INTEGRATED PEST MANAGEMENT IN NORTHERN NSW GRAINS CROPPING: LESSONS LEARNT FROM AN INDUSTRY-FOCUSSED PROJECT

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SUMMARY

We review the status of insect pests and beneficials in northern NSW, the role of Integrated Pest Management, the potential impacts of climate change on these interactions, and the ability of farmers to adapt and prepare to manage insect pests and beneficials in grain crops and adjacent areas. This outreach and extension project was undertaken between 2009 and 2012. The primary considerations that need to be made about pest insects and reducing reliance on prophylactic chemical sprays are in understanding the role that adjacent remnant vegetation plays in harbouring beneficial insects and having an understanding of both pest and beneficial insect biology. Here, we also assess the current support for Integrated Pest Management (IPM) in northern NSW and identify the barriers farmers face in implementing and using IPM. We then evaluate methods used to integrate an Information-Based Service to growers and agronomists using extension activities, workshops, website, blog and insect identification service. Finally, we identify capacity to facilitate practice change in pest management using the IPM workshops, extension activities and integrating research into this knowledge transfer.

Keywords: IPM, grain crops, extension activities, beneficial insects, land management, climate change

INTRODUCTION

The Australian grain industry is an essential contributor to Australia's overall agricultural production. Recent estimates of grain, pulse and oilseed production indicate approximately 26% of Australia's gross value of agricultural production and 21% ($12.8 billion) of the economic value of farm commodity exports to be made up of these crops (ABS 2019b). In the period 2017-2018 total broadacre crop production in Australia reached 75 million tonnes from 24 million hectares planted (ABS 2019a) and over the same time the total gross value of broadacre crops was $19.2 billion (ABS 2019b).

In Australia, grain production occurs across a range of climatic and geographic areas. These are broadly split into three agro-ecological zones reflecting environmental, market and production differences. These zones include the (i) Northern region (incorporating farms in northern NSW and Queensland); the (ii) Southern region incorporating farms from central and southern NSW, Victoria and south-western South Australia; and (iii) the Western region which includes Western Australian grain farms.

This review focuses on the adoption of Integrated Pest Management (IPM) in the northern NSW grains crops and strategies to support increased adoption of IPM. The Northern NSW grain-growing region that includes farms extending north from latitude 32°S (Dubbo/ Kempsey) to the Queensland border.

We have structured the manuscript into four sections. Firstly, we review the main crops in the northern NSW region and aspects of pest management. Secondly, define IPM and its challenges and uptake in the region. Thirdly, we review the findings of a Grains Research Development Corporation funded project in developing a research and communication strategy to foster implementation and uptake of IPM for grains crops in this region. Fourthly, we identify the research gaps that became clear from the assessment of this project.

The Northern NSW grain growing area encompasses the NSW north-west and north-east agro-ecological zones and is characterised by a tropical and subtropical climate. Farming enterprises are typically large scale, occur on areas with high inherent soil fertility, and have high-potential yields with a focus on high-protein wheat for export and domestic markets (Australian Natural Resource Atlas 2009; Grains Research Development Corporation 2009). The region is summer rainfall dominant with yield being highly dependent on the retention of soil moisture from subtropical rain. These climatic features mean that winter cropping is restricted mainly to areas with heavy soils that can hold and store moisture (Hammer *et al.* 1996; Shaw and Yule 1978). Summer crops such as sorghum, maize and sunflowers are also grown in the northern region.

