Working on a new frontier: exploring the methodological challenges of addressing complex problems

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Abstract: The purpose of this paper is to explore the area of complexity and its link to systems thinking, with a view to defining the methodological requirements for extension services targeting complex problem situations. Agriculture in Australia is faced with a set of challenges that seem more complex than those several decades ago. In a change management context this poses significant challenges to the tools and methods employed.

Within the dairy industry it has become clear that the methods we have historically employed are increasingly inadequate to deal with the suite of problems associated with complex challenges such as climate change. Development work in farming systems extension within the Dairy Extension Centre (DEC, a collaboration between DPIV and Dairy Australia) has identified a 'new frontier' for extension practitioners. This frontier is in relation to problem spaces that are increasingly difficult to define and therefore have limited reference points upon which to base method selection decisions. A review of the literature has led to the emergence of a methodological 'sieve' with potential application in the review of existing methods and the development of core attributes of emerging methodologies.

In this paper we will describe this 'sieve' and apply it to the current suite of methods employed within RD&E in the dairy industry. Through this process it will become clear that matching methods with problems will become an increasingly important element of extension service delivery in the future. This poses significant challenges to extension systems that are built upon relatively linear approaches to knowledge generation and dissemination.

Systems RD&E – a new frontier?

G.K. Chesterton once had a desire to write a romance about an English yachtsman who sets off seeking to discover a new island in the South Seas only to find that, through a miscalculation, he had in fact re-discovered England:

> There will probably be a general impression that the man who landed (armed to the teeth and talking in signs) to plant the British flag on that barbaric temple, which turned out to be the Pavilion at Brighton, felt rather a fool. (Chesterton, 1908)

When it comes to systems thinking, agriculturalists are a bit like this yachtsman, at once sailing uncharted waters *and* standing on familiar ground. And this is a good thing! Humans have been thinking about systems since ancient Greek times and the arguments today seem to centre on the same issues as those of 2 millennia ago. Schiere et al. (2004) points out that the argument between those who think in terms of fluidity and uncertainty (*ceretis imparibus*) and those who think in terms of steady states (*ceretis paribus*) resembles the arguments between the Greek philosopher Heraclitus, who said "nothing is permanent", and the Pythagoreans who believed everything could be understood in terms of geometry. This being the case, it could be that 'systems approaches' are in vogue at the moment primarily because of each generations need to 'discover England' for themselves. Thinking in terms of systems may just be another case of history repeating itself. On the other hand, it could be argued that the operating environment, and hence agriculture itself, has fundamentally changed and systems approaches are the only option left if ecological and economic disaster are to be averted.

What do we mean by the term 'systems'?

Not surprisingly there are several potential definitions of the term system relevant to those working in agriculture. The perceived 'accuracy' of each definition will be dependent upon the orientation of the reader. The first example comes from Schiere et al. (1999, p 377):

> "A system is a limited part of reality with clearly defined boundaries. [It is] an arrangement of components or parts that act as a coherent whole with a common goal that interact according to some process to transform inputs into outputs."

This definition is particularly suited to the engineering field where the task of systems engineers is to model complete replicates of a problematic situation so as to design solutions to observed problems within the system. Hence the emphasis on clearly defined boundaries, components and a common goal. Without these it would be impossible to model anything. It is also a definition that has suited classical agricultural science in its attempts to improve the level of control exerted over the natural environment. Such a view of systems is highly appropriate where issues being explored can be translated into reasonably discrete problems or variables and where the functional relationships between these are to be quantified and explored through computer based simulations (Bawden, 1992). The Dairymod pasture growth simulation program (Cullen et al. 2008) is an example of such a 'hard systems' approach.

Although the hard system school of thought has been highly effective in describing the physical world, it has struggled to deal with the somewhat surprising and emergent properties that are observed in many agricultural systems of interest (Bawden, 1992, Checkland, 1981). Other criticisms of this view of systems relate to its mechanistic nature (Scheire, et al., 2004) and the absence of the observer as a fundamental part of the system. In response to some of these, Roling (1994, in Schiere et al., 2004 p. 68) proposes the following definition:

> "A system is a construct with arbitrary boundaries for discourse about complex phenomena to emphasize wholeness, interrelationships and emergent properties."

