Developing conservation agricultural innovations and practice change: a model for future research, development, extension and training in a brave new world

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Abstract
Incorporating crop residues (stubble) after harvest and adding soil nutrients (fertiliser) is thought to increase soil carbon. However, this has not been quantified over a range of soil types, climates and farming systems. The impact of this practice on grain yield and soil carbon in broad acre cropping was tested in a large collaborative project undertaken by a consortium of farming systems and grower groups, extension personnel and researchers. The project: 1. gauged growers' attitudes to the benefits of stubble management and carbon farming; 2. determined the need for, and provided training in soil carbon and biology; and 3. conducted a field experiment to measure the impact of stubble incorporation and nutrient addition on soil carbon and grain yield at 14 sites from the eastern wheat-belt central NSW to south-west Victoria. Most growers were sceptical of stubble incorporation as a technique for sequestering carbon but recognised the need to quantify benefits and costs. Integration of stubble incorporation must provide financial returns and flexibility in farming systems. Growers were keen to undertake broad training in soil biology rather than focusing on soil carbon alone. The field experiment had variable success and identified the needs of such an ambitious approach to research. These are: clear experimental protocols, careful site selection, excellent communication, sufficient resources, and the clear definition of the roles and responsibilities of partners. We identify both the benefits and problems of a collaborative consortium. The engaged partners are keen to further develop this model for future collaboration.

Keywords
On-farm research, herbicide resistance, low-input systems, socio-economic drivers, adaptation, participatory research

Introduction
Conservation agriculture (CA) with stubble (crop residue) retention and reduced or no-till has clear benefits and costs for the dryland and irrigated mixed farming systems of south-eastern Australia (Scott *et al*. 2010; Kirkegaard *et al*. 2014). CA increases ground cover and soil conservation, reduces energy and labour costs, increases water use efficiency, improves timeliness of sowing, and reduces environmental and human health risks from smoke pollution. In addition, evidence suggests that stubble incorporation after harvest with added nutrients (nitrogen, phosphorus and sulphur) can significantly increase soil carbon sequestration in the top layers of soil (Kirkby *et al.* 2011). However, tillage and stubble burning are replaced by herbicides for weed control in CA, leading to increased selection pressure and widespread herbicide resistance worldwide, especially to glyphosate in crops and fallows (Heap 2014). Crop competition through plant breeding and agronomy (Lemerle *et al*. 2001) has gained renewed interest recently for weed management. Other constraints to CA include difficulties in sowing into high stubble loads, increased machinery costs, and more complex management decisions. As a result, rates of adoption have been relatively slow in this zone (e.g. Llewellyn *et al*. 2012). Many growers now are utilising 'strategic' tillage and burning of stubble for weed, disease and pest control (Kirkegaard *et al*. 2014; Higgins *et al*. 2015). Recently, political pressures for

environmental protection and adaption to climate change have increased government incentives for farmers to adopt conservation agriculture. Clearly, both complex biophysical and socio-economic factors influence adoption of new farming systems and adoption is more likely if systems are more flexible, profitable and resilient to the challenges of climate change, rising costs and herbicide resistance.

This paper describes an Australian Commonwealth Government-funded project (*Action on the Ground Program* 2012/3 -2014/5) that examined the relationships between stubble/nutrient practices (from 'burnt' to 'fully incorporated with nutrients') on soil carbon and grain productivity from a regional perspective. The aim was to develop a multi-disciplinary consortium of dryland and irrigated systems groups, advisers and researchers for collaboration and integrated research, development, extension and training (RDE&T). The project combined on-farm experimentation with training of farmers and advisers, and also included social science studies of farmers' knowledge, attitudes and practices. Communication and extension activities were an important component of the project.