Major crops in the Northern NSW grain-growing region include coarse grains (wheat, barley, maize, oats, sorghum and triticale), pulses (chickpeas, faba beans, field peas, lentils, lupins, mung beans, soybeans) and oilseeds (canola and sunflowers). While soybeans after often classed as oilseeds, this review follows Brier et al. (2008) by regarding them as pulses because of shared pests and their botanical (legume) classification. Of the above crops, wheat is the dominant crop in the northern NSW grain region both in terms of hectares sown and tonnage. Summer cropping is typically dominated by sorghum which represents around 76-79% of the total summer crop tonnage (~500,000 tonnes/year) with sunflowers, corn and soybeans making up the majority of the remaining summer cropping in the region. Other important crops for the northern region include winter crops such as barley, oats, canola and chickpeas with canola and chickpeas, both becoming increasingly significant in the period since 2006 (Scott 2010). However, due to the 2019-2020 drought, winter crop estimates are much lower (ABARES 2020).

The northern grain-growing region is highly sensitive to climatic influences with both wet and dry years, causing substantial fluctuations to yield and grain quality (ABARE 2010; ABARES 2020; ABS 2019a; Scott 2010). CSIRO climate change scenarios predict that by 2030 and 2070, summer temperatures in NSW will become hotter (1-3°C) with the highest increases expected to the north-west of the state (BoM-CSIRO 2018). Changes in rainfall patterns are also likely with decreases in winter rainfall predicted. While summer rainfall may increase in some areas, this is likely to be offset by increased summer evaporation as a result of increased temperature. As a result, dry soil conditions are likely to be even more prevalent in western parts of the state. Similarly, despite projected increases in rainfall across the north and east of the NSW in autumn and spring these regions can also expect an increase in evaporation that may result in drier soil conditions (BoM-CSIRO 2018).

While increases in CO_2 will have the potential to increase grain yield, it is predicted that changes to the duration of phenological stages resulting from increased temperatures will, in general, reduce grain yields overall (Anwar *et al.* 2007; CSIRO 2008; Howden *et al.* 2007; Shen *et al.* 2018). Significant adaptive changes to management practices, varietal or species selection and planting times have the potential to substantively offset many of the negative impacts of climate change on grain-growing regions in Australia, particularly under scenarios of only moderate warming (<2°C) (BoM-CSIRO 2018; CSIRO 2007; Howden *et al.* 2007).

Management practices that may buffer the effects of climate change include adopting zero-tillage practices, developing more minimum disturbance techniques, extending fallows to capture and store more soil moisture, adaptive planting times to take advantage of water availability, widening row spacing or skip-row planting, staggering planting times, lowering plant populations, reducing irrigation system losses, adaptively assessing fertiliser inputs, managing erosion and salinisation (CSIRO 2007; Howden *et al.* 1999; Ugalde *et al.* 2007). Seasonal forecasting and climate modelling (Al-Kindi *et al.* 2019; Hammer *et al.* 1996), along with effective research delivery, education and extension activities are also likely to become increasingly important in maintaining efficient on-farm management (CSIRO 2008). Indeed, if growers and agronomists are to adapt to new climate change conditions, continued monitoring, and rapid responses to emerging pest, disease and weed issues will become increasingly important (Andrew and Hill 2017). For example, in the northern region, different insect life stages are more susceptible to temperature and humidity change (Chanthy *et al.* 2015), and can acclimate to extreme temperatures (Chanthy *et al.* 2012; Nguyen *et al.* 2014) and different temperature regime exposures (Ghaedi and Andrew 2016); and be more abundant on different crop varieties (Gia and Andrew 2015), or respond to insecticide exposure (Betz and Andrew 2020). In many ways, IPM strategies which already implement such processes will be well situated to aid growers in managing a changing climate. This latter point will be discussed further within the context of changes to pest assemblages and integrated pest management.

INVERTEBRATE PESTS IN THE NORTHERN NSW GRAIN GROWING REGION

Insect pests of Northern NSW and Queensland have been reviewed by Brier *et al.* (2008). In general, summer pulse crops in the northern grain region are at higher risk of economic damage than oilseeds or cereals. This is in part because of the higher number of major pests affecting summer pulses (20 major pests) than oilseeds and cereals (each with less than nine major pests), but also because of the more stringent market requirements of the summer pulses. Summer pulses are also typically attractive to pests at any crop stage (Brier 2007; Brier *et al.* 2007; Brier *et al.* 2008; Franzmann 2007a; b; Hopkins and McDonald 2007; Murray 2007).