Here the emphasis is on the socially constructed nature of systems. In other words, the nature and boundary of a system is dependant upon the orientation of the person interested in the system. An agronomist might see a farming system as being about soil, grass, cows and supplements, whilst a sociologist may see the system as the farmer, their networks and their management strategies. The farmer first paradigm (Chambers, 1989), which will be discussed further in this paper, is an example of an approach taking such a view of systems.

A critical reflection to make on these two 'systems orientations' is that there exists a clear divide between how systems are viewed and understood in research and development circles, with practitioners aligning themselves to either 'hard' or 'soft' systems outlooks. This has implications for systems RD&E activities. Each position on systems brings with it a related worldview which is bigger than science or farming – it is fundamental to the makeup of the individual observer. Enquiry that fails to deal with inevitable conflicts between such worldviews, what Schon and Rein (1994) describe as 'frame conflicts', will struggle to improve the problem situation as different perspectives on what it means to 'resolve' a problem cannot be integrated (Kenny & Paine, 2008). Each 'worldview' will retreat to safe methodological ground and hence return, in the case of agriculture, to classical approaches to research and extension. Sweeping such differences under the carpet will simply result in an inadequate response to any given problem. Managing such differences will require more comprehensive elaboration of complex agricultural problems with a view to co-developing a methodological response that can effectively combine contributions from science, farming and extension. Achieving this in practice is in essence the 'systems challenge'.

Complex agricultural problems

Systems approaches have been looked to due to a perceived increase in complexity around the problems faced by agriculture and society. This is not a new phenomenon. Bawden (1990), writing retrospectively on the evolution of systems approaches to agricultural development in the 1970's, commented that the problematic situation in agriculture during that period was characterised by an ever increasing complexity. This drove the academics within the department of rural development at Hawkesbury Agricultural College to radically transform their curriculum to make it more 'systems oriented'. Interestingly, a similar statement around the complex challenges facing agricultural industries in the first part of the 21st century was made by the Victorian government on release of their 'future farming strategy' (DPI 2009, p.4):

> … farm businesses also face significant risks. The sector is under pressure from drought, water scarcity, labour shortages and increasing competition from overseas markets. It must also manage the long-term impact of climate change, growing urbanisation and new patterns of land use, threats from the introduction and spread of exotic weeds and pests, and changing community and consumer expectations.

However, Australian farmers have faced risks and uncertainties along these lines for some time. Since the 1950's there has been on average one significant drought every decade (Kenny & O'Brien, 2007), with several long term droughts such as the federation drought and those of the 30's, 40's and now early 2000's. Also farm numbers within all agricultural industries have declined at a similar rate since the 1960's (ABARE 2005) creating challenges around retracting rural communities and transitional landscapes (Barr, 2005). Global trade in commodities has always been a point of opportunity and risk for agricultural industries. Many wool farmers went to the wall in the aftermath of World War 1 due to reliance on the British war machine to take wool for uniforms, and the Victorian dairy industry was gutted in the 1970's due to the overnight evaporation of the UK market upon their joining the European common market (Bromby, 1986).

It is clear that any enterprise that combines climatic uncertainty with economic uncertainty through exposure to global markets will be exposed to a range of risks and hence a suite of complex challenges. Is it therefore relevant to talk about *increasing* complexity within agriculture? Or are the challenges we face today merely re-incarnations of challenges faced in times gone by? Is it that our problems are complicated by globalisation, information technology, increased mobility and rapid social change? Or is there a limit to the capacity of society to cope with the complexity inherent in agricultural problems?

