Chapter 4
Methods to Study Agricultural Systems

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Abstract Modern agriculture faces complex and ever-evolving challenges. Productive, environmental and social requirements are to be met while fulfilling the needs of numerous stakeholders across a wide array of conditions. To better meet these challenges, researchers study agricultural systems using a myriad of methods, across varied disciplines and contexts. To help connect and orientate these research efforts, an overview is required to assess and categorize the diversity of approaches and methodologies being used to study agricultural systems. Whilst a plethora of specialized studies are available, broad-scope methodological reviews are lacking. Here we review methods used in Australia and New Zealand to study farms, farmers and their broader environment. Both quantitative and qualitative studies were included across a particularly wide range of publications while retaining a high level of methodological detail. An original overarching framework was produced that coherently summarized, described and categorized the diversity of methods encountered. This included defining classification criteria that can be conveniently applied to compare methods, assess their relative use, and identify linkages between approaches.

To achieve this, a new interpretative approach was employed. From a diverse pool of 400 items, 92 publications were reviewed in detail. Three overarching approaches were identified, with publications focusing on "characterizing agricultural situations" (64%), "identifying relationships" (59%), or "retracing processes" (42%). A total of 28 method groups were identified, clustered in 11 broader methodological families that ranged from simple indicators, statistics and narratives to elaborate participatory research, system modelling and mathematical programming. These categories were used to appraise Australian methodological practices. This included highlighting the connectivity between the high number of quantitative

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methods encountered (used by 72% of publications) and their usually clear, well-established protocols. In contrast, qualitative studies (41%) frequently suffered from inconsistent terminologies and demonstrated a lower diversity of methods in use. The review also noted that details and justifications about descriptive methods were often neglected, in spite of their impact on the entire analysis process. In addition, relatively few studies made use of long-term historical information to generate new knowledge and insights about future directions. Mixed methods were little used (only in 13% of publications), as well as some frameworks including those pertaining to social-ecological systems, agrarian systems or evolutionary economic geography.

Overall, these results show that agricultural research in Australia remains highly quantitatively oriented, favoring analytical details over data origin, and eclipsing a range of qualitative methods and emerging frameworks. Likely explanations include enduring disciplinary and topical divides (notably social/technical), lack of awareness, and lack of expertise. To remedy this, under-used methods would benefit from being pro-actively promoted and taught, and from concerted efforts to build shared, stable nomenclatures about meanings and protocols. Better documentation of data sources is also required.

Keywords Interpretive synthesis • Literature review • Multi-disciplinary • Research practice • Mixed methods • Farming systems • Farmers • Rural processes

4.1 Introduction

As with most research fields, the study of agriculture nowadays benefits from the input of numerous disciplines. Overarching assessments of this large body of literature are required to inform and improve research practices. To date, however, such characterizations remain rare (Cañas-Guerrero et al. 2013). Specifically, there is a paucity of broad-scope studies categorizing the myriad of methods employed by the research community when addressing problems at the rural, farm, and farmer scales (Fig. 4.1). The objective of this study was to provide such a broad-scope, multi-disciplinary methodological review, that was relevant and accessible to a wide audience across the agricultural research community.

Whilst specialized methodological reviews are routinely conducted in agricultural system research, attempts at comparing approaches across the many relevant fields and disciplines are hindered by practical issues. The difficulty resides in integrating very different methodologies from varied strands of literature. Particularly challenging is to assess jointly both quantitative and qualitative contributions, and bridging technical and social sciences. These issues were addressed here by using an "interpretative" type of review. This novel procedure, unlike commonly used "systematic" reviews, is able to encompass varied types of research in order to provide a broad-scope, integrated overview of the approaches and methodologies used to study farms, farmers and the broader agricultural environment.

Fig. 4.1 Diversity of methods in agricultural system research: scales, topics, disciplines. The study of agricultural systems can be undertaken at various scales through a myriad of methods. For instance in the broadacre crop-livestock systems of Western Australia, varied examples include: rural and farm studies at the landscape scale (e.g. **a**: organization of lupin, wheat and canola fields across heterogeneous soils); bio-physical monitoring of productive attributes (e.g. **b**: weather station and machinery yield-mapping in wheat field at harvest); participatory evaluation with farmers (e.g. **c**: feedback on farming system economics)

The interpretative review procedure was applied to Australian research, and included New Zealand. Relevance to the global sphere and the study of agricultural sustainability was ensured with a majority of publications published internationally, and with the breadth of topics covered that was purposively kept as broad as possible. Outputs include an overarching methodological framework and classification criteria that can be used as references to identify research practices across varied fields. The value of categorizing methodologies and approaches includes aiding the critical appraisal of research practices, as well as the search and selection of tools to orient future research and the design of sustainable systems. This involves identifying mainstream methods with their advantages and pitfalls, and conversely, recognizing promising emergent methods seldom acknowledged due to the smaller size of the communities employing them. Documenting methodological perspectives is also meant to foster dialogue between fields. Specific goals include increasing transdisciplinary collaboration and the use of mixed methods, which are both increasingly recognized as necessary to adequately study complex agricultural systems and address real-world societal problems (Tashakkori and Teddlie 2010; Simon and Schiemer 2015). Other applications include comparing the research practices of given communities (e.g. disciplines, countries, institutions), and monitoring the evolution of school of thoughts together with their practical applications (e.g. Gautier and Hautdidier 2015).

The paper is organized as follows. First, an overview of review procedures is provided to justify the approach used in this study. The review protocol used is then described. An overview of the resulting methodological classification follows, prior to describing each category in more details. This allowed appreciating the range and diversity of methods encountered, contrasting methodological nuances, detecting common relationships, and identifying emerging tools. Lastly, as recommended by Dixon-Woods et al. (2006b), a reflexive account of trialing an interpretive type of review is provided. Strengths and weaknesses of the procedure and of its outputs are discussed, with the aim of allowing others to learn about and improve on a type of review that is not yet formalized in agricultural research.

4.2 Review Frameworks: "Systematic" versus "Interpretative"

A plethora of methodological reviews are available that evaluate the relevance, applicability and contribution of various methods, tools and their conceptual basis to the current state of knowledge (e.g. Reed et al. 2009; Renting et al. 2009). Closer to the object of this study are the reviews that specifically assess the extent to which these methods are actually applied by academic communities. Objectives include assessing the current research situation, monitoring change, and evaluating discrepancies between what is recommended and what is used. In agricultural sciences, the vast majority of these reviews are conducted according to "systematic" frameworks. However, this framework is unsuitable for use here, as discussed hereafter.

4.2.1 Systematic Reviews

Systematic review frameworks involve the exhaustive inclusion of all relevant publications following an explicit protocol. The corresponding 'complete' pool of items, that may be characterized as a whole, sampled or downsized, allows describing statistically the distribution of publications. Most systematic techniques make use of the standardized bibliometric information compiled by academic databases. Broad-scale examples include Cañas-Guerrero et al. (2013), Bravo-Vinaja and Sanz-Casado (2008) and, in Australia, Pratley (2015). In these studies, international and national agricultural research activities were characterised and monitored using year impact factors, number of collaborators, research institutions, and other similar indicators combined with keywords. However, the impracticalities of indexing in-depth article information hinder other bibliometric descriptions of the literature. For instance, Brym and Reeve (2016) performed a systematic review on terminologies but reduced their sample to ten items in order to adequately developed their commentaries. Addressing methodological details over a vast number of publications is similarly unfeasible. Crucially, systematic reviews often exclude qualitative studies altogether are these are inconsistently referenced in databases (Dixon-Woods et al. 2006a). For the same reason, grey literature is rarely included either.

To remedy these issues, other studies employ data-mining techniques combined with participatory approaches which allow the definition of more endogenous and relevant criteria (e.g. Barbier et al. 2012). However, even with the contribution of academics who are experienced with varied nomenclatures, automated procedures reach their limits when content cannot be parted from context in order to make sense. Keywords can be useful proxies, but only careful reading can dissect the correct meanings associated with complex concepts, evolving vocabulary and ill-defined terminologies. This includes terms that are: widely employed but particularly polymorph such as "interviews", "survey", "models" or "participatory"; ambiguous and malleable such as "resilience"; bearing multiple definitions and usages such as "agroecology" (Reed et al. 2009; Reid and Botterill 2013; Brym and Reeve 2016).