Changes in pest assemblages and emergent pests

The effects of changing management practices, increased use of chemicals, particularly synthetic pyrethroids, landscape-level changes, biosecurity issues, altered insecticide applications and climate change have all been implicated in shifts in pest complexes (Altieri 1999; Andrew and Hill 2017; Arthur *et al.* 2020; Hoffmann *et al.* 2008; Maino *et al.* 2019; Schellhorn and Lawrence 2008; Ugalde *et al.* 2007). Such shifts can, in turn, lead to significant changes in pest pressures. For example, some cultural control practices that rely on deep-ploughing of egg-laying insects (such as *Austroicetes cruciata*, small plague grasshopper) to disrupt egg masses are much less effective when minimum-till ploughing is used (Walker *et al.* 2007). Similarly, in the cotton industry, intensive post-harvest cultivation ("pupae busting") is routinely recommended as part of insecticide resistance management strategies to reduce the survival of overwintering *Helicoverpa* pupae (Fitt 1994a; Lloyd *et al.* 2008), but this does not fit well with no-till management practices that are commonly used in the northern grain-growing region.

Conversely, carabid beetles and predatory earwigs are effective predators of wireworms, slugs and moth larvae are favoured in reduced tillage systems (Andersen 2003; Hoffmann *et al.* 2008). Of interest is recent work undertaken by Lloyd *et al.* (2008) who found that "pupae busting" strategies for combating overwintering *Helicoverpa* pupae in cotton industries did not necessarily translate well into grain systems. Indeed survey data indicated that in the absence of tillage practices, late-season cotton, sorghum, maize, soybean, mungbean and sunflowers were equivalent in the number of *H. armigera* moths/hectare produced in spring with enormous variations in and between seasons. They conclude that in most years, healthy crop development means that most grain crops are sufficiently mature in late summer and autumn that they no longer support *Helicoverpa* spp. larvae – thereby posing little risk of a build-up of overwintering pupae that would require "pupae busting".

Higher risk grain fields can be individually identified based on scouting history and timing and "pupae busting" action taken only when appropriate (Lloyd *et al.* 2008). Fallowing is also commonly practised for water storage, nitrogen mineralisation and to control invertebrate pests, pathogens and weeds. Increasing use is being made of crop rotation, stubble retention and herbicides during fallows rather than cultivation (Williams *et al.* 2002).

Climate change as a driver

Decreased rainfall, increased temperature, increased atmospheric CO_2 has occurred over much of the grain-growing region in northern NSW (BoM-CSIRO 2018). In Australia, many pest invertebrates such as the red-legged earth mite (*Halotydeus destructor*) and blue oat mites (*Penthaleus* spp.) have increased in prevalence over the last twenty years (Hill *et al.* 2012; Yang *et al.* 2020). This is thought to be at least in part due to climate change (Andrew and Hill 2017; Hill *et al.* 2012; Hoffmann *et al.* 2008).

Native vegetation

Of interest is recent work showing high degrees of predator aggregation within crops where it has been found that generalist predator populations are rarely distributed randomly within cropping systems and that field edges and adjacent crops have a significant influence on within-field predator abundance (Pearce and Zalucki 2006). Native vegetation is a critical habitat for invertebrates within farming regions (Andrew *et al.* 2019; Oliver *et al.* 2016). Naturally, this is of great importance when monitoring and estimating pest and predators abundances (or ratios) from randomly distributed samples taken from within a crop. Similarly, caution must be exercised when extrapolating predator numbers or biodiversity within a cropping system for use in an index of effective pest suppression or control because few studies explicitly link predator abundance with pest mortality (Furlong and Zalucki 2010).

