The top ten tenets of 'agronomics' – farmer-centric research

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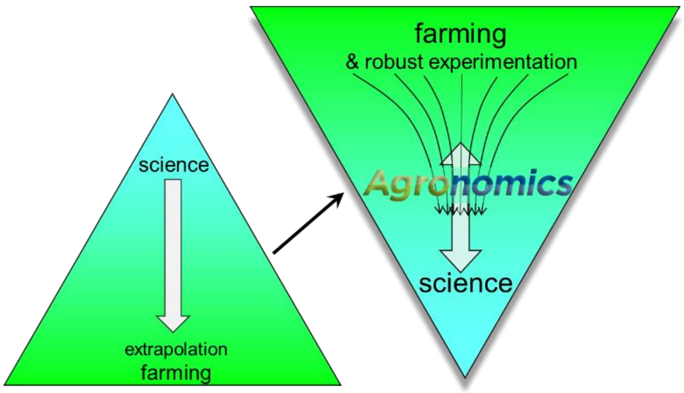
Summary:

Digitisation of agriculture is not only energising but reversing the generation and flows of knowledge, from top-down to bottom-up, so creating a new crowd-sourced, multi-scale science which we call agronomics. Benefits in enhanced productivity and sustainability should be large but mainly public and diffuse. This review of our top ten tenets of agronomics suggests that essential innovations need to be conceptual and social more than physical, so difficult to justify commercially. Priorities for investment to maximise agricultural progress through agronomics are the creation of (i) an open digital ecosystem for interoperable software services, and (ii) a structured network (or 'virtual institute') to lead thinking, research, education and training in agronomics.

Introduction

As explained already[i], we are excited by the emergence of a new technology which we call 'agronomics' – this is farming, but as revealed and facilitated by the burgeoning digital technologies[ii]. Of course agronomics incorporates conventional agricultural science, but it offers to provide far more intensive and extensive quantification, it applies across multiple scales of both time and space, and it has farmers and their supporters as central players, both as exponents and investigators, unravelling the variation that they, and everyone that depends on them (i.e. everyone!), seek to control. In particular, the new dynamics of measurement and communication enabled by digitisation are offering to supersede conventional rates of progress in agriculture.



The agronomic revolution, from top-down to bottom-up, being brought about by the digitisation of farming.

With hundreds of farmers already involved[2], and with these farmers having done hundreds of experiments[3], we are now beginning to see the key attributes of agronomics, hence the

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[2] for example those in our YENs (Yield Enhancement Networks); Sylvester-Bradley, R. & Kindred, D.R. (2014). The Yield Enhancement Network: Philosophy, and results from the first season. *Aspects of Applied Biology* **125**, *Agronomic decision making in an uncertain climate*, pp. 53-62.

[3] for example comparing fertiliser rates in our LearN group, or fungicides in BASF's Real Results Circle.

vital investments needed to enable agronomics to fulfil its obvious, urgent and huge potential. Here, briefly, we describe our top ten tenets that should enable agronomics to 'fly'. However, we must initially explain the fundamental contrast between agronomics and all that has gone before – digitisation creates a new arena of knowledge generation and offers not only to energise but to *reverse* knowledge flows in agriculture[iii]. Agronomics challenges the widely held supposition that most agricultural innovations and progress largely originate in labs., rather than in fields and on farms. They seldom have done[iv,v] and now, fields and farms are becoming 'where it's at'[ix].

1. Optimising between rigour & urgency:

The over-arching and major challenge that stands out from our experience of facilitating agronomics so far is the strong contrast between farmers and scientists in their attitudes to evidence, proof, expertise and scholarship. The immediacy, complexity, uncertainty and commercial nature of farming inevitably lead farmers to focus on incremental change, entertain hear-say, follow fashion, and be subject to ignorance or bias. On the other hand science progress is measured but slow; the discipline of science honours the written word and the history, evolution and provenance of ideas, it has created exacting standards of testing and proof, and it values professional qualifications; but this all takes time. Hence in combining farming with science, agronomics must achieve the tolerance and humility necessary to bridge between these two poles; appropriate understandings, relationships, protocols and standards must be developed.