Complexity and the limits of human problem solving

Human beings have a certain way of confronting problems, be they simple or complex, with such a distinction being dependent on the context and the problem solver. It will dismay many agricultural scientists to discover that such an approach is far from 'rational' in the classic sense of the term. Klein (1998, in McLucas, 2003) suggests that decision makers typically take a naturalistic approach to decision making. Naturalistic decision making is made up of three key elements: 1) extensive situation analysis (not necessarily formalised) to come to grips with the problem; 2) evaluation of options individually via mental simulation of outcomes, and; 3) acceptance of options if they are seen as satisfactory, rather than optimal (McLucas, 2003 p. 215).

Naturalistic decision making can be seen as an 'heuristic' approach, that is, an approach built on a set of decision rules and routines that the decision maker feels will give them the greatest chance of success. Heuristics are typically subjective but this is not to say that they are irrational or ineffective. On the contrary, they are so effective that Klein (1998) suggests naturalistic approaches were not only used to address complex problems under time constraints, they were also the method of choice when time was not a limitation. In other words, it is an approach that even highly intelligent people prefer to use.

However effectiveness as measured by the capacity to generate a solution that works in the short term can be different from generating real improvements in complex problem situations. Argyris (1993, p.15) takes a slightly darker view of heuristics when enacted in organisational settings. He labels them 'defensive routines' and describes them as:

> "….any policy or action that inhibits individuals, groups, intergroups, and organisations from experiencing embarrassment or threat and, at the same time, prevents the actors from identifying and reducing the causes of the embarrassment or threat. Organisational defensive routines are anti-learning and over protective."

Like Argyris, McLucas (2003) suggests that whilst naturalistic decision making can often 'work' it does have a shadow side. This relates to what he calls 'cognitive failure', which is the tendency of naturalistic decision making to draw on experiences, or frames of reference, which can be recalled easily. Just because a 'frame' is easy to recall and seemingly a good mental 'fit' for the situation, does not mean it is appropriate for the context or helpful in resolving the problem at hand. Schon and Rein (1994) discuss the role of such 'frame's' in exacerbating already complex problem areas. They talk of *policy controversies*, which are problem areas that are immune to resolution through any amount of appealing to the relevant facts. Combatants in a policy controversy typically engage in the area due to interests that are shaped by problem setting stories grounded in different frames. When an opposing frame enters the debate, argument is inevitable. Given that the process of naming and framing for each contestant in the argument involves a selective application and interpretation of 'the facts', no position can be falsified through appeal to the facts alone (Schon & Rein, *ibid*). Resolving such problems requires a process described as 'frame reflection', central to Schon and Rein's (*ibid*) concept of design which will be discussed later.

Another limitation faced by humans grappling with complex problems relates to our capacity to take account of the numerous feedback loops associated with certain actions. These feedback loops are what add considerably to the complexity of problem situations. Kline (1995) proposes an index of complexity, C, which is a function of variables (V), parameters (P) and feedback loops (L) ie: $C = V \times P \times L$ (pg.51). In total, Kline identifies 6 classes of systems, each with increasing levels of complexity (Table 1).

Table 1. Kilne's Complexity index

System class	Complexity index estimate - C	Example
A	4	Refraction, semiconductors, turbulence
B	10^6	Human designed hardware such as cars, planes & computers
C	10^9	A single human being
D	10^{11}	Human social systems
E	10^{11}	Ecologies containing humans[1]
F	10^{13}	Sociotechnical systems[2]

Source: adapted from Kline (1995)

[1] Kline (1995) makes the point that in reality this is an underestimate of the measure of complexity for this class of systems. Not being an ecologist he has resisted a more detailed analysis of complexity for these systems.

[2] Defined as "systems of coupled social and technical parts which humans erect and operate primarily to control our environment and perform tasks that we cannot do without such systems." (Kilne 1995, p. 60)

Along similar lines to Kline, Boulding (1956) proposes a 9 level hierarchy of systems, with each level representing a step up in complexity (Table 2).