Integrated Pest Management

Integrated pest management (IPM) involves the integration of several strategies to manage pest species in crops or pastures. It encourages a movement away from a sole reliance on insecticides and combines a variety of biological, ecological and cultural controls that target pest species and encourage host-plant resistance whilst conserving beneficial insect populations (Stern and van den Bosch 1959). Successful IPM tactics may include, the use of selective insecticides or biopesticides, destruction of weed host plants, conservation of natural enemies, the use of economic thresholds combined with regular sampling to monitor pest and beneficial activity (Macfadyen *et al.* 2019). IPM is in general recognised as a response to an overuse of insecticides and the management crises that subsequently ensue (Zalucki *et al.* 2009). However, importantly, IPM does not necessarily equate to an absence of insecticides, rather it encourages a sustainable approach to pest management problems. Whilst in many cases this may entail favouring a selective "soft option" insecticide over a more broad-spectrum non-selective insecticide, this is not always the best or most long-term sustainable option. An IPM approach recognises that the right combination of management options is essential, as is its timely application; however, in many cases this has not occurred (Coll and Wajnberg 2017). In this sense, IPM can be thought of as a decision support system for the selection and use of pest control tactics. Tactics can be used singly or in a coordinated manner as part of a broader management strategy based on cost/benefit analyses that take into account the interest of and input of producers and the environment (Eilenberg *et al.* 2001).

Accurate and up-to-date information allows land managers to (i) understand the biology and ecology of the pest species and (ii) the agro-ecosystem as a whole and the interactions within it. With this information, farmers can use a variety of relatively simple techniques to monitor their farms for pest species. Common monitoring methods include: beat sheet sampling, pheromone traps, pitfall traps, sweep net sampling, suction sampling, visual inspection/sampling, shelter bags, germinating seed baits, spade sampling and spear sampling (for pests of stored grain) (Bellati *et al.* 2018). Through the use of appropriate monitoring techniques, farmers can gather information about what pest/beneficial species are present, what life-cycle stage they are at, and at what densities they occur. Information can then be shared at a broader scale such that pest outbreaks can be predicted and action taken as pest species exceed their economic threshold. However, due to the lack of systematic monitoring strategies and their direct relationship with economic thresholds, the dynamic nature of pests and natural enemies temporally and spatially; and the lack of taxonomic resolution for individual species (Macfadyen *et al.* 2019), incorporating IPM into practice is extremely challenging.

Other key tactics within an IPM framework include resistance management strategies that attempt to limit the number of pest generations exposed to particular insecticides or groups of insecticides. This may be done by restricting the number of sprays from within an insecticide group that are applied per season (or other specified period) and by controlling the number of insecticides applied to individual crops (Brier *et al.* 2008; Cotton CRC Development and Delivery Team 2010; Holloway 2002; Holloway *et al.* 2008). The introduction of insecticide resistance strategies has proven essential in the cotton industry where insecticide resistance to *Helicoverpa* spp. remains a constant threat (Cotton CRC Development and Delivery Team 2010; Fitt 1994a; Wilson *et al.* 1982; Wilson *et al.* 2010).

The IPM framework has further led to a focus on Area-wide Management strategies that attempt to coordinate pest management strategies across an entire pest population (or multiple pest populations) within a biologically relevant geographic or spatial area (Coll and Wajnberg 2017; Zalucki *et al.* 1986). Area-wide strategies acknowledge that pest populations are both mobile and have varying vulnerabilities according to what part of the pest's life cycle is targeted (Zalucki *et al.* 2009). This requires communication between growers in order to identify and achieve a common goal integral to area-wide strategies. As an example of this, it is more strategically beneficial to focus on management actions in areas where larvae develop and can be readily controlled before dispersal and breeding. Similarly, integrated pest management actions may be more effective if they can be applied at a larger scale. For example, an area may allow the build-up of beneficial insects within the system by adhering to pest thresholds and delaying or avoiding the application of disruptive chemicals. Similarly, trap-crops (e.g., chickpeas or other legumes) may be used to divert and capture *Helicoverpa* spp. during early spring or late summer when these species experience bottlenecks in host-plant availability (Deutscher *et al.* 2005; Grundy *et al.* 2004; Sequeira and Playford 2001a; 2002). Whilst area-wide management has significant benefits in terms of its ability to target pest populations at their most vulnerable life stage, it requires planning, a long-term commitment and a widespread understanding of the biology and ecology of pest populations as well as that of the broader agro-ecosystem in which they reside.