As a result, the more detailed the study, the smaller the corpus covered. Methodological reviews are complex and thus generally downsized to manageable levels by answering focused questions within restricted scopes. Examples include: assessing a given method within a given set of academic journals (e.g. whole-farm models, Robertson et al. 2012b); performing a quantitative meta-analysis (Philibert et al. 2012); reviewing a conceptual approach and its applications within a topic and/or sub-discipline (e.g. systems approaches to innovation in crop protection, Schut et al. (2014); life cycle assessment in aquaculture, Henriksson et al. (2011)). Whilst suitable for the detailed assessments of restricted methodological topics, systematic reviews are thus impractical for the purposively broad-scope goals of this review that also require accessing a high level of detail. Consequently, an interpretive type of review was used instead.

4.2.2 Interpretative Reviews

Interpretative reviews specifically aim at combining heterogeneous sources and connecting segments of the literature that are methodologically different. The approach, extensively described by Dixon-Woods et al. (2006a, b), is based on the iterative analysis of manually selected items until theoretical saturation is reached, i.e. when no new information is encountered. Whilst searching strategies and categorization criteria are explicit and pre-specified in systematic reviews, in interpretative reviews they are shaped progressively with each retrieved item. Instead of precisely defined research questions, queries are purposively flexible in order to cross disciplinary boundaries. The transparency and reproducibility requirements upheld by systematic procedures are thus not necessarily claimed by interpretive reviews. In fact, like most topical reviews, producing a concise account of disparate literature strands implies a certain degree of subjectivity. Evidently, this is counterbalanced by evidence and reflexivity.

Interpretive review procedures have gained popularity in various health-related research fields (Morrison et al. 2012; e.g. Moat et al. 2013), largely for their potential to synthesize both quantitative and qualitative evidence (Suri and Clarke 2009). No such use of the approach could be found in agricultural research. Review procedures featuring similarities exist but scopes remain focused, rendering the thought process involved relatively self-explanatory and diminishing the explicit need for theoretical saturation. Examples includes Le Gal et al. (2011) and Pearson et al. (2011) whose methodological classifications were the results of the researchers' own informed understanding, based on publications selected manually.

Lastly, it should be mentioned that other types of reviews exist which specifically aim at combining heterogeneous sources and connecting segments of the literature that are methodologically different (Suri and Clarke 2009). Among them is the meta-narrative of Greenhalgh et al. (2005), illustrated on the topic of food security by Weiler et al. (2015). The review process described hereafter was retained for the possibility to cover a particularly broad scope in a cost-effective manner.

4.3 Methods: Interpretative Review Procedure

The review process was conducted in 2014 in three stages. The selection of relevant publications started using Google Scholar. This source of publications was chosen over the more traditional Web of Science or Scopus databases because of its academic and topical comprehensiveness, ability to access varied material, and importantly, convenience of use (Harzing 2012; Lasda Bergman 2012). This facilitated the broad-scope search and the inclusion of a range of documents readily accessible to non-academics such as conference papers and reports. "Popular" publications most cited and likely to be used were targeted, i.e. those appearing at the top of search results ranked by "relevance". This ranking criteria integrates contents, location, authors, citation dates and frequency (Google 2015). Multiple searches were performed with various combinations of broad-spectrum keywords such as "Australia", "farmer", "farming systems", "rural", "agricultural practices", "analysis" "methods", etc. Searches were initially centered on the broadacre sector of Western Australia, but re-run to include others industries across Australia. New Zealand was also included, for the similarities and linkages shared by the two countries' research communities. Publications were selected by rapidly screening their title and header. Besides a 10-year publication date limit, inclusion criteria were *(i)* a majority of authors affiliated to an Australian or New Zealander institution, *(ii)* addressing aspects of what farmers do, and *(iii)* demonstrating some farm-level or broader scale considerations. These last two criteria remained purposively imprecise, resulting in a wide range of disciplines and topics being included about both existing agricultural systems and virtual representations, the people implementing these systems and their interactions with the broader environment at various scales, as well as the wider contexts in which farming can be understood such as value chains, natural resource management, and rural governance. Studies purely furthering knowledge on biological mechanisms were excluded, unless the paper objectives clearly addressed management issues or other farming system aspects. A pool of 400 publications was thus manually compiled.

The second stage involved randomly retrieving publications from this pool which were read in-depth and organized according to three hierarchical levels of categorization, or discarded if appearing out of topic. First, papers were assigned to one or several "method groups" featuring similar tools and techniques that constituted the base unit of the categorization. When significantly overlapping and sharing comparable underlying principles, method groups were clustered to form a higher categorization level named "methodological families". These were in turn grouped into "overarching approaches" according to the general type of information pursued to address the research question. An iterative process to identify patterns was used, during which the criteria discriminating each group were progressively refined to accommodate new information. Method groups, methodological families and overarching approaches were thus defined interpretatively throughout the analysis procedure, sometimes merged or split. A situation of saturation at which point no new group could be identified was reached after retrieving 192 publications, from which 82 were retained and classified.

The third stage brought 10 non-random contributions to the sample. These were added primarily to populate method groups that featured too few items, as some types of studies were much rarer than others and thus too rarely encountered using random selection. These non-random contributions were sourced from the pool, from references cited in retrieved publications, and from the authors' own libraries.

Results were summarized into a "method map", i.e. a schematic showing all the categories identified, their hierarchy and common linkages. A network graph was also produced with R using methodological families as nodes (Fruchterman-Reingold layout, seed = 14, Csardi and Nepusz (2006); R Core Team (2015)). The relative importance of each methodological family in the sample was represented through the size of the nodes, based on an index summing the number of times each method group was used, weighted by their importance within each publication (companion method group = 1 point, core analytic method group = 5 points). All the links between methodological families existing within each publication were included (e.g. a publication using 4 methodological families produced 6 links; 2 families, 1 link; 1 family, 1 looped link). Finally, an *a posteriori* measure of network modularity using qualitative and quantitative divisions was calculated, to assess whether the two types of research formed distinct communities within the network.

4.4 Overarching Approaches, Methodological Families, Method Groups

A total of 92 publications were retained for analysis, with 89% sourced randomly. Peer-reviewed journal articles represented over two thirds of items, with grey literature also well represented (Fig. 4.2). The analysis resulted in the identification of 28 "method groups" that were clustered in 11 "methodological families" and 3 "overarching approaches" (Fig. 4.3). The "method map" (Fig. 4.3a) shows the diversity of method groups encountered, an appraisal of how frequently they were used, and how they were most often combined. Although necessarily simplified, this visual representation of a complex research situation allows for an overall perspective of the common relationships between methodological families and their relative positioning within overarching approaches in terms of underlying principles. The actual number of publications on which each category was based is provided in Table 4.1 and in the descriptions thereafter. Numbers in brackets e.g. [20/9] correspond to the total number of publications in which the method was encountered, followed by the number of cases in which it constituted a core analytic method.

