	Harvest and daily labour management with payroll integration	Blenheim, NZ
Hectre [139]	Apple	Harvest QC, labour management with payroll integration, scout and fruit sizing	Auckland, NZ
Onside [140]	Any	Check-in, inductions, incident reports	Christchurch, NZ
Dataphyll [141]	Any	Monitoring worker harvest rate (quantity and quality)	Auckland, NZ
Definitiv [142]	Any	Workforce management	Perth, Australia
Muddy Boots [143]	Any	Farm management (pesticide and fertiliser use), postharvest—supply chain	Herefordshire, UK
Pairtree [132]	Any	Integration of output of MIS systems	Molong, Australia
Freshtrack [144]	Any	Crop monitoring, activity scheduling, crop forecasting, dispatch records	Boonah, Australia
Escavox [145]	Any	Postharvest shelf life through temperature logging	Sydney, Australia
XSense [146]	Any	Postharvest shelf life through temperature logging	Tefen, Israel
HarvestAnt [147]	Any	Labour management and harvest traceability	Australia

The regulatory requirement for the maintenance of chemical usage and labour records, e.g., under the Horticulture Award 2020 [148], were identified as adoption drivers by the commercial orchard MIS providers. Regulatory pressure can also drive the development of public sector-delivered decision support systems. For example, regulations on horticultural practice have been developed to mitigate nitrate pollution of the wetlands in Spain, e.g., for the Campo de Cartagena catchment [149]. In response, the Irriman system was developed for irrigation communities. This system is based on inputs from a regional array of sensors for the Penman–Monteith modelling of crop evapotranspiration in addition to other inputs, e.g., NDVI imaging, to guide orchard managers in achieving reduced water use and leaching [9,88]. It will be interesting to observe if this service continues as a public resource or if it transitions to a commercial service.

Several systems for harvest labour management and traceability are now commercially available, e.g., HarvestAnt [147] logs both worker movement and harvest activity based on the global navigation satellite system (GNSS)-enabled shoulder-harnessed picking bags equipped with a load cell. Commercial software also exists for the capture of fruit size information from images of fruit in field bins following harvest, e.g., Hectre [139].

In another application area, the rapid development of area wireless national communications has facilitated the development of decision support systems for the estimation of postharvest shelf life. These systems are based on the automated real-time reporting of temperature in fruit consignments, with the use of models for the prediction of shelf life, e.g., XSense and Escavox (Table 9).

In addition to the direct data drawn from on-farm sensors, such as soil moisture metres and trunk dendrometers in an irrigation management module, commercial orchard MISs trend toward increased 'external' data interoperability, both by drawing data and exporting data from/to other external services. Examples of the external data drawn include regional weather forecasts, regional spray timing recommendation services, and financial information from internal accounts on the pricing of inputs such as electricity, fertiliser, water and labour costs. Examples of 'internal' data pushes include the output of activity data per employee in payroll systems, while fruit inventory data can be shared with the downstream value chain.

The input of financial data to the orchard MIS is required if orchard management decisions are to be made on a cost–benefit basis. Agricultural extension services have produced a number of spreadsheet-based economic decision support tools, e.g., for production practices and potential returns in organic apple production [109]. Most farms operate standard third-party accounting packages, with MYOB [150] or XERO [151] commonly used on Australian farms. These packages allow for data extraction to a database, which can be queried by a MIS for inputs such as the costs of water, electricity, fertiliser and labour. However, there is a level of complexity and nuance in such a coupling, and this capacity is not, as yet, widely integrated.

There is also a trend in the provision of bespoke dashboards for each client. Commercial orchard MIS providers report a balance between the need for a low-cost and simple-to-use system to attract farm management and farm staff 'buy in' against the need for specific features to address management needs. This balance can be achieved through the use of modules that can be added by the user (at a cost) as their needs develop. The design of a user-bespoke dashboard is part of this requirement. Providers trend towards the use of data lake storage and reporting tools such as PowerBI (Microsoft, CA, USA), which allows for custom reporting.

Commercial products also exist that are focused on forecasting product postharvest life based on continuous temperature measurements during transport and storage (Table 9). A likely trend is the meshing of such systems with preharvest information from a broader orchard MIS. For example, a range of preharvest factors, as well as postharvest storage factors, impact the development of the internal browning disorder of apples [152].

A common comment is that growers had trialed software but discontinued its use—which perhaps requires a period of handholding. Any parallel example? An issue for such starter support is the scalability and cost of individual support. The rise of AI support holds great promise in this respect.

5. Conclusions

To the best of our knowledge, this study is the first review of orchard MISs. The adoption of MISs in orchard management is increasing from a lower base than in some other agricultural areas, such as broadacre cropping and dairy. The lower base ascribes to a lower level of need related to the smaller scale of operation, a greater level of manual operations, and the past relative lack of measurement tools, e.g., yield mapping. The drivers for the uptake of commercial orchard MISs most mentioned by farm managers were (i) the increasing complexity of management of increasingly large orchard operations, including reporting responsibilities to off-farm management, and (ii) the regulatory and certification requirements. Successful farm adoption rests on the perceived benefit by farm managers as reflected in improved workflows, which will depend on the system's usability, as well as its accuracy of data and predictions, scalability and cost.

The broad trends that will shape the development of the orchard MIS and influence its adoption include the use of cloud computing and distributed applications, developments in sensor technology and related data processing (including artificial intelligence) for the generation of information from data, developments in broadband communications capability across orchards and the value chain, and the extent of data interoperability between systems.

Most orchard MIS research and commercial deployments have targeted the applications of pest and disease, irrigation and labour management. Other applications range from the selection of orchard location and the choice of cultivar for a given site to harvest and postharvest management. In particular, we expect further development of harvest MIS applications, as a number of relevant measurement tools have recently become available.

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Appendix A

Table A1. Data extraction form.

ID	Extraction Element	Remarks
	General Information	
1	EID	
2	Title	
3	Abstract	
4	Year	
5	Authors	
6	Type	Journal/Article/Book Chapter/Conference
7	Source	Acta Horticulture/Compag/Agronomy
8	DoI	
	Specific Information	
9	Country	The United States/China/Spain/etc.
10	Crop	Apple/mango/olive/orange/etc.
11	System type	DS/OFMIS
12	Application	Plant health/plant/irrigation/nutrition
13	Aim	Design/development/implementation/use
14	Platform	Mobile/web/desktop
15	Name of the system	A/B/C
16	Technological features	Data acquisition/management/analysis/visualise
17	Development tools	Frontend/backend/DBMS/Map Server
18	Operational challenges	Network connectivity/continuity of services/affordability/etc.
19	Evaluation	Efficacy/satisfaction/usability
20	Accessibility	Availability/distribution channel

Appendix B. Database of Literature Search Metadata

The database is available at "https://doi.org/10.25946/25037576.v1".

Appendix C. Semi-Structured Interview Questions

What is your primary need for keeping records in managing production?
Are you required to share data with others in your value chain?
Is any automated process used in data acquisition?
Is any automated process used in decision support?
How are harvest timing and load estimated?
Do you use a commercial OFMIS product?
What are the barriers to the use of a commercial OFMIS product?

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