RESEARCH AND COMMUNICATION STRATEGY

Integrated Pest Management and Area-wide Management are well known and supported in the Australian horticultural (Smith *et al.* 1997; Williams 2000) and cotton industries (Cotton CRC Development and Delivery Team 2010; Fitt *et al.* 2009; Fitt 1994; Fitt 2000; Wilson *et al.* 2010; Zalucki *et al.* 2009). Similar levels of IPM adoption have long been desirable within the grains industry. To this end, the Grains Research and Development Corporation (GRDC) co-ordinates and funds research and extension activities that support IPM in the grains industry (Rainbow *et al.* 2010).

Existing support for IPM

The content and direction of IPM training, information services and extension activities in the grains industry vary somewhat according to the grain-growing region. This is in part due to different imperatives and motivations for IPM extension between the northern, western and southern regions. In the grains industry, interest in IPM extension activities has tended to be directed by current research interests, grower groups and extrinsic driving forces such as emerging resistance to insecticides, climatic pressures, cropping systems, or changing farming practices. Overall, there has been little impetus for widespread practice change in the absence of direct driving forces leading to IPM adoption.

Barriers to IPM adoption

Implementing IPM practices and maintaining practice change at a paddock or whole-farm scale is a significant challenge within the grains industry, this is particularly the case if we include broader AWM network-based strategies. At a regional level, on-ground IPM and AWM implementation remains relatively low. One of the main obstacles to implementation is the complexity of crop diversity and rotational systems within grain farming systems and agro-ecosystems. For IPM or AWM to be effective in grains, it must be able to deal at a regionally-specific scale with a variety of pests and pest assemblages both within and among different crops. IPM strategies also need to be able to take into account past cropping history whilst anticipating future cropping requirements, seasonal conditions, landscape influences such as surrounding habitat, weed presence, soil type and control history (Holloway *et al.* 2008; Horne *et al.* 2008; Rainbow *et al.* 2010). These difficulties are overlaid by the challenges presented by a highly variable climate (especially rainfall), differing market requirements specifying acceptable levels of pest damage and an enormous diversity of insect and other invertebrate pests and beneficial species (Brier *et al.* 2008). Additionally, low cost, highly effective synthetic insecticides enables the widespread use of prophylactic or "insurance" sprays in the grains industry, and this is a significant barrier to IPM. Thus, for many broadacre crops there is an entrenched "spray and forget" culture that is reinforced by a perception that insecticide application is the lower risk, it is less complicated and is a higher-yielding option for invertebrate pest control (Horne *et al.* 2008). Within this context, there is often little motivation to implement IPM strategies until other options are exhausted. However, there is now a growing recognition within the industry that heavy reliance on prophylactic broad-spectrum "insurance" sprays of insecticides and fungicides are raising the risk of insecticide resistance (Umina *et al.* 2019).

Extension activities and workshops

There are a number of IPM training and extension activities that aim to assist in the implementation of on-ground practice change within grain systems. Because of the complexity of IPM and the regional-specific nature of many of IPM strategies, such capacity-building activities are imperative if confidence in an IPM framework is to be established. These activities give advisors and growers the confidence and skills to implement an IPM framework on their properties. An additional advantage to these activities (i.e. workshops and field days) is their ability to facilitate the development of regional networks that can assist in the establishment of AWM groups as well as on-going information-support for IPM in the area. The workshops give agronomists and growers a personal introduction to support personnel (i.e. researchers and extension people) which then encourages the further utilisation of these support services – i.e. queries, discussing emerging issues and utilising insect identification services. These activities are typically developed and run by University or industry-based research groups and overseen by Government or Industry associations.