The network graph (Fig. 4.3b), built on a total of 432 links, completes the method map with an automated visualization of the relationships between methodological families. Whilst the method map aims at synthetic clarity, the network graph captures

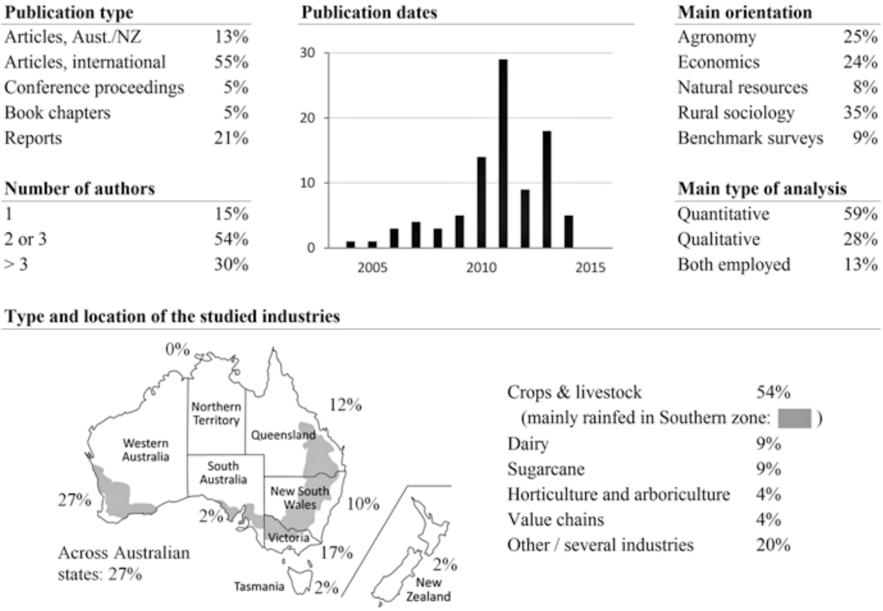

Fig. 4.2 Characteristics of the review sample. Total number of publications included: 92, of which 82 were retained out of 192 retrieved randomly from a pool of 400 sourced from Google Scholar, discarding 110 out-of-topic items. An additional 10 publications were added non-randomly. The sample size was determined by theoretical saturation i.e. when no new information is encountered (interpretative review procedure)

other aspects of the sample such as connectivity structure (proximity of families), connectivity strength (density of connections), and modularity (denser connections within qualitative and quantitative groups of methodological families).

Prior to detailing the methodological categories, some of the terms employed and limitations to this type of representation should be clarified. Generally, it should be remembered that the actual diversity and complexity of methods and their uses are naturally richer than the simplified picture provided by an organized grouping.

First, methods crossed boundaries. Consequently, some make more sense when considered in a broader context than that of a “methodological family”. This is notably the case of qualitative methods that may produce both quantitative and qualitative information, and often corroborate evidences in a triangulation process (e.g. Kalaugher et al. 2013; Rodriguez et al. 2014). Similarly, overarching approaches can easily overlap. The objective of an analysis can be both to “characterize a situation” and “identify relationships”, which sometimes involve “retracing processes”. Most publications, however, present results focused on one or two of these aspects through a “core” method, the others being inferred in discussions, or addressed by companion procedures. Sometimes, this occurs because studies are purposively split in more or less complementary articles submitted to different journals, each focusing on different sets of results and corresponding methods.

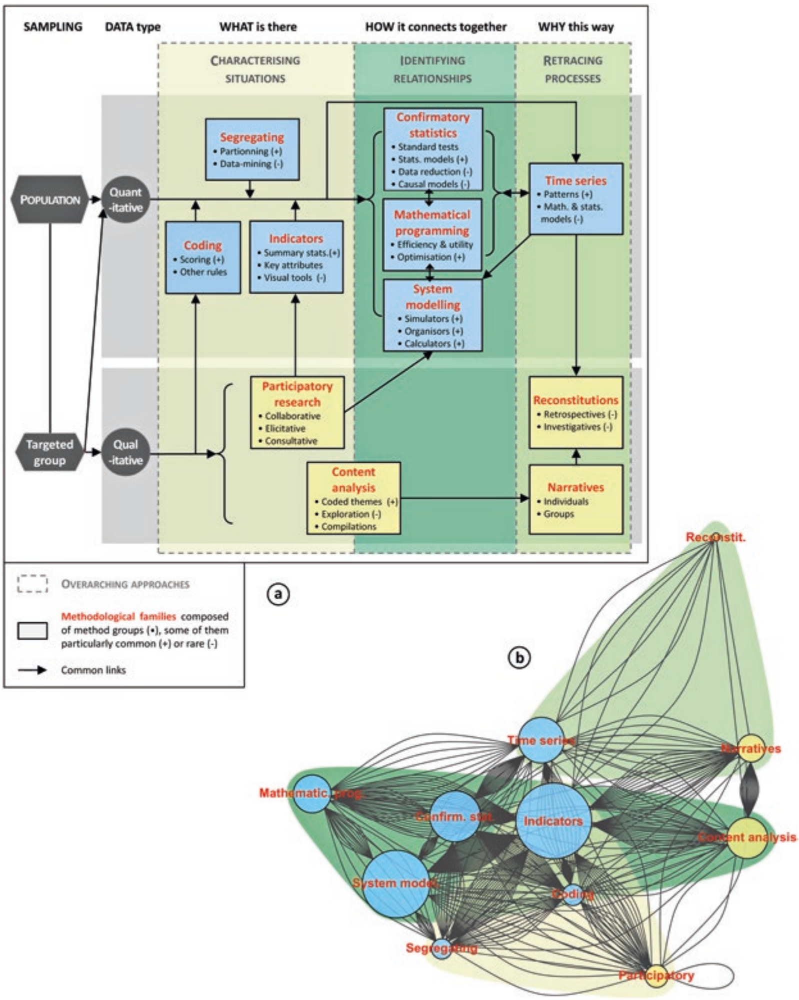

Fig. 4.3 A classification of methods to study agricultural systems. The review results were synthetized in the *method map* (**a**) that shows the 3 hierarchical levels retained ("method groups", within "methodological families", within "overarching approaches"). This simplified representation of the myriad of methods encountered also summarizes relative frequencies and common relationships in the Australian context, i.e. similarities in underlying principles, and how methods were found in the sample to be commonly employed concurrently in order to complement each other. The *network graph* (**b**) is an alternate, computer-generated visualization that complements the method map. The position of each methodological family (nodes) and the density of linkages corroborate the descriptions detailed in sections 4.4.1-4.4.3: central position and importance (size of node) of "indicators" which are rarely used as core analytic methods but are ubiquitous (overlapping all three overarching approaches, represented in green); importance of "system modelling" for which the opposite applies; dominance and close connectivity of the quantitative methods of the second approach (darkest green); high connectivity of "content analysis" and "narratives"; remoteness and small size of "reconstitutions"; divide between quantitative (blue) and qualitative (yellow) research, confirmed visually (qualitative methods confined to the network periphery) and by a positive modularity of 0.38 (denser connections exist within each research type than overall). Interestingly, "participatory research" is the qualitative family best connected to quantitative methods, notably to "system modelling" and "coding": when added to the quantitative research group, modularity increases to 0.45

Table 4.1 A classification of methods to study agricultural systems with published Australian and New Zealand examples. A total of 28 "method groups" were identified, clustered in 11 "***methodological families***" and 3 "**overarching approaches**". The number of publications on which the description of each category was based is provided. The number of publications for which it was the main or core method used, i.e. the method(s) on which emphasis is put to perform the analysis and produce results, is placed in parenthesis. Many publications are double-counted as they are legitimately placed in several categories simultaneously. The entire list of 92 publications and their attributions to categories is available from the authors.

Characterising current situations (Approach 1)		**92 (59)**
Indicators		**84 (16)**
Summary statistics	e.g. means, ranges, standard variations, frequencies, histograms (Wheeler et al. 2013)	64 (16)
Key attributes	e.g. characteristics of farm case studies (Ransom and Trapnell 2011), values of representative systems (Biggs et al. 2013)	34 (7)
Visual tools	e.g. relative mapping (Cary and Roberts 2011), bubble plots (Stott et al. 2013), cluster maps (Kingwell et al. 2013), schematics (Raymond and Robinson 2013)	20 (8)
Coding		**24 (8)**
Scoring/rating	e.g. Likert scales (Raymond and Spoehr 2013), scores/weights (Price and Leviston 2014), ranking adaptive index (Wheeler et al. 2013)	19 (5)
Other rules	e.g. categorisation (Cary and Roberts 2011); binary statements (Llewellyn et al. 2012); digital mapping (Welsch et al. 2014)	9 (5)
Segregating		**19 (9)**
Partionning (pre-set criteria)	categorising with factors e.g. dominant enterprises (Sheng et al. 2011), soil types (Robertson et al. 2009); segmenting with continuous variable e.g. operating profit per hectare (Browne et al. 2013), input and output levels (Stott et al. 2013)	14 (6)
Data-mining (automated criteria)	e.g. grouping statistics incl. cluster analysis (Sherren et al. 2011); spatial algorithms (Zerger et al. 2011) and mapping rules (van Gool 2011)	7 (5)
Content analysis		**24 (23)**
Coded themes	e.g. cross-case analysis and hierarchical nodes coding (Broderick et al. 2011), open coding (Raymond and Robinson 2013), manual coding (Moon 2013)	14 (13)
Exploration (iteration)	e.g. repeated interviews (Gill 2011), reaching saturation (McKenzie 2013), alternating individual data analysis and group discussions (Cheshire et al. 2013)	6 (6)
Compilations	commented summary of answers (McConnell 2011)	7 (7)
Participatory research		**16 (12)**
Collaborative (consensus)	e.g. participatory modelling (Rodriguez et al. 2014), steering committee (Armstrong et al. 2010)	6 (3)
Elicitative (focus groups)	e.g. standard (Cary and Roberts 2011) or computer-based (Islam et al. 2006) focus groups, workshops (Roebeling and Webster 2007)	7 (6)
Consultative (step-wise process)	e.g. Mixed Methods Framework (Kalaugher et al. 2013), Multi-Criteria Assessment (Zerger et al. 2011)	7 (4)