Table of some contrasting knowledge building traits of farmers and scientists

FARMER	SCIENTIST
Optimism & trust	Rigour & scepticism
'Proof' = >50% certainty	'Proof' = 95% certainty
Holist & Generalist	Reductionist & Specialist
Synthesis & Design	Analysis
Lore & Experience	Laws & Mathematical models
Commercial metrics	Bio-physical metrics
Large scale	Small scale
Spatial	Dynamic

Our experience so far in promoting and engaging in agronomics has highlighted (i) the vital role of on-farm advisers, students and their parent organisations in providing essential mediation and two-way technical support, and (ii) the value of collaboration, both farmer to farmer and between industry and academia. New social structures are currently being tested to optimise between rigour and urgency including 'Thematic Networks' and 'Operational groups'[vi], 'Field Labs.'[vii], 'Science & Technology Backyards'[viii] and 'Farmer Innovation Groups'[x]; these show a mix of constitutions, protocols and communications.

2. Admitting & quantifying uncertainty:

It follows from Tenet 1 that farmers, their advisers and supporters, must find ways of knowing and sharing their uncertainties. That is, they must gauge accurately, and admit to their clients, the degree of confidence that they have in each aspect of their knowledge and advice. This will be a big change for many advisers and farmers. It has been natural hitherto for farmers to trust their advisers according to the 'confidence' that those advisers portray, and hence it has been natural for advisers, and advisory organisations, not only to find ways of expressing advice that transmit most certainty, but commonly to overplay the certainty that they have in their own advice and recommendations[ii]. Whole sets of procedures have evolved whereby intelligence for farmers is standardised before being communicated; these are common to most extension organisations which seek to inform farmers. For example in the UK, the AHDB committees considering 'Recommended Lists' of crop varieties or fertiliser guidance (RB209) have, in the last two decades, formalised the procedures that previously evolved in the hands of NIAB, NAAS and ADAS through the previous five decades. But as farmers seek to make urgent technical advances, and are enabled to make their own tests, they will need and want to identify, question and test those current practices and products that are most telling and least certain. So, in devising recommendations into the future, procedures must evolve to identify, manage and carefully communicate the most important uncertainties.

3. Disseminating research processes:

Given that the seat of knowledge generation in agriculture is moving more firmly onto the farm, and that farms are so numerous and busy, farm advisers and other supporters, including students, are coming to assume vital new roles. Supporters who in the past provided 'one-way' knowledge transfer, must come to provide a 'two-way' channel. Supporters must acquire sufficient expertise in research methods that good questions are formed on the farm, efficient tests are set up, and crucially, on-farm findings are fed-back, collated and added to the public knowledge-base.

To support these new skills, and avoid large extra costs, the newly acquired research capacity on farms needs to be automated as far as possible, with new systems to support searching and acquisition of current knowledge (e.g. through 'wikis'), networking and discussion to share ideas, data capture and benchmarking, data analysis and visualisation. Bespoke services will then be needed for data-sharing, social networking and distance learning.

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4. Facilitating pre-competitive knowledge sharing and generation:

Relationships between farming and food production businesses become competitive at some point. Scientists also compete for funding and career advancement. But the vast majority of farming businesses, and scientists seeking practical impacts, stand to gain far more than to lose by collaborating with each other in their learning and knowledge generation activities. Farmers, and those that most closely support and supply them, must realise the value of sharing and comparing ideas and data between farms and across landscapes. Farms are inherently dispersed (so to capture and photosynthesise as much global solar energy as possible), but their challenges and technologies are common globally, and the environmental effects that they seek to understand are best studied across big distances (so providing necessary big contrasts). Hence players in agronomics must be enabled and encouraged to engage with the vast knowledge mine that the global farm represents. We must develop means whereby farmers, advisers and scientists (and any other stakeholder) can control yet allow access to each other's ideas and data within a shared arena. As Kindred[ix] has recently pointed out, agronomic progress will be stifled if science and farming maintain their quite separate spheres of debate.

5. Developing semantics and ontologies:

An essential prerequisite for automating knowledge acquisition and searching is that terminologies and metrics become standardised and systematised. The development of so called 'ontologies', already being addressed in some sciences, must be expedited across agriculture so that all involved can access and exploit the efficiencies and global purview of the new 'semantic web'.