Efforts by the National Invertebrate Pest Initiative (NIPI) and the GRDC to formalise pest insect identification and IPM training and extension activities in the southern and western grains regions have resulted in the production of the *I SPY: Insects of Southern Australian Broadacre Farming Systems Identification manual and Education Resource* (Bellati et al. 2018). The *I Spy* manual was originally a collaborative effort compiled by staff from the South Australian Research and Development Institute (SARDI), the Department of Agriculture and Food Western Australia (DAFWA), the Centre for Environmental Stress and Adaptation Research (CESAR) from the University of Melbourne (Bellati *et al.* 2010). *I SPY* (Bellati *et al.* 2018) currently provides the most comprehensive information on basic taxonomy and insect identification, common pest and beneficial species, IPM, monitoring, sampling, the application of economic thresholds and biosecurity in Australia, and is also updated and available free of charge (as of March 2020).

Northern NSW grain-growing region

The northern grain-growing region has actively promoted IPM in grain cropping systems for over thirty years (Charleston 2009). In the period up to and including 2009, 14 soybean and mungbean IPM workshops were held and pest management modules were developed and delivered as part of 19 mungbean, ten chickpea and four sunflower workshops (Charleston *et al.* 2009). The course content predominantly targeted agronomists, consultants and growers. These courses have identified significant gaps in the IPM capacity of the northern grain region and have highlighted the need for ongoing training in insect identification and IPM (Brier *et al.* 2008; Charleston *et al.* 2009). From these experiences, extension activities and workshops specific to the northern NSW grain cropping situation also developed into a University of New England project: *Introduction and Extension of IPM in Northern NSW* (2009-2011). The workshops run by the UNE project built on the work already undertaken in the northern region by focussing on the on-ground implementation of IPM, techniques for insect identification and role of beneficial insects in cropping systems.

Initiating a Research and Communication strategy

In order to motivate growers and advisors to change entrenched management practices, it is essential that the benefits of IPM are clearly articulated. This is important in the context of the clarity and relevance of the science, but also in terms of economic and environmental benefits that a movement towards more IPM-friendly practices bestows. Despite these many benefits, we need to recognise that in the adoption of any new on-farm management practices there are also difficulties and potential costs. The multiple changes to management practices required by IPM will, for example, require increased investment as a result of added time and complexity in decision-making processes. There may also be additional costs in crop monitoring and staff training as well as elevated costs associated with selective insecticides, crop rotations, biological control or investment in new technologies. Ultimately, however, farmers will assess their decision to adopt IPM within the context of benefits weighed against perception of overall risk. As such on-ground benefits will vary markedly between cropping systems and will be perceived differently amongst individual farmers. It is timely then to facilitate more active involvement of growers and advisor interest in adopting an IPM framework. Whilst there is no question that the risks associated with any new on-farm practice need to be managed appropriately, existing knowledge of IPM is on the whole well-established and sufficient for the commencement of on-farm IPM in most cropping situations (Rainbow *et al.* 2010). This approach is consistent with the findings of recent work undertaken by Horne *et al.* (2008) in developing and implementing IPM strategies in broadacre crops in Victoria.

Horne *et al.* (2008) emphasise the importance of a collaborative approach between farmers, agronomists and entomologists that focus on local demonstrations and the facilitation of information networks that empower local agronomists with IPM decision-support and training. Key to this is the willingness of growers to be involved in farm-scale trials concurrent with the availability of one-on-one in-field support systems by experts, over multiple years (Bajwa and Kogan 2003; Horne *et al.* 2008; Horne *et al.* 1999; Olsen *et al.* 2003). This approach recognises that IPM is complex and its successful implementation relies not only acknowledging what has already been done, but on continued expert support to assist agronomists and growers in interpreting information. To this end, decision support tools and efforts to simplify information is imperative (Horne *et al.* 2008).