Table 2: Boulding's systems hierarchy

Level	Characteristics	Examples	Relevant disciplines
1. Structures & frameworks	Static	Crystal structures	Description in any discipline
2. Clockworks	Predetermined motion	Clocks, machines	Physics
3. Control mechanisms	Closed loop control	Thermostats, homeostasis	Cybernetics
4. Open systems	Structurally self maintaining	Cells	Theory of metabolism
5. Lower organisms	Organised whole with functioning parts	Plants	Botany
6. Animals	A brain to guide total behaviour, ability to learn	Cows	Zoology
7. Humans	Self consciousness, knowledge of knowledge, symbolic language	People	Biology, psychology
8. Social systems	Roles, communication, transmission of values	Families, co-operatives, states	History, sociology
9. Transcendental systems	'Inescapable unknowables'	The idea of God	??

Source: adapted from Checkland (1981)

Such hierarchies help to describe our intuitive sense that some systems are more complex than others. They are by no means definitive in that they can be supported by empirical evidence, but as Checkland (1981) points out, they tend to be seen by most people with an interest in problem solving as helpful in making sense of the various levels of complexity in both the designed and natural world.

A key reflection from the above discussion on human problem solving relates to how the level of complexity associated with the problems we face can limit our capacity to adequately resolve them. Kline (1995, p. 57) uses the example of turbulent flow in fluid dynamics to highlight a key point in relation to the methods available to us in understanding and resolving complex problems:

> "In turbulent flow of gases or liquids usually L=0, and if we fix the values of the parameters, then we are in the operating space, and C=V=4. A complete detailed computer solution of one such problem in turbulent flow in 1990, even of the simplest sort, required about two man years of very skilled programming and three to six months running time in the largest supercomputers then available…… In 1990 each solution of the simplest problem in this class cost more than $250,000 in computer time alone….. It is thus not surprising that turbulence has often been called "the hardest problem in classical physics". Thus for our discussion, C=4 locates in a rough way the boundary between simple systems for which we could

> accurately predict all details of behaviour and complex systems for which we could not in 1990."

Sociotechnical systems, which farming and agricultural industries can be described as, are made up of thousands of human beings, feedback loops which circle the globe and hundreds of variables. He conservatively puts the complexity of such systems as greater than 10^{13}. If a complexity index value of 4 is taken as the threshold over which complexity becomes impossible to analyse fully, then sociotechnical systems such as agricultural industries or even the commercial farm become highly problematic for the scientific method.

Complexity, systems & method

The notion of a hierarchy of systems complexity helps to clarify why some methods can sometimes seem ineffective in enabling innovation and change, a problem particularly felt by biophysical scientists as they grapple with problems of a social nature. As can be seen from the above hierarchies there are clear areas where:

1. Particular scientific disciplines have a lead role to play;
2. Integration of the disciplines is required, and;
3. The development of whole new practices is necessary.

If we take each level of the hierarchy independently, it could be argued that applied agricultural science has a track record up to level 6 of the hierarchy. Using Kline's typology, science has a clear role to play in understanding class A systems. The fields of genetic engineering, agronomy, rumen physiology and animal behaviour have generated significant insights which have led to huge advancements in farming practice. Where applied agricultural science has struggled is around the integration of these fields and understanding the place of people in the application of scientific knowledge (combining 'mind' and 'matter' - level 7, or classes B-F). Recent experience with 'farming systems' projects in Australia has shown that although several approaches exist to examine the 'human' or 'non physical' elements of problems (Crawford et.al, 2007), in practice there has been limited success in effectively integrating these knowledge perspectives with those of the physical sciences (Kenny & Paine, 2008). This highlights the significant challenges faced by RD&E practitioners when applying classical applied scientific methods to complex problems.

The limited capacity of existing farming systems approaches to address the relatively 'simple' challenge of adapting technology to commercial conditions suggests that even less success can be expected when tackling issues of greater complexity, such as those associated with climate change, using similar methods. This is because the problem area is not just focused on the application of technology to individual contexts, but the adaptation of entire social systems to highly complicated and uncertain problem situations (eg: level 8, class F – the development of responses to an emissions trading scheme).