RDE&T Consortium

The consortium was formed in 2012 between farming systems groups (Central West Farming Systems, FarmLink and Southern Farming Systems), a consultancy (Rural Management Strategies, Wagga Wagga), the research subsidiary of the rice growers cooperative company (Rice Research Australia Proprietary Limited), Holbrook Landcare Network and researchers at the Graham Centre for Agricultural Innovation, an alliance between Charles Sturt University (CSU) and the New South Wales Department of Primary Industries (NSW DPI). The partners covered a wide range of growing conditions and soil types from the eastern wheat-belt of central NSW to south-west Victoria. The annual average rainfall was between 408 and 624 mm, growing season (April-November) rainfall between 247 and 351 mm, with expected average wheat yields of between 1 and 4 t/ha, and up to 8t/ha for irrigated systems. The scale and nature of farming operations varied between partners and thus the techniques were tested under a wide range of stubble load and breakdown conditions. The aim was to provide information and experience in stubble techniques and examine the benefits/costs of stubble for carbon farming to over 1500 farmers across the broad range of environments. Information and innovation was shared between growers, advisors and researchers across the region. Demonstrations of the latest research locally aimed to provide knowledge confidence and capacity for practice change and for landholders to understand impacts on soil carbon.

Field experiment conducted at 14 sites

Three core treatments were tested at all locations: current local practice (usually standing stubble), stubble incorporated with a disced implement, stubble incorporated with extra nutrients applied according to the stubble load at the time of application. Some groups tested other treatments, for example nutrients applied to standing stubble. The variability of each site was assessed by electromagnetic surveys. Two zones were identified within each field which were used as 'blocks' in a replicated block statistical design. All trials were undertaken by farmers using their own equipment with the width of each plot being dictated by the width of the machinery. Protocols to sample stubble and soil were devised in conjunction with the farming systems groups. Soil sampling was carried out to determine the initial, pre-treatment, values of soil carbon. Grain yield was measured using a variety of methods.

Detailed plans were drawn up for twelve field trials and communicated to the project partners. Ten of those experiments were established in 2013 as planned and grain yields were harvested in 2013 and 2014. The partners where this was achieved were close to Wagga Wagga or had a history of collaboration with NSW DPI and CSU. Soil carbon values were low at all sites and generally 50% of soil carbon was in the humic fraction. The initial, pre-treatment, soil carbon content in the top 10 cm of soil increased with increasing annual rainfall. A number of important issues were identified while establishing the sites, including that it was a complex process that took much longer than anticipated. Advisers felt that the experiment focussed too much on the science and was insufficiently resourced to achieve the objectives. Communication could have been much better; however, competing demands on people's time was an on-going problem. Of critical importance was having the right farmers and sites who are happy to be involved and willing to participate. Also, uniformity of equipment across all sites was important to reduce variation in grain yield results, and so the success of measuring yield by on-header harvest yield monitors was variable. Again, those partners who were local and had a history of collaboration delivered the best results. Some yield monitors failed, one was set to record at thresholds above that which would identify variation in the paddock, and some monitors suffered data loss. Those yield data recorded showed no clear effect of the treatments. It seems likely that variation in yield was dominated by weather events like frost or drought. Short-term yield benefits were of more interest to the farmers than longer-term changes in soil carbon.

Soil biology and carbon training

Training workshops were delivered to 221 landholders in Soil Biology (153 participants) and Soil Carbon (68 participants) from June 2012 to April 2014, by NSW DPI staff with some workshops co-delivered by Riverina Local Land Services staff as a 'train the trainer' program. Face-to-face training was delivered, and in addition, participants were shown how to access the *Evertrain* online courses (www.futurefarmonline.com.au/agribusiness...evertrain.htm.) at the training days. Evaluation surveys indicate some participant interest in the online courses. The more popular Soil Biology course was designed to provide participants with knowledge about the functions of soil organisms, and highlighted the importance of soil organisms for soil health. The course presented techniques to identify and monitor soil biological health and manage soil organisms for sustainable land management. The Soil Carbon course enabled farmers to develop an understanding of the carbon cycle, by examining different types of soil carbon, location, measurement and benefits to the soil, and for mitigation of climate change under different soil types and climatic zones. There was an overall positive response from participants to the workshops due to the: practical component of the courses; opportunity for participants' to examine their own soils; use of local advisory staff where possible to tailor content to regions; and group discussions that enabled land managers to share experiences and ask questions.