FACILITATING PRACTICE CHANGE IN PEST MANAGEMENT – IPM WORKSHOPS AND EXTENSION ACTIVITIES

In essence, to maximise the benefits of IPM, farmers and agronomists need to be given the tools to identify and manage risks that may arise as a result of taking on new farming practices. Face-to-face workshops offer an active forum in which to acknowledge and address some of the perceived complexities of IPM. They also represent a valuable opportunity for researchers and extension staff to interact directly with growers and agronomists and as such provide a number of benefits to both growers/advisors and researchers. For researchers, they help to identify where IPM research needs to be more targeted and assist them in addressing some of the on-ground realities of implementation as well as providing a means of obtaining feedback on material being presented or even the work currently underway. They can also be used as a way to make initial contact and build trust and credibility with a variety of stakeholders, whilst offering a service that is useful to them. Workshops also have the potential to bring a variety of different participants together to share experiences and discuss the practicalities of implementing IPM in an on-farm situation. They can deliver a significant change in the confidence of course participants in managing pests whilst emphasising the importance of building confidence in insect identification and decision making (Charleston *et al.* 2009).

Pest management practices in Australian grains survey

Also relevant to the northern grain region is a recent survey on pest management practices in Australian grains conducted by researchers at the University of Western Australia (January-June 2011, n=185, agronomists/advisors=144; growers=41) (Spafford 2011). The survey revealed an excellent understanding of what IPM is with 94.4% of respondents identifying IPM as using multiple approaches including careful use of insecticides to manage pests. Survey responses identified resistance issues (19%), pest identification (15%), economic thresholds (14%) and insecticides issues (overuse of broad-spectrum; too cheap; no cheap selective insecticide; application issues; residual impacts; efficacy) (12.5%) as the top four pest management problems.

Interestingly, the survey identified some IPM strategies as already being utilised on-farm, with agronomists/advisors recommending that farmers use selective insecticides (86.1%), remove and/or destroy host plants using herbicide (72.2%) and select crop varieties resistant to pests (60.4%). Unfortunately, other IPM-friendly strategies such as providing alternative habitat for beneficial insects (13.2%), using biological control agents (9.7%) and use of biopesticides (27.1%) remain well below recommendations to use broad-spectrum insecticides (53.5%). This is despite 17.4% of advisors always recommending IPM to farmers and 40.3% mostly and 35.4% sometimes recommending it (Spafford 2011). The survey also offers an interesting insight into the decision-making processes underlying the choice of prophylactic spraying. Overall, there appears to be a strong indicator that IPM strategies are perceived of as being a “riskier” pest management strategy than prophylactic spraying. Of interest also is the relatively low proportion of advisors who have an intrinsically negative response to monitoring and IPM *per se*. Indeed, only 0.7% indicated that they recommended prophylactic spraying because they lacked overall confidence in monitoring, or that monitoring for pests is too time consuming (9%), whilst only 2.8% never recommended IPM to farmers and 4.2% only rarely recommended it. Unfortunately, few advisors had a high level of confidence in their ability to identify pest species (14.6%) with most indicating that they had only medium (36.1%) to medium-high (35.4%) confidence. This confidence became somewhat lower when asked about their confidence in identifying beneficial species with only 10.4% having high or medium-high confidence (16.7%), with most having medium (36.1%) or low-medium (25.7%) confidence. This is despite 43.1% of advisors having attended pest identification workshops in the past 1-5 years and 20.8% attending in the previous 12 months. These results strongly suggest that ongoing information and extension support is needed to assist advisors on their pest insect and beneficial insect identification.