This is not a new situation. Farming systems research (FSR) was in part a response born out of this very challenge. It arose in the late 1960's from work on the Green Revolution because results from the experimental fields were increasingly inapplicable in variable contexts (Schiere et al., 1999). Another reason for its emergence related to the range of trade offs associated with applying new technology in practice due to the interrelations at the individual farm level (Schiere, 1999). FSR became widely accepted within developing country research and development and the small landholding systems that characterised this work. However in many ways the methodology failed to deliver on expectations that were imposed upon it. Primarily this was due to it becoming captive to the mechanistic orientation it was reacting against. Programs of work were often just an adaptation of the transfer of technology (TOT) approach as the power still remained in the hands of the scientists rather than the farmers who participated in the research (Kabore, 2003). It also struggled to be clear on its intent. Was it primarily focused on understanding the problem situation better or intervening to improve it? Scaling up from the individual landholder became a challenge with the resources required to develop a rich picture for each context limiting the number of landholders that could be effectively engaged. It was also beset by differences of opinion amongst development workers around what the objectives of FSR were (Kabore, 2003).

The farmer first movement (Chambers, 1983) was an emergent 'paradigm' associated with FSR but attempted to address the overemphasis on technology transfer that began to consume FSR. It attempted to address the issue of power by placing far greater emphasis on indigenous knowledge. Such work began to recognise that farmer actions are most often 'logical' and 'right', as opposed to the traditional scientific view of much farming practice in the developing world as 'illogical' and 'wrong' (Chambers, 1989). It therefore took participation to another level again from FSR, elevating the farmer and their knowledge to the equivalent, or as some would argue superior, of the scientist. Informal R&D was emphasised over formal research and the place of trial and error, intuition and experience was seen as a primary source of innovation. However the farmer first paradigm still struggled with the issue of scale. The ability to scale up from the local farm is an even more pressing issue with the total number of people dependant on the 'third agriculture' climbing into the billions. It also struggled to adequately deal with power relations at play within local communities (Gubbels, 1994, in Scoones & Thompson, 1994, p. 241).

> "….putting farmers first is striking, resonant rhetoric, but not easy to put into practice. It requires deciding which category of farmers should come first. Not deciding inevitably means that local elites come first."

This exposed a weakness in the farmer first paradigm. It was soon realised that focusing on farmer participation and empowerment, though fundamental to enabling sustainable change, must be accompanied by associated change within the wider organisational structures striving for improvements in farming practice. Without this the hopeless situation arises where individuals are empowered to make a change but their efforts are thwarted by a 'system' which perpetuates the status quo.

FSR and the farmer first approach, used here as primary examples of systems oriented participatory approaches to RD&E, are highly useful for understanding the challenges associated with methodological responses to complex problems:

- There is a significant challenge in moving from understanding systems and their associated problems to improving complex problem situations. This has implications for how systems are bounded and the methods used for systems based work. For example, bounding a system enquiry by the farm gate will by default ignore the supply chain issues that may be dictating management practices of the farmer.
- In systems enquiry it is difficult to identify where research to understand a complex problem stops and extension and intervention for change begins. It may be asked; is it in fact useful to think along these lines? It may be that the process of problem identification and resolution are the same activity. This has implications for how we structure systems research and extension to address complex challenges.
- It may be that systems research can not be 'scaled up' and as such 'systems extension' will always be context dependent. If so, a new enquiry is required for each context, seriously constraining the scope of R&D programs.
- The nature of participation is critical to enabling genuine systems enquiry. Participation without power stands opposed to the thinking underpinning systems approaches. As such, issues of leadership and authority in systems projects need to be examined early on. Making a decision on method is by default taking a position on power relations and therefore will drive the nature of participation.
- Methodological developments that target intervention at the farm level will have a high risk of failure if they are not accompanied by organisational changes to support the new methodology. A shared vision and agreement around the methodological challenges associated with complex problem solving are critical to any sustained improvement in the areas of interest.