(continued)

Table 4.1 (continued)

Identifying relationships (Approach 2)		**59 (54)**
Confirmatory statistics		**34 (21)**
Standard statistical tests & correlations analysis	e.g. χ^2 (Weller et al. 2013), t-tests (Llewellyn et al. 2012), analysis of variance (Emtage and Herbohn 2012), z-score (Wheeler et al. 2012), rank order correlations (Greiner and Gregg 2011)	19 (6)
Statistical models	e.g. multiple linear regression (Christie et al. 2011), Ordinary Least Squares (Llewellyn and Pannell 2009), mixed models (Lawes and Kingwell 2012), logit (D'Emden et al. 2008), probit (Nossal and Lim 2011)	26 (15)
Data reduction methods	e.g. Factor Analysis ((Rodriguez et al. 2014), Principal Component Analysis (Greiner and Gregg 2011)	7 (3)
Causal models (path analysis)	Structural Equation Modelling (SEM) (Price and Leviston 2014)	3 (3)
Mathematical programming		**23 (22)**
Efficiency and utility analysis	e.g. Total Factor Productivity indexes and Data Envelopment Analysis (O'Donnell 2010), stochastic distance functions (Cattle and White 2007); Duration analysis (D'Emden et al. 2008)	12 (11)
Optimisation	e.g. maximising response function (Lawes and Robertson 2011), mean-variance models (Komarek and MacAulay 2013), linear programming incl. MIDAS model (Bell et al. 2008)	13 (13)
System modelling		**29 (27)**
Simulators	e.g. field-scale crop production incl. APSIM with yield prediction (Kirkegaard and Hunt 2010) and environmental impacts (Thorburn et al. 2010), pasture production systems (Browne et al. 2013), regional production (van Gool 2011))	13 (12)
Organisors	e.g. field operations (Webster et al. 2009), crop sequences (Lawes and Renton 2010), whole-farm resource allocation incl. MIDAS (Bell et al. 2008), whole-farm management rules (Rodriguez et al. 2014)	12 (12)
Calculators	e.g. nutrient requirements (Lawes and Robertson 2011), greenhouse gas emissions (Christie et al. 2011); cost-benefit analysis (Bell et al. 2008), annual whole farm budgets (van Grieken et al. 2010); sensitivity analysis (Monjardino et al. 2010), Monte Carlo simulations (Heard and Leddin 2012)	23 (18)
Reconstituting past mechanisms (Approach 3)		**45 (39)**
Time series		**32 (22)**
Patterns	e.g. trends and conjunctures (Kingwell and Pannell 2008), standard patterns (Llewellyn et al. 2012), comparative demographics (Stewart et al. 2011a)	25 (11)
Mathematical and statistical models	e.g. production function (Sheng et al. 2011), distance function (Villano et al. 2010), duration analysis (D'Emden et al. 2006), longitudinal regression (Lawes and Kingwell 2012)	17 (15)

(continued)

Table 4.1 (continued)

Narratives		**20 (17)**
Individuals (case studies)	e.g. personal records (Stewart et al. 2011b)), in-depth interviews (Ransom 2011), exploratory longitudinal (Eastwood et al. 2012), content analysis methods	7 (7)
Groups (commonalities)	Content analysis methods (see examples above)	13 (10)
Reconstitutions		**5 (5)**
Retrospective	Historical and geographical documentation (Tonts et al. 2010), comparative contextualisation (Wilkinson 2011), cycling patterns (Allison and Hobbs 2004)	3 (3)
Investigative	Integration of varied sources (Oro and Pritchard 2010), content analysis (Beilin et al. 2011)	2 (2)

Second, methods can be applied in slightly different ways for very different objectives. For instance, data reduction methods can be used to segregate a sample ("data-mining") and to establish relationships between variables ("confirmatory statistics"). Incidentally, this example shows that deductive/inductive types of reasoning do not always match the quantitative/qualitative type of data analysis they are frequently attributed to.

Third, different methods can be hidden behind similar or ill-defined terminologies. Efforts were made to match existing discipline-specific vocabulary, however this was not always possible. The names attributed to each method category were tailored to best convey results to a wide, non-specialist audience. For instance, the term "content analysis" was applied to a category broader than practitioners may commonly refer to, for similarities in principles rather than for commonalities in software or material. To facilitate reading, italic fonts are used to highlight that nomenclature, as well as the core criteria upon which the categories were built.

The next three sections, one for each overarching approach, describe the categories and some of their relationships. Differentiating criteria and common topics are highlighted along with typical examples. Mainstream and emerging methods are pointed out, and finally issues frequently encountered during the classification process.

4.4.1 *Characterizing Situations: Focus on Describing the Object of Study*

The first overarching approach [92/59] comprises methods that describe what is present, be it a group of fields, farms, farmers, management practices, agroecosystems, or a region encompassing all the above. All 92 publications used descriptions that most often represented simple analytic pre-requisites, capturing what is done, owned or thought, by whom, where and when, in order to provide material for the methods of the second and third approaches. Characterizations can also constitute a core analytic tool themselves, providing explanatory results by exposing critical information, pointing out evidence, comparing results and building hierarchies.

Although the act of describing may seem a straightforward activity, a large variety of methods was encountered. These methods were organized into five methodological families (Fig. 4.3). Three involved tools that compiled data in quantitative formats: "*indicators*", "*coding*", "*segregating*". Two involved qualitative procedures: "*content analysis*" and "*participatory research*".

- ***"Indicators"*[84/16]**. This methodological family comprises the simplest tools available to explore, assess and compare given characteristics. Indicators are primarily used as introductory or accompanying tools which *simply describe the information* at different stages of the analysis. The main instance where indicators are truly central to studies is *benchmarking*, i.e. the collection of a critical number of observations compiled to provide standards for a population. Examples range from national to local surveys that address, mostly, farm standard characteristics and performances at farm or field level (Nossal and Lim 2011; Browne et al. 2013; Planfarm and Bankwest 2013). A similar exercise consists in characterizing *specific aspects* of a population, for instance technology adoption status (Llewellyn et al. 2012), awareness levels (Watson and Watson 2013), farmers perceptions toward land management issues (Sherren et al. 2011), etc. Three method groups were distinguished.

The most common are the well-known "*summary statistics*" [64/16], also called "descriptive statistics" (averages, variance, distributions etc.) that gauge samples and present results. They are not necessarily followed by statistical tests.

Indicators can otherwise be reduced to "*key attributes*" [34/7], typically farm structure, productivity and profitability characteristics. These features, completed or not by descriptors, are most often encountered when the sample is small or when the analysis dissects a given farm, real or virtual (Armstrong et al. 2010; Ransom and Trapnell 2011; Biggs et al. 2013)

The third method group is composed of "*visual tools*" [20/8]. The idea is not necessarily to fit a statistical trend line but to allow for a more manual analysis of the observations, for instance to appraise the scope of differences. Examples include: mapping the relative private and public benefits of farm practices for environmental management (Cary and Roberts 2011); prioritizing research on best management practices (Roebeling and Webster 2007); comparing production with bubble plots (Stott et al. 2013); representing farm similarities with cluster maps (Kingwell et al. 2013); obtaining benchmark frontiers by hand-fitting curves on modelled data (Kingwell 2011); graphically representing mathematical solutions (Komarek and MacAulay 2013). Schematics were also included when crucial to the representation, interpretation and discussion of results (Oro and Pritchard 2010; Raymond and Robinson 2013; Rodriguez et al. 2014).