6. Providing education in agronomics:

The novelty, potential universality, and breadth of agronomics require that it quickly becomes a subject for education and training. Any new science such as agronomics generates a highly dynamic 'noosphere' where ideas and evidence engender lively debate. We need teachers and academics to engage in this. Additionally, as the source of new data and ideas shifts from lab to farm, students will come to form an obvious and vital bridge between farms and colleges, farmers and professors, whilst benefiting their own education and employability e.g. the Science & Technology Backyards in China[vii].

7. Incorporating social science & metrics:

We must accept that behaviour, attitudes and social circumstances play large parts in explaining the success of farming strategies, decision making and performance[x]; so understanding of social and cultural relationships must be recognised as equally crucial in explaining farm performance as understanding of the purely 'natural' sciences. Availability of and access to multiple performance metrics at field and whole-farm scales provides a huge new opportunity to bring together the social and bio-physical sciences in a way that builds new explanations and suggests new solutions to the enhancement of farm performance.

8. Developing agronomics as a new science:

Agronomics merits being recognised and developed as a new multi-scale, holistic science, evolving out of the existing agricultural sciences. Through its new wealth of farm-centric, field- and farm-scale data, agronomics offers an exciting large-scale creative arena where novel farming systems and designs will be imagined, discoveries made, and rules and laws will be forged. Whereas agricultural science has hitherto worked in disciplines, analytically – in genetics, chemistry, engineering, hydrology, physiology, animal health & welfare, nutrition and economics – agronomics offers to build these, by synthesis, into new holistic designs according to quantitative conceptual frameworks that describe, explain and predict farm performance at field and farm scales – something that agricultural science has largely shirked or shunned so far. Whereas the agricultural sciences hitherto have sought to build understanding from testing, explaining and extrapolating from single agronomic factors – environments, genotypes and husbandry treatments – simple sums show these can never address the trillions of trillions of options that farmers face annually[xi]. New philosophies must be developed for observation, experimentation and data interpretation that provide farmers with more certain outcomes, and scientists with more certain insights[xii].

9. Designing bespoke sensing systems:

Whilst new technologies can create vast data-bases of new metrics, there are multiple deficiencies in the current data-sets available to properly explain farming outcomes according to current conceptual frameworks. We cannot re-write the agricultural sciences – nutrition requires that we measure nutrients, health requires that we measure pathogens. Whilst some vital metrics like the weather are now available cheaply and automatically worldwide, methods of measuring many equally essential metrics remain manual, laborious and unautomated. The UK government has recently invested in Centres for Agricultural Innovation; these now need to prioritise the most telling farming metrics, or their best surrogates, and to find funding for campaigns to automate their sensing.

10. Exploiting new analytical opportunities:

If this new science is to progress, the large datasets now routinely being created must be processed: captured, stored, referenced, cleaned, calibrated, analysed, modelled and easily visualised and shared. Exciting current advances in mathematics and computing must be applied to the torrent of new agricultural data. However, experience in science shows the labour required to assemble the apposite data for each impending question, and the labour involved in making sense out of multi-dimensional datasets. The extent of and need for this labour, and its power in knowledge generation, are not widely appreciated outside science, so for decades applied agricultural research has accumulated multiple large, potentially valuable but unanalysed datasets – the AHDB's RL database being just one example. Analytical tools and teams must be developed to undertake 'pump-priming' exercises which demonstrate to farmers and their support organisations the power of big-data analysis, and evolve efficient procedures for this. It must become inherent in new agronomic systems that data providers and analysts see mutual benefits in close engagement. The current data explosion dictates that many new commercial services should emerge for data interpretation, but these can only do so when farmers and associated stakeholders come to value their full power (whilst trusting that their data can remain secure).

Conclusions:

These top ten tenets are offered to support current comment and debate about how R&D investments in the UK should be targeted to make fastest progress in agriculture. It is evident that the tenets are as much notional as physical, so any investments to exploit agronomics must address social relationships and skills, as much as software and sensors. Whilst recent government investments have created 'innovation centres' for Agrimetrics, Crop Health & Protection, Livestock, and Precision Engineering[xiii], these focus on important physical factors, whilst they largely eschew the more fundamental changes in socio-economic relationships in agriculture, driven by amplifying and reversing the flows of data and knowledge. Whilst agricultural levy bodies continue to address agricultural productivity and sustainability issues through conventional top-down research and knowledge exchange mechanisms, they have recently been recognising the potential of bottom-up knowledge generation; agronomics now formalises this change and offers a major opportunity for crowd-sourcing and more intimate engagement with levy-payers and their advisers.