Making progress in complex problem areas: the need for a design orientation

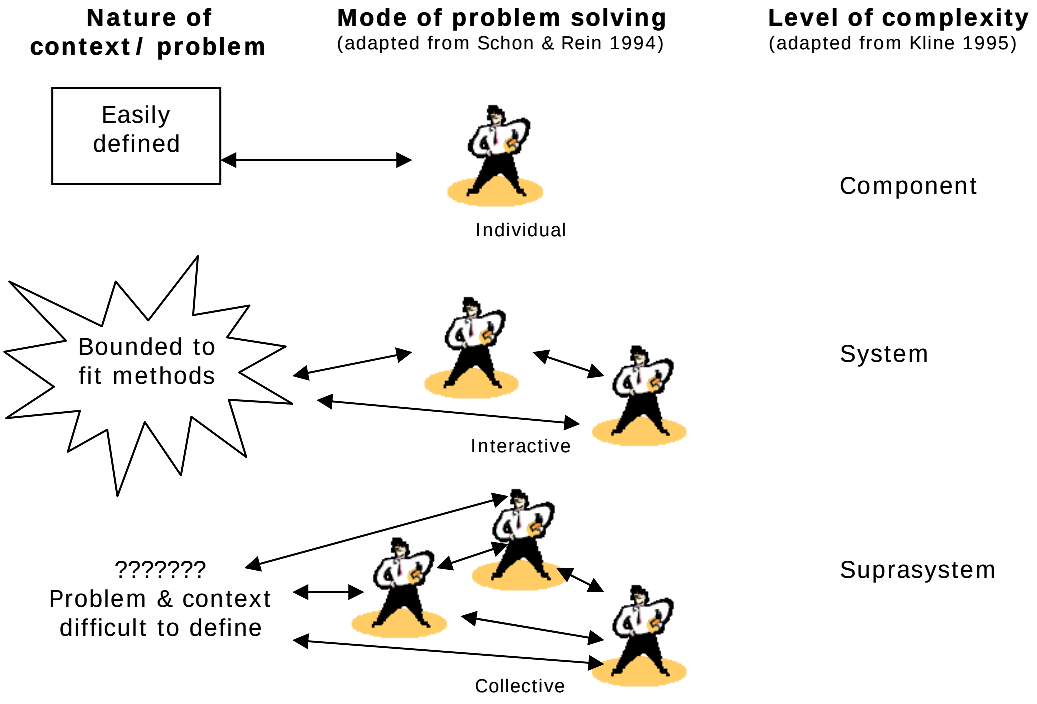
The purpose of the discussion above was to highlight how there is no simple methodological solution to the problems we face. Denying this actually exacerbates the problem. Kline (1995) suggests that given the enormous complexity associated with sociotechnical systems we have no choice but to take an approach centred on a mode of enquiry he calls 'human design feedback' (p. 62). The emphasis here is that suitable solutions to complex problems have to be constructed, or designed, on a case by case basis. Kline's (1995) complexity index highlights that the primary source of complexity is the number of feedback loops a system may contain. As RD&E professionals attempting to improve complex problem situations we need to generate ways of describing such complexity and hence developing our approaches that Kline (ibid) and Schon & Rein (1994) refer to as a 'design orientation'. Kline (1995) suggests that one element of this is to explore problems from at least three different 'systems' perspectives. We have described these perspectives in terms of *'level of complexity'* and labelled them 1) component, 2) systems and 3) suprasystems. The implication of this is that highly complex problems will require a range of approaches that enable the 'problem solvers' to explore the parts, the whole and the overall system within which the whole may be a part of.

Aligned with this, Schön and Rein (1994) in their model of design rationality suggest that there exist three main ways of grappling with problems of varied complexity. We have described these as *‘modes of problem solving’* and adapted them as follows:

1. **Individual**, which is in essence one individual or group of individuals working with a particular context. Information flows from context to the individual or group, with limited interaction occurring with other groups interested in the same problem.
2. **Interactive**. Here work at the individual level brings you into contact with other individuals or groups working in the same context. Ideas and experiences are shared but the individuals ultimately return to their work and the interaction is not used to challenge the worldviews and assumptions underpinning their actions.
3. **Collective**. Here interactions at the 2nd level cause conflict as different views of what it means to improve a problem situation are aired and discussed. Ineffective resolution of these conflicts will result in the stubborn persistence of problems as new ways of acting are dependent upon the co-development of new strategies. Such co-development requires a resolution of the conflicts that are at the heart of any groups inability to act differently in a situation. This is in effect the knowledge generation task (as opposed to a classical linear RD&E process).