- ***"Coding"*****[24/8].** This process involves *transforming qualitative information into numerical variables*. Numbers and categories are attributed to specific types of answers, often to build indexes, following rules that are either pre-decided or which definition is part of the analytic process. Typically, coding allows inputting farmers' attitudes, perceptions and other psychological and behavioral traits into quantitative analysis methods (Price and Leviston 2014). Another case is the translation of spatial information into numerical datasets. Welsch et al. (2014) provided detailed examples of both situations.

  "Scoring scales" [19/5], which produce semi-continuous variables, were found to be the most common method used in coding, particularly 1-to-5 Likert type scales (Raymond and Spoehr 2013).

  A variety of "*other rules*" [9/5] exist. For instance, Nossal and Lim (2011) built a measure of farmers' innovative efforts based on the number and extent of innovations that each grower had adopted, whilst Cary and Roberts (2011) and Price and Leviston (2014) both scored environmental land management practices using iterative processes.

- ***"Segregating"*****[19/9].** This type of procedure consists of *dividing the sample to be worked with into groups*, rather than addressing the information pool as a whole.

  The most frequent procedure is to "*partition*" [14/6] the sample according to *preset criteria*, *generating classes* for which descriptive statistics are then provided. Typically, partitioning is applied to census and benchmark data. The most common partition criterion is probably farm enterprise type, assessed through either production outputs or land use. For instance, the Australian national farming surveys divide broadacre farms into cropping specialists, mixed crop-livestock, sheep specialists, beef specialists and mixed sheep-beef (Sheng et al. 2011). Classes can also be created by *segmenting a continuous variable* using quartiles, median, average, or other e.g. top 10%. These variables are typically related to farm structural characteristics, productivity or profitability (e.g. operating profit per mm rainfall or hectare, Browne et al. (2013); Planfarm and Bankwest (2013)). Variables can be combined, with for instance Kingwell et al. (2013) coding several financial indicators to define classes of performance, Stott et al. (2013) differentiating dairy farms according to intensification, or van Gool (2011) who divided land into potential productivity classes according to the incidence of several constraints. A spatial example includes defining agro-ecological zones by segmenting and crossing isotherms and isohyets (Planfarm and Bankwest 2013).

  Generating groups can also be done through "*data-mining*" [7/5]. This involves *automated procedures* able to integrate large amounts of data and numerous variables, when available. Methods include writing classifying protocols or using grouping statistics. For instance Kingwell et al. (2013) used a set of statistical techniques, including cluster and network analysis, in order to distinguish groups of farmers on the basis of social and managerial information. Zerger et al. (2011) employed spatial algorithms. Sherren et al. (2011) and Emtage and Herbohn (2012) both used cluster groups to develop typologies of farmers based on their socio-economic characteristics and attitudes toward natural resources management in order to explain their practices.

• ***"Content analysis"*[24/33].** This methodological family grouped qualitative analysis procedures which involve the *identification of dominant themes drawn from individual experiences,* usually targeting specific groups of people. Often, identifying relationships between these themes and their elements is also an objective. Content analysis therefore stands in two overarching approaches simultaneously (Fig. 4.3a). Although content analysis can be applied to any type of visual and textual material, techniques in the sample nearly always focused on capturing the views, perceptions and preferences of farmers, recorded during interviews and illustrated by representative quotes. Content analysis is therefore largely dominated by social and psychological sciences. Rare counter-examples include Robertson et al. (2009) and Ransom and Trapnell (2011) who reported on technical aspects, for instance farm operations and practical implementation issues. Otherwise, common topics include: how farmers' personal experiences change, for instance regarding climate (Fleming and Vanclay 2011; Head et al. 2011) or relationships (gender, Alston and Whittenbury (2012); institutional, Gill (2011)); which constraints are faced in specific sectors (meat marketing, Broderick et al. (2011); supply chains competitiveness, Nasiruddin et al. (2011); tomato industry transition, Pritchard et al. (2007)); which factors pre-empt the adoption of innovations, such as learning processes and sources of information (Ritman et al. 2011; Eastwood et al. 2012; McKenzie 2013).

Three main method groups were identified, with the largest referred to as "*coded themes*" [14/13] (also termed "qualitative coding"). These procedures involve *coding fully transcribed interviews* in order to identify dominant themes. The coding analysis can be done manually (Moon 2013; Raymond and Robinson 2013) but is most often at least partially automated using the software NVivo®, hence representing a type of qualitative data-mining.

"*Exploration*" methods [6/6] could be considered a sub-group, since the principles involved are very similar. Open-ended questions are also preferred for flexibility, themes as well as the relationships they involve are identified and discussed. However, whilst the previous coding procedure remains relatively linear (i.e. questions elicit responses which are transcribed and then analyzed), exploratory protocols are much more *iterative*, involving a back-and-forth process between questions, responses and results which allows for a progressive construction of results, sometimes until explicit theoretical saturation (Gill 2011; Cheshire et al. 2013; McKenzie 2013). The explicit use of exploratory methods was found to be rare.

In contrast to these two method groups, "*compilation*" studies [7/7] use predefined questions and produce *a commented summary of the group answers*, often ranking them or presenting frequencies (McConnell 2011). Of all the method groups identified, compilations provided the weakest quality of evidence, notably due to frequent sampling and procedural issues (e.g. questionable replicability, simplistic or absent methods, unacknowledged caveats and biases, lack of differenciation between results and interpretations).

- ***"Participatory research"*****[16/12].** This methodological family grouped qualitative methods whose results were *the product of a discussion*. Common objectives are to determine what constitutes a representative farm (typically for use in system modelling), or which practices or views exist in a community. Three method groups were identified.

The most inclusive of stakeholders was named "*collaborative*" [6/3] and involves participants *working together and discussing until reaching a concerted agreement.* In order to define the characteristic of virtual farms, Armstrong et al. (2010) thus involved a varied industry steering committee, whilst Rodriguez et al. (2014) integrated both farmers' and researchers' perspectives into the research process.

Another method group was qualified as "*elicitative*" [7/6] and involved focus groups (often simply called workshops). During these meetings, the participants follow a discussion guide facilitated by a moderator who remains external (generally the researcher). Rather than a consensus, the moderator seeks to prompt and gather the *existing diversity of views*. Unlike content analysis, focus groups involve a *specific pre-set procedure and tabulate the opinions of the group as a whole, not individuals'*. Examples include Cary and Roberts (2011) and Thorburn et al. (2007) who used focus groups to identify management practices, whilst Jackson (2010) gathered the views of farmers and consultants on grain productivity drivers.

A third group is referred to as "*consultative*" [7/4] and is characterized by *successive steps*, with the objective of refining results by consulting stakeholders in a *pre-set iterative process*. While their input can be considerable, the stakeholders' involvement in the actual research process remains limited. Collaboration can nevertheless be part of the process, with for instance Zerger et al. (2011) who developed a draft map of revegetation priorities with regional personnel prior to seeking farmers' views. Another consultative example is provided by Kalaugher et al. (2013) who gradually defined a typical farm by integrating the farmer's and researchers' separate perspectives into an elaborate framework that progressed through scoping exercise, pooling ideas, analysis, validation and evaluation. In its simplest form, consultative research consists of asking stakeholders to review results.

Categorizing the methods of this first overarching approach revealed that, saved for coding, the procedures used to capture and translate information were not always fully or well presented, in spite of their impact on downstream analysis. Specifically, two concerns were frequently identified: a lack of clarity regarding both terminologies and data origin.

These two issues were most evident in participatory research, mirroring the observations of Reed et al. (2009) about stakeholder analysis. Truncated theoretical framework, partial protocols and inconsistent nomenclatures, together with a profusion of techniques, maintained widespread confusion about meanings and doubts regarding transparency and replicability. Often a related issue, the criteria for participant selection were commonly over-simplified, when not overlooked. Many studies simply relied on local knowledge laced with value judgements, without consideration for representation bias or alignment with the study objectives (e.g. "progressive farmers were invited"). When participatory research was used for modelling, results were generally based on very small groups or case studies, complemented with sensitivity analyses. Either way, concerns for representativeness, relevance and objectivity can legitimately be raised. This is particularly alarming considering the aims of participatory research.