In conclusion we propose that our more conceptual tenets might be addressed by a new structured network or 'Virtual Institute for Agronomics' (VIA) which would lead thinking, research, education and training in agronomics: in particular developing the new science and forging engagement with the knowledge generators – farmers and their advisers. But also it would seek to reconcile rigour with urgency, develop ways to quantify and report uncertainty, develop farming ontologies, and incorporate social understanding (with appropriate metrics) into more conventional (physical) explanations of agricultural performance.

The more procedural tenets above, involving the sharing of data, knowledge and ideas, could be best addressed by developing a new open digital ecosystem for interoperable software services. These would automate research processes, facilitate pre-competitive knowledge sharing, generation and recording using newly developed ontologies, design bespoke sensing systems for prioritised metrics, and provide new analytical tools to distil the multiple, new, big, agricultural datasets.

New investments on the scale of an institute and a digital ecosystem are justifiable because, even though the UK is only responsible for 1% of global agriculture, such infrastructures should form a leading global resource. The UK is far from unique in its farmers, its farm variation and its agricultural challenges; if the UK can take a lead in developing the technologies and procedures for agronomics, these will be immediately applicable and relevant worldwide, even where levels of governance, education and technology don't match those of the UK. By creating the systems, software, sensors, and skills to enable mainstream agronomics in the UK, and by doing this in cognizance of other regions, agronomics investments could become exploited globally, and pay off handsomely, whatever the current challenges for global farming are seen to be.

References:

[i] Sylvester-Bradley, R. & Kindred, D.R. (2019). *Farmers are sitting on the secrets of their future success.* ADAS News; available here.

[ii] Sylvester-Bradley, R., Kindred, D.R., Marchant, B., Rudolph, S., Roques, S., Calatayud, A., Clarke, S. & Gillingham, V. (2017). Agronōmics: transforming crop science through digital technologies. *Advances in Animal Biosciences: Precision Agriculture (ECPA)* 8(2), 728–733. doi:10.1017/S2040470017001029

[iii] Kindred, D., Sylvester-Bradley, R., Clarke, S., Roques, S., Smillie, I. & Berry, P. (2016). *Agronōmics – an arena for synergy between the science and practice of crop production.* Paper presented at the 12th European IFSA Symposium at Harper Adams University. Pp. 12. Accessed here.

[iv] Sylvester-Bradley, R. (1982). Plant physiology in advisory work. *Agricultural Progress* **57**, 13-18. (Available here.)

[v] Sylvester-Bradley, R. (1991). Modelling and mechanisms for the development of agriculture. *Aspects of Applied Biology* **26**, *The Art and Craft of Modelling in Applied Biology,* 55-67. (Available here.)

[vi] EU (2017). *A strategic approach to EU agricultural research innovation. Final outcome of the European Conference: 'Designing the path'* 26-28 January 2016, Brussels. Available here.

[vii] Macmillan, T. & Benton, T. G. (2014). Engage farmers in research. *Nature* **509**, 25-27.

[viii] Zhang, W., Cao, G., Li, X., Zhang, H., Wang, C., Liu, Q., Chen, X., et al. (2016). Closing yield gaps in China by empowering smallholder farmers. *Nature* doi:10.1038/nature19368

[ix] Kindred, D.R. (2019). *Fulfilling the opportunity to transform Knowledge Generation in Agriculture ... by transforming the Science of Agriculture*. Article available here.

[x] Sylvester-Bradley, R., Clarke, S., Kindred, D., Roques, S. & Berry, P. (2019). Variation across scales indicates that best progress in crop yields should come from farmer-centric research. *European Conference on Precision Agriculture* (in press).

[xi] Sylvester-Bradley, R., Kindred, D. & Berry, P. (2018). *Agronōmics: eliciting food security from big data, big ideas and small farms.* Proceedings of the 14th International Conference on Precision Agriculture June 24 – June 27, 2018, Montreal, Quebec, Canada. Accessed here.

[xii] Cook, S., Cock, J., Oberthür, T. & Fisher, M. (2013) On-farm experimentation. *Better Crops with Plant Food* 97 (No. 4), 17-20.

[xiii] For details of UK government Centres for Agricultural Innovation, see here.