Social research

The broad aim of the social research component of the project was to assess growers' knowledge, understanding and practices of stubble management at the beginning of the project, and following the field trials. To achieve this aim the social research was divided into two phases. The first phase involved group interviews in June, July and September 2013 with a sample of landholders from each of the six grower groups involved in the project, as well as individual semi-structured interviews with two growers from each group. The group interviews provided valuable baseline data on landholders' knowledge, understanding and practices of stubble management. Individual in-depth interviews enabled more detailed exploration of, as well as insights into, stubble management practices. It was found that partial adoption of stubble retention is normal, with many using it as a tool in their stubble management kit (Higgins *et al.* 2015). Growers showed little interest in carbon sequestration, and they were sceptical about measuring soil carbon, maybe due to cost, accuracy and need. Growers partially adopt stubble retention and combine this with selective burning under a 'flexible combined system' of stubble management. The second phase of the social research commenced in late March 2015. This phase involves semi-structured interviews with the grower group leaders/coordinators as well as two growers involved in the field trials from each group (total of 18 interviews). Changes in attitudes and knowledge will be benchmarked, as well as future RDE&T needs.

Communication and extension activities

An annual forum aimed to provide a platform for the growers, researchers and industry experts to engage and network, building knowledge and understanding about the use of stubble for carbon sequestration and sustainable cropping. However, this was poorly attended by farmers and advisers. Field days were generally well attended especially those involving machinery and demonstrations, which really engaged the farmers and resulted in good and robust discussion between the farmers and researchers. It was obvious that growers require information that relates to practical application on-farm. It was also noted that for engagement of growers at the field sites it is important to have consistent messages about carbon farming, realising that systems are very complicated, i.e. regional and farmer specific. Field events which targeted farmers and industry aimed at increasing knowledge and understanding about the role of stubble for carbon sequestration, soil microbiology, soil acidity, and other management decisions experienced with stubble retention. Internal communications amongst project partners occurred regularly with email updates and a webpage of project activities being circulated, however, feedback suggested there was room for improvement.

Conclusions and future directions

In early 2015, two and a half years after the project commenced, a number of conclusions could be drawn about the successes and problems of forming such a consortium for collaboration. It was generally agreed that the project has created an important framework to look at systems and integration, and that linking researchers and growers is important for generating and testing 'science-based' innovations and providing reliable advice for farmers. The integration of training was a very important component of the project. The benefits of a multi-disciplinary team were clear and essential to address the complex biophysical and socio-economic drivers in CA systems. However, the integration of ‘business management’ into the project was required to examine risk management and quantifying the costs and benefits of innovations. The project was over ambitious given the limited budget, and it would have benefited from a longer planning phase. In future, such projects should have simple objectives with obvious benefits to farmers and last long enough to measure changes in soil properties, as well as short-term yields. The number of partners and the area covered was probably too large for a preliminary study. In future, effective collaboration and the building of trust between partners require more time, resources and better communication. It was suggested that a half-day training and team-building meeting of the farming systems group leaders and the researchers is required at the beginning of such a project, to agree on objectives, go through the protocols, and establish an understanding of the roles and responsibilities of partners. This is critical to ensure clear and consistent communication to the farmers. Considerable opportunities exist to improve communication of ‘reliable’ advice, especially through the use of social media and for new models for field days, including careful choice of demo sites with the right farmer champions. The engaged partners identified a will to continue such an RDE&T collaboration to address future priorities, including herbicide-resistant weeds, rising input costs, and the potential of precision agriculture, and the integration of livestock enterprises into mixed farming CA systems. Engagement using soil carbon, which farmers have little interest in, is unlikely to succeed.

In summary, the participatory research model works but lessons learnt are: effective communication is critical; distance covered must be manageable; on-farm experimentation is important but there can be problems with different equipment used at different sites and conflicting priorities; the need for achievable research questions about potential new techniques; long-term funding is required; established trusting relationships are most effective when roles and responsibilities are well defined and resourcing adequate; integration of social and economic sciences are important for understanding the knowledge and motivation of farmers for change; and benefit cost analyses. Long-term experiments combined with reliable advice underpin the adoption of new innovations.

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