A lack of explicit procedures was also found within the indicator groups – perhaps due to their apparent triviality. Even simple averages involve sampling choices, thus effectively starting the analysis and interpretation process. Yet the origin of summary statistics was commonly glossed over, even when studies procured second-hand data that was potentially produced for other purposes, and which characteristics may well impact the production and interpretation of results. Kingwell et al. (2013) provided a counter-example, describing possible representation caveats caused by data origin. Similarly, the sources for key attributes were not always justified, dated or even specified. The common recourse to assumptions, extrapolations and indirect information together with actual observations often blurred the distinction between real and built representations.

Likewise, the criteria upon which partitioning was performed were seldom justified, in spite of being the most common method to segregate a population. Pre-set arbitrary classes can impact results, for instance by hiding trends or by overlooking multi-modal distributions. Participatory and exploratory techniques can prevent these issues but are rarely used for segregation purposes.

Lastly, the overall issue regarding terminologies is perhaps best illustrated by the common terms of "survey". This word effectively translated into a wide diversity of methods, depending on the target (everyone in a sub-group vs. varied sampling techniques), the study scale (national vs. local, large databases vs. small datasets), the type of information (nature, origin, collection procedure), how data is meant to be analyzed, and possibly transformed.

4.4.2 Identifying Relationships: Focus on Linking Elements

While the first approach largely exhibited an ancillary status, the opposite applied to the second overarching approach [59/54]. "Identifying relationships" almost always constituted the analytic core of studies. With a few exceptions, the methods groups described here can thus be considered as mainstream.

Qualitative approaches belonged to content analysis and most often involved coded themes (see previous section). Otherwise, determining how specific elements are linked meant identifying and quantifying which input(s) explain a given output. Objectives include isolating factors of importance (which ideally can be influenced to the desired ends), and providing grounds for predictions and extrapolations (to aid proactive decisions). A typical example is to assess the degree to which economic factors constrain the adoption of given technologies. The variables investigated ranged from farm physical characteristics and management practices to more intangible factors such as risk and resilience. A large number of studies aimed at explaining outputs related to productivity and profitability. Important variations included evaluating environmental externalities (e.g. emissions, contamination, erosion), which provide the study of farming performances with additional constraints. Another important research stream addressed farmers' behaviors, most often in relation to the adoption of innovations or recommended practices, and mainly for production and for the sustainable management of natural resources. Explanatory variables likely to impact the farmers' decision-making process commonly include demographic and socio-economic factors, as well as psychological traits such as individual perceptions, attitudes or motivations.

Similarly to the first overarching approach, numerous methods were found here. However, they proved easier to classify. This resulted in only three but large quantitative methodological families named "*confirmatory statistics*", "*mathematical programming*" and "*system modelling*".

- ***"Confirmatory statistics"*[34/21].** This methodological family comprises tests and models which confirm *the extent to which relationships between variables can be trusted to exist and to matter using statistical significance.* Confirmatory statistics usually require a large amount of data but are powerful and flexible, which explain their great popularity: nearly all disciplines employ these research tools to successfully produce evidence despite the variability of observations, including when controlled experiments are not an option. Examples of topics explored were thus diverse, including: confirming the contribution of management to nutrient and water use efficiency at plot level (Anderson 2010; Kirkegaard and Hunt 2010); unravelling which business indicators are associated with farming resilience at regional scales (Lawes and Kingwell 2012; Kingwell et al. 2013); investigating the role of practical, social and psychological drivers in the adoption of innovations at farm or national level (Llewellyn and Pannell 2009; Robertson et al. 2012a). Four method groups were distinguished.

"*Statistical tests and correlations analysis*" [19/6] are often *simple procedures* which essentially assess similarities between populations in terms of mean or distribution, and whether particular factors can be deemed to be associated with these differences (e.g. χ^2 tests, z-score, rank order correlations). For instance, Weller et al. (2013) detected that the capital structure of businesses chosen by farmers tended to be different across age groups but not across industries by studying proportional differences between population classes.

"*Statistical models*" [26/15] often represent the *more advanced stage* of statistical procedures. Regression models are particularly ubiquitous and by far the most common. Robust and varied versions are available for both simple and multivariate analysis (Llewellyn and Pannell 2009; Christie et al. 2011), with mixed models adding flexibility (Lawes and Kingwell 2012). Non-continuous, categorical variables are also catered for with a variety of probit and logit regression models (D'Emden et al. 2008; Nossal and Lim 2011). This large subgroup is often encountered in social studies where the answers of respondents are classified in a limited number of categories, with the binary extreme of yes/no. Convenient tools allow the most appropriate models to be selected, such as model ranking or the stepwise selection of factors.

The prior recourse to "*data reduction methods*" [7/3] which *select variables* is also an option. Examples include Factor Analysis (Rodriguez et al. 2014) and Principal Component Analysis (Greiner and Gregg 2011).

A major drawback of statistical analysis is that proving relationships between variables does not imply causality. A rare, notable method endeavoring to address this issue is Structural Equation Modelling (SEM). Although technically a statistical regression model combined to factor reduction methods, SEM attempts to prove causality, or at least the existence of paths, by *testing compound relationships* that define "directional assumptions". An example of such "*causal modelling*" [3/3] is provided by Price and Leviston (2014) who hypothesized and tested the ability of a specific set of sequential relationships between psychological, social and contextual variables to predict pro-environmental behavior.

- ***"Mathematical programming"*****[23/22].** Studies assigned to this methodological family are distinctive in that an analysis *begins with an elaborate mathematical construct*. Concepts and problems are expressed as sets of equations using diverse types of *assumed response functions*. These include standard agronomical functions at field level (e.g. yield and economic response to nutrient application, Lawes and Robertson (2011)), production functions addressing input/output relationships at farm-level (e.g. structural adjustments and returns to scale, Sheng et al. (2011)), or utility functions which assume relationships between more subjective and intangible elements such as the perceived benefits or risks of, for instance, adopting a practice (D'Emden et al. 2006). These mathematical models, of varying complexity, are then tested 'empirically', i.e. using real data. Case studies, field observations, representative farms or modified databases are used to estimate the model parameters or to illustrate the model demonstrative abilities (Komarek and MacAulay 2013).

Mathematical programming techniques most often belong to the fields of econometrics and production function theory, or more generally, production economics, measuring "*efficiency and utility*" [12/11]. As such, important topics include measuring agricultural efficiencies (productivity, profitability), and explaining choices made by farmers using rational economic arguments (Pannell 2008). Methods include Data Envelopment Analysis (O'Donnell 2010), stochastic distance functions (Cattle and White 2007), duration analysis (D'Emden et al. 2008).

Another vast endeavor of mathematical programming is to support managerial decisions by providing *optimal solutions* to agricultural problems (Nuthall 2011b). "*Optimization*" [13/13] procedures involve expressing conditions, then finding the parameters that typically provide the highest economic return. Diverse techniques exist, ranging from simply maximizing a response function (Lawes and Robertson 2011) to using sophisticated solvers that combine equations and decision algorithms in order to accommodate numerous constraints (e.g. the international GAMS software, van Grieken et al. (2013)). An optimization technique that remains popular is linear programming, notably used in the prolific MIDAS model to allocate resources under competing circumstances for a specified production system of the Western Australian wheatbelt (Bell et al. 2008).

- ***"System modelling"*****[29/27].** Computerized representations of farming systems usually *compile large amounts of information in order to evaluate current systems and assess alternatives*. Constructing such models often represents a considerable synthesis exercise and collaborative effort. Investing in the development of these tools is justified by the further understanding provided by considering the whole rather than the parts alone (for instance leading to emergent properties, Asseng et al. (2010)), and by their ability to fill gaps in data (for instance completing benchmark data, Kirkegaard and Hunt (2010)). A variety of tools exists that address questions at field, enterprise, farm or regional scales. Due to the complex and multi-disciplinary nature of farming systems, most studies use a combination of these tools in order to examine jointly several processes. 'Soft' systems thinking that integrates qualitative elements is encountered (Kalaugher et al. 2013) but quantitative 'hard' systems methodologies largely dominate. Parameters are generally sourced from participatory methods, national surveys, one or several case studies, farmers providing farm records, and/or expert knowledge. System modelling is a particularly vast and multiform domain which numerous branches benefit from numerous specialized reviews (Le Gal et al. 2011; Martin et al. 2012; Robertson et al. 2012b, etc.). For the purpose of this synthesis, three method groups were distinguished.