So whilst exploring complex problems from multiple perspectives, the ‘problem solver’ also needs to vary the nature of participation in the problem solving process relative to the approach being taken. If we combine the elements of a design approach with our understanding hierarchical systems, a model of problem complexity can be constructed which highlights the way in which approaches to problem solving vary with problems of increased complexity (Figure 1). Increasingly complex problems at the ‘suprasystem’ level can be defined as those problems which are hard to tangibly describe the implications and impacts of, and hence what appropriate action to resolve might be. Component problems are self evident and problems at the systems level are those which interested people choose to bound in a way that suits their methodological capacity. For example, a farming systems project will deliberately bound the system to issues associated with feedbase management as to not do so would render any attempts to apply the scientific method impossible.

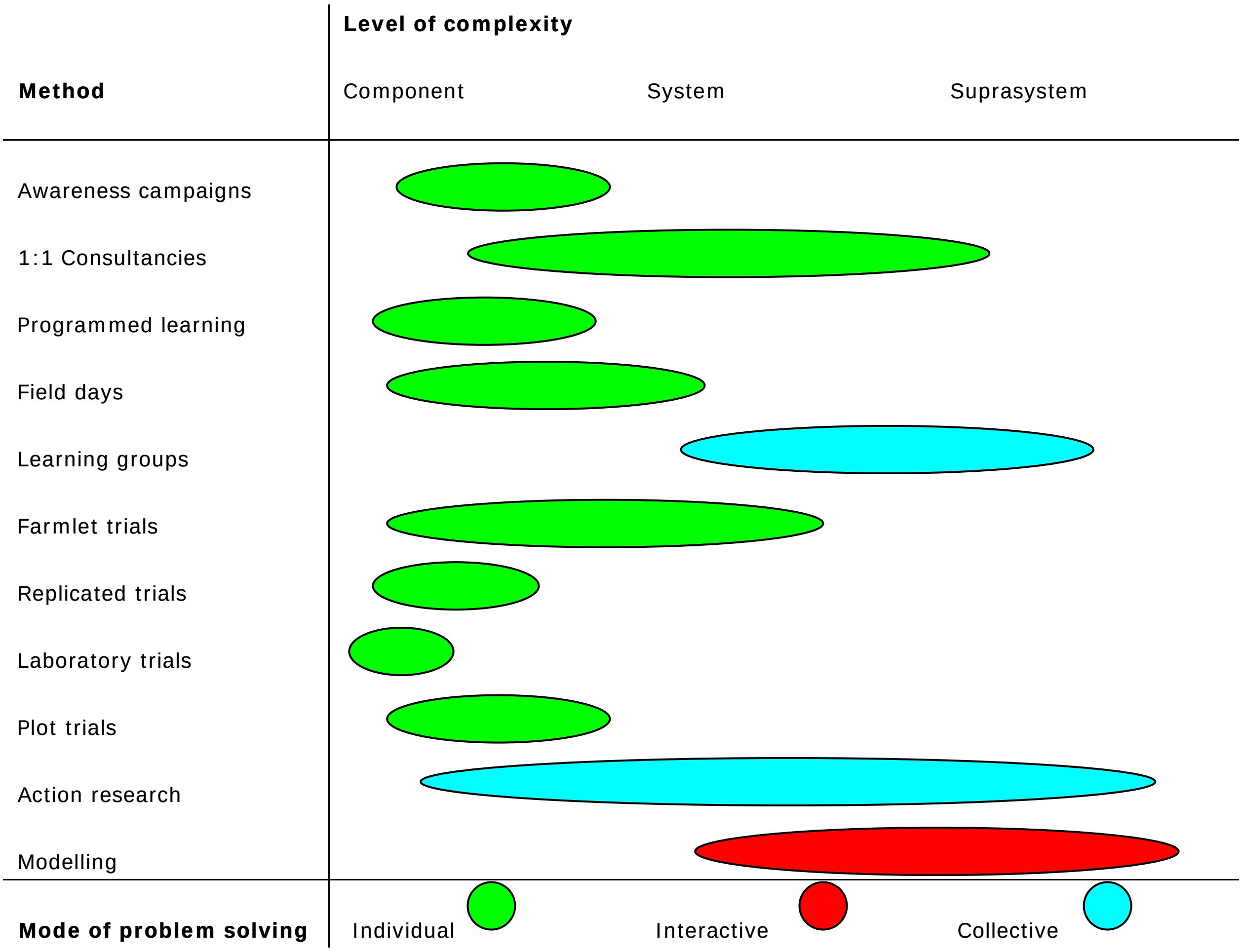
Figure 1: A model of problem complexity that describes the link between mode of problem solving, context and level of systems complexity