  "*Simulators*" [13/12] are defined here as *detailed biophysical tools used to predict agricultural outputs under various climate and management scenarios*, generally calibrated with historical climate data and field experiments. The most prevalent crop simulation model in Australia is APSIM. Originally developed locally for farming systems as varied as temperate cereals or tropical sugarcane (Webster et al. 2009; Kirkegaard and Hunt 2010; Thorburn et al. 2010; Biggs et al. 2013), its numerous modules are used and continuously improved by a large community of scientists globally. Typical examples include investigating the potential consequences on productivity and on the environment (e.g. gas emissions, nutrient losses) of adapting to climate change by changing management practices. Browne et al. (2013) and van Gool (2011) provide other examples of simulators.

  "*Organizers*" [12/12] comprise *models which focus on the organization of farming systems*. Applications include identifying the benefits of various management strategies or explaining current adoption levels by investigating resource allocations, option combinations, constraint variations. Usually these models use average years and at least some economic perspective. For instance using the whole-farm model MIDAS and its "Land Management Units", Kingwell (2011) explored the performance and economic implications of increasing farm complexity, whilst Robertson et al. (2010) investigated the benefits of adopting various amounts of break crops. Other modelling examples exist for crop sequences (Lawes and Renton 2010), field operations (Webster et al. 2009), management strategies (Rodriguez et al. 2014). Most focus on matters internal to the farm, although modelling the organization of farms in a given agricultural space is encountered (Asseng et al. 2010).

A third method group comprises tools of varying complexity that *focus on a very specific aspect* and can be referred to as "*calculators*" [21/18]. Standard, custom-built or derived from other models outputs, calculators can be used alone, as building blocks for simulators and organizers, or as linkages between complementary aspects. For instance, agronomic input or output calculators improve or expand simulators (Christie et al. 2011; Lawes and Robertson 2011); accounting and financial tools add economic indicators (Bell et al. 2008; van Grieken et al. 2010); whilst stochastic and sensitivity analysis complete results with risk assessments by modelling a likely range of variations (Monjardino et al. 2010; Heard and Leddin 2012).

The connections existing between the three methodological families identified above should be highlighted. Notable examples include organizers based on optimization techniques, or using statistical tools to test the significance of estimated parameters in mathematical programming, or to assess the explanatory power of theoretical and simulated relationships. Complexity also blurs methodological frontiers, for instance when mathematical models reach scopes that are characteristic of system modelling.

Although intertwined, the methods of this second overarching approach proved much better established than the first approach, with generally clear protocols and consistent terminologies. The studies also demonstrated greater care to analytic technicalities than to the origin of the data worked upon. For instance, retracing model mechanisms was often easier than sourcing its base parameters. Likewise, statistical and mathematical models were usually entirely explicit, however the nature, quality, and relevance of the sample used were often very briefly described or not referenced at all. Correspondingly, the success and mainstream status attained by some computer programs, typically in system modelling, raises the concern that methods (and research objectives) become tailored to the tool (and its constraints), rather than the reverse.

A second general observation is that the rarer qualitative methods were mostly represented by one method group, namely coded themes within content analysis (see previous section). They also covered a more restricted range of themes, with social topics much better covered than technical ones. Quantitative studies proved more eclectic in spite of facing practical issues when addressing social matters, large datasets being required to compensate for the necessary simplification imposed by coding techniques. Nevertheless, system modelling and exploratory techniques showed particular promise to integrate both qualitative and quantitative information. Yet, disciplinary boundaries endure: system modelling has become a polymorph field of mainstream status but remains dominated by quantitative thinking tailored to agronomy and economics, while exploratory techniques are only marginally used and focus on qualitative information for social sciences.

4.4.3 Retracing Processes: Focus on Establishing Causality

The third overarching approach [45/39] places current observations within a succession of events, investigating how social, economic and technical mechanisms shape agriculture. This overarching approach was the least common. Relatively few studies aimed at producing new knowledge by explicitly investigating long-term evidence. Many did consider the past but with the aim of compiling existing knowledge, positioning their particular objectives or theoretical framework within the wider scope of their topic, or providing background information against which interpreting, comparing and extrapolating results (including calibrating simulation tools, typically using historical climate data and farm records). Overall, agronomy was much less represented than economics and social sciences, with rural studies often making social issues and industry dynamics their specific objects of study.

Three contrasted methodological groups were identified. The largest encompasses "*time series*", a quantitative tool used by a variety of disciplines. The main alternative was "*narratives*", i.e. exploring farmers' experiences qualitatively. Lastly, an anecdotal number of publications aimed at "*reconstituting*" past situations.

- ***"Time series"*****[32/22].** The most common manner of addressing the past is quantitatively, through the use of time series which essentially come from *collecting descriptive statistics throughout time*. The resulting large amount of data allows investigators to follow changes in a population for demographic, physical and economic variables. Such data is either collected by national monitoring programs, or sold by consultancy firms. Collecting quantitatively any other types of information pertaining to farmers' history is notoriously difficult. Studies endeavoring to do so usually require the input of several hundred interviews coded toward the analysis of very specific topics. Examples include Wheeler et al. (2012) who collected long-term data on farm succession issues in irrigated agriculture. In adoption studies, Llewellyn et al. (2012) and D'Emden et al. (2006) circumvented the data scarcity issue by gathering time-dependent variables.

Time series can be analyzed by studying their "*patterns*" [25/11]. Kingwell and Pannell (2005) thus extrapolated on the future of broadacre farming by comparing several long-term economic trends and inferring on the scope of their variations; Llewellyn et al. (2012) evaluated the diffusion of no-till technology by interpreting cumulative adoption frequencies as a classic adoption curve; Tonts et al. (2010) used records since 1800 to distinguish distinct phases in the introduction of cattle breeds in Australia.

Alternatively, time series can be analyzed using *confirmatory statistics or mathematical modelling methods* [17/15], typically producing productivity analyses by aggregating data at state or country scale (Sheng et al. 2011). Otherwise, single farms act as study cases (Komarek and MacAulay 2013). Large and complete datasets allowing time-dependent analysis at the scale of individuals are seldom available.

Lawes and Kingwell (2012) and Kingwell et al. (2013) provide such rare examples, in which hundreds of broadacre farmers provided decade-long economic and production indicators that permitted the longitudinal analysis of business performances.

- ***"Narratives"*[20/17].** In this qualitative methodological family, *the past is explored though the lens of personal experiences*, to determine how current situations came to be.

"*Individuals*" based studies (or "case studies") [7/7] are characterized by investigating *few people at length* (rarely more than five) with the objective of reconstructing personal circumstances and the resulting paths with in-depth details. The evidence collected is in essence qualitative (e.g. storylines or biographies explaining past decisions), but can include quantified specifics as well (e.g. budgets and rainfall records). The quality of evidence provided by case studies ranges from questionably weak, as warned by Tonts et al. (2012), to strongly defended. Eastwood et al. (2012) and Gill (2011) thus followed very explicit procedures supported by elaborate theoretical frameworks that emphasized the wider relevance of their results.

Other studies aim at identifying "*groups*" commonalities [13/10]. Whilst conclusions also rely heavily on individual examples for illustrations, *results are built from a pool of evidence coming from several people*, not dissected from particular stories. To build parallels with quantitative research, these studies analyze data in an aggregated form, as opposed to case studies which researchers often refer to as "providers of longitudinal information".

Almost all examples in this methodological family employed methods and covered topics pertaining to content analysis on the topics of change and transition.

- ***"Reconstitutions"*[5/5].** Lastly, a marginal methodological family was identified. Instead of focusing on individuals or given groups, these studies *broadly contextualized their object of study*, be it case study farms (Beilin et al. 2011), a technology (Wilkinson 2011), a value chain (Oro and Pritchard 2010), a region (Allison and Hobbs 2004), or an industry (Tonts et al. 2010). Contextualizing is done by triangulating information together with considering wider temporal and spatial scales, typically including a variety of sources. Results include distinguishing historical phases, retracing processes, and contrasting timelines. Conceptual frameworks are used that recognize the need for the systemic characterization of complex situations in order to assess change and transition. These characterizations lead to the identification and comparison of development pathways, with generally much greater scopes than case studies. In spite of the few examples encountered, two methodological families were tentatively distinguished.

First were "*retrospective*" studies [3/3] which revisited existing information. These differed from standard reviews or historical narratives in that new knowledge was produced, typically using the analytical lens of a novel conceptual framework.

For instance, Allison and Hobbs (2004) applied the concept of social-ecological systems to the Western Australian wheatbelt to re-interpret historical cycles.

Second were "*investigative*" studies [2/2] which added an important field component to their analysis, integrating novel material to existing documentation. This is the case with Oro and Pritchard (2010), who based their comparative analysis of value chains trajectories on varied documents and on interviews.

A major characteristic of this third overarching approach was the use of tools belonging to the first and the second approach. This was in spite of the difficulties of sourcing sufficient (quantitative) and representative (qualitative) information, and in spite of the existence of specifically suited concepts and methods e.g. social-ecological systems, agrarian systems, evolutionary economic geography and life cycle theories, that were all very little employed. These frameworks are not new (Boschma and Martin 2010; Cochet 2012; Darnhofer et al. 2012; Gautier and Kull 2015), raising the question why concepts and methods that should have passed the stage of emerging tools remain greatly under-used. These observations corroborate Tonts et al. (2012)'s critical appraisal of Australian academic traditions in rural sciences.

Concurrently, and as a conclusive note to the description of the method map (Fig. 4.3), it should be pointed out that publications employing mixed methods were rare as well: only 13% employed both qualitative and quantitative methods (Fig. 4.2). Regrettably this is a poor improvement on the low numbers identified by Bryman (2006) a decade ago for Australian mixed methods in social fields.

Further work could assess why methodologies that make use of qualitative and historical approaches are under-used. Possible reasons may include a lack of: compatibility between conceptual frameworks; awareness among agricultural scientists (e.g. disciplinary and topical divides notably technical/social); expertise in qualitative and mixed methodologies (e.g. due to lack of relevant education programs); communication and collaboration across disciplines (e.g. rare transdisciplinary programs); funding to support novel or under-used research procedures (e.g. innovative projects perceived as "risky").

4.5 Notes on the Interpretive Procedure and Its Outputs

The interpretative review procedure that was chosen proved successful in achieving the ambitious goal of this study. Detailed methodological aspects (principles) as well as method use (relative frequencies) were addressed across a particularly broad range of topics and disciplines that are all relevant to the study of agricultural systems. No similar example could be found in reviews using systematic procedures. The novelty of interpretative approaches for agricultural research justifies highlighting key strengths and limitations that were identified during the review process.

4.5.1 Strengths

The flexibility permitted by the progressive development of classification criteria was an undeniable asset, allowing definitions to be validated, rejected or adjusted with new information. Sorting methods according to pre-defined criteria such as disciplines, topics or data type was trialed but could not encompass all the publications of the sample, especially those featuring rare methods. In fact, it appeared early that, unlike focused methodological classifications (e.g. Renting et al. 2009; Le Gal et al. 2011; Kraaijvanger et al. 2014), categories in this study could not be structured according to the same analytical dimensions.

The possibility to access detailed publication content also proved crucial to determine precise classification criteria, as well as to sort out methodological subtleties that were frequently complicated by inconsistent terminologies. This common problem is noted by reviewers even within given fields or topics (e.g. Brym and Reeve 2016). Here, terminology issues were particularly evident for qualitative research. This may be a symptom of the general fragmentation of scholarly communication that was identified by Varga (2011) within sociology. Worse, distinctions between qualitative and quantitative methods were sometimes unclear in spite of their fundamentally different principles (e.g. within compilations and participatory research). Manual sorting was already difficult, therefore automated indexation via algorithms had little chance to succeed. Many of these studies could have been discarded using quality criteria (Heyvaert et al. 2013). However, and although this review highlighted concerns regarding result validity, the primary goal was to assess method use. Reports and other industry publications that may have had less stringent peer-review processes were included considering their impact within the non-academic community.

A third key strength was the ability to include both quantitative and qualitative studies. Continuing review efforts that assess all types of analysis methods is essential given that qualitative research is still under-used, often misused or considered as a mere companion tool, its contributions mis-understood and thus undervalued (Dixon-Woods et al. 2006a; Northcote and Alonso 2010; Nuthall 2011a). This was confirmed here, with Australian research remaining highly quantitatively oriented. It is, however, not a new problem in agriculture, in which the enduring lack of qualitative methods, and consequently mixed methods, has led authors to ask at least since the 90s whether protocols are chosen depending on the research problem, or whether the problem is chosen depending on which available techniques predominate (Bitsch 2005).

4.5.2 Limitations

The main weakness of the review procedure applied here regarded the initial search strategy. Cross-disciplinary reviews are generally large projects, involving multidisciplinary teams that are able to draw from several databases and to undertake workshops to further benefit from the input of experts (Dixon-Woods et al. 2006b; Pearson et al. 2011; Heyvaert et al. 2013). These options were not available for this study (one investigator). Whilst the data thus benefited from more standardized treatment, searches and analysis were slower, resulting in an initial pool of retrieved items that possibly over or under represented some fields. For instance, a lack of geography studies was noticed that may be related to the choice of keywords. This could also simply be linked to the sizes of research communities, their orientation and their publishing preferences, which all influence the number of publications available as well as citation metrics (Barbier et al. 2012). However, it was not the aim of the review to produce a representative sample of agricultural topics, but to cast a net wide enough to cross disciplinary boundaries.

Another concern regarded a number of studies that repeatedly appeared at the top of search results. This highlighted the overwhelming influence of citation numbers and author prominence as criteria for ranking "relevance" in Google Scholar. These metrics effectively favor mainstream methods in a snowball effect while eclipsing marginal methods, irrespective of their quality and originality. The issue was answered with non-random additions which, in spite of remaining few, proved indispensable to complete the method map. In future studies, a comparison of search results with other academic engines would be valuable.

Lastly, the emphasis of this review on protocols and terminologies may be critiqued. There is no doubt that nomenclature consistency matters less than methods being adequately used. Beyond the efforts of this broad-scope synthesis, specialized reviews are necessary to fully evaluate whether this is the case. Nonetheless, the above results can be used to argue that higher nomenclature standards may be a necessary step to increased methodological quality, recognition and adequate use.

4.6 Conclusion

A broad-scope yet detailed multi-disciplinary review was undertaken of the varied methods used to analyze agricultural systems. No similar review could be found in the agricultural literature. The practical challenges of synthetizing a large and diverse body of literature could not be done using bibliometric information and automation, which made a standard systematic review not possible. The interpretative procedure chosen instead, novel in agricultural research, produced an overarching framework categorizing the diversity of approaches and methodologies encountered. This new information was summarised in a "method map" format.

The results, notably the criteria retained to classify methods, can be used to critically assess the research practices of agricultural research communities. Here, with the case of Australia and New Zealand, methodological weaknesses were identified. These led to highlight the need for more careful accounts of how data is sourced, and for more consistent terminologies, particularly regarding qualitative methods. The relative use of methods and their relationships in terms of underlying principles and common combinations was also assessed. This determined mainstream and marginal methods, notably here regarding the use of some qualitative and long-term frameworks. Further research could determine why this situation endures. Applications include helping orientate research efforts, stimulate discussions about research design, or make practical suggestions to increase transdisciplinarity. For instance, the use of mixed methods could be increased through teaching and active promotion among agricultural scientists. Other interesting lines of further examination include comparing Australian research strategies with the practices of other communities. Each section of the method map could also be enriched using specialized reviews. Changes in dominant methodological paradigms could be monitored, discrepancies between what is recommended and what is used determined in greater detail, and the value to the current situation of new, emerging and marginal methods further investigated.

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