Testing the thinking – applying a methodological sieve

It is useful to ask, where do current approaches to RD&E fit in relation to this matrix? Table 3 below is an attempt to assess this. We have ‘clumped’ methods under a number of what we believe to be generic and easily understood labels. Some methods, such as awareness campaigns, can only really deal with components of a system as complex messages are difficult to get across through means designed to raise mass awareness of an issue or problem. Likewise they lend themselves to an individual mode of problem solving as the instigator of the campaign will be the key individual/group gaining feedback from the activities. Consultancies can cover the spectrum of component through to suprasystem but by nature will always be individual. Action research is one method that potentially has scope to handle the spectrum of foci and enable a collective method of problem solving. That is because action research by definition is a design process of action and reflection.

Table 3: An analysis of existing methods used in RD&E using the 'method sieve'



Even though our analysis is highly subjective and somewhat superficial, it does highlight that current methods seem weighted to the individual mode of problem solving. As such they typically are applied to component and systems based problems. This is hardly surprising given the fairly linear orientation of knowledge generation and dissemination that has dominated agricultural RD&E for most of its history. As a concrete example, the relative investment of the dairy industry research and development corporation, Dairy Australia, in feedbase RD&E equates to approximately 80% in applied research with the remainder spent on extension. Farmlet, replicated, laboratory and plot trials make up the majority of the research investment whilst awareness, programmed learning, field days and learning groups make up the majority of extension investment. From a portfolio management perspective this highlights some potential gaps that would need to be filled if complex problems are to be adequately addressed through RD&E investment.

Conclusions

Clearly agriculture in Australia is faced with a set of challenges that seem more complex than those several decades ago. As discussed above, this presents significant challenges for those working in the field of change management. Central to this is the seeming inadequacy of current methods to help us address the suite of problems associated with complex challenges such as climate change.

The above discussion highlights that no one approach will be capable of resolving the challenges we face, rather a mix of methods is required. Along with this is a need to challenge the linear view of knowledge generation and dissemination that has dominated agricultural RD&E for so long and replace it with a design orientation. This is because in complex problem situations both the context and the problem are perceived differently by a number of stakeholders. This in itself represents a significant knowledge management issue let al.one the task of actually resolving the problem!

It is evident that moving to a design orientation is not a simple task. Even if we agree that such a shift is required, we are still left with questions around how is the system or context of interest bound? Who decides what constitutes the problem and its improvement? And what competencies, skills and knowledge may be required to resolve this? A robust discussion of the principles of RD&E will never do away with the very political nature of investment decision making. The act of taking a design approach at least brings this task into the sights of RD&E professionals rather than simply ignoring its existence and influence on outcomes.

The aim of this paper was to open up the discussion around the methodological challenges associated with addressing complex problems. Our method sieve has shown that such a discussion is a powerful tool in engaging with others around the challenges we face. The next step is to engage with the RD&E community to developed approaches that begin to address such a challenge.

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