DEVELOPMENT OF A RESEARCH AND COMMUNICATION STRATEGY

In order to provide substantive support for growers and advisors, the Research and Communication strategy identifies opportunities for research in the northern NSW grain region and suggests ways that IPM can best be communicated to assist with adoption. Consultation with growers, advisors and industry stakeholders has identified a number of areas not fully developed in the grain industry in Northern NSW. The strategy acknowledges the effects of changing land management practices and the effects of climate change on pest assemblages in the region as well as increased levels of uncertainty associated with the management of invertebrate pests in the grain region. To both identify research gaps and to target workshops most effectively for the target audience, we undertook consultation with grower groups and industry and research stakeholders including, the Northern Growers' Alliance (NGA), Grain Orana Alliance (GOA), GRDC, CRDC, NSW DPI, DEEDI as well as workshop participants and local growers and agronomists.

The initial focus of the *Introduction and Extension of IPM in Northern NSW* project was on providing an insect/pest identification service that could be used to support on-farm IPM decisions. This was in part a response to a lack of support for insect identification services, particularly in the northern NSW area, as well as a perception that there was little information-support for less experienced agronomists. This was very much in keeping with the project funding requirements to provide a pest identification service to NSW. In order to provide on-line support and provide a point of contact for the insect identification service, the project provided blog-style updates (*The Sweep Net*) on pest and IPM issues of interest to growers and agronomists in the area. Ultimately, while many people viewed this site (Google Analytics), there were only around 50 actual subscribers. There were likely to be two reasons for this low level of interest, firstly that *The Sweep Net* was competing with the better-known and more comprehensive (because of experience and funding level) *Beat Sheet* and secondly, there was a general feeling that people were overwhelmed by web-based information. This second point is highlighted in the move, and concomitant favourable response to emerging "app" technology for smartphones and tablets. Whilst the pest identification service and *The Sweep Net* has continued, the project has expanded to offer more in the way of providing workshops and extension activities aimed at improving grower's and agronomist's interest and capacity to implement IPM strategies on their properties. The workshops in particular, focussed on insect identification, but during the course of those workshops discussion around IPM issues was encouraged. This worked very well owing to the small size of the groups and the fact that in that informal environment people were open to ideas and contributed willingly to discussion about insect management and IPM related issues. It often helped when workshops were targeted just within one workplace (as an example Landmark), or very much within a local area. In that environment again people were comfortable discussing IPM issues openly among their peers. The particular focus of these workshops also was largely in response to consultation with the above mentioned growers' groups as well as other industry and research groups relevant to the project.

The workshops highlighted the fact that in the absence of good entomological knowledge, agronomists and advisors appear to be "going it alone" and in many instances choosing what is perceived to be the "lower risk" option of chemical application to manage uncertainty surrounding insect pests – again it is an agronomists ultimate responsibility which further feeds the idea of taking the "lower risk" option. Related to this is a lack of confidence in "holding off" spraying until threshold levels are reached or "going soft early" with insecticide application because of a lack of research, data and case studies. Similarly, there is a perception that IPM strategies are overly complicated, or that information (particularly when it comes to incorporating thresholds across multiple cropping systems), is confusing or even conflicting. There also appears to be insufficient information about the on-ground incorporation of beneficial species into an overall IPM strategy. For example, there are very few reliable pest to beneficial species ratios or thresholds that incorporate multi-pest assemblages and their interactions with beneficial insects.

As a result, we presented a series of workshops that aim to increase knowledge of pest species, natural enemies and IPM strategies in the northern NSW grain-growing region. The workshops and extension activities were constructed to provide the sort of base-line entomological knowledge needed for the successful on-ground application of IPM. As such, the workshop material gave attendees a general overview of insect biology and ecology and topics include information about what constitutes an insect and the roles insects have in an agricultural ecosystem with some focus on the sort of insect/plant interactions that occur over and above that of plant versus pest.

The workshop material was structured into two main parts. The first part consisted of basic insect biology including ecological roles, the importance of insects overall in the agro-ecosystem, then there is a minor focus on taxonomy with anatomy (mouthparts, wings, legs etc) being covered in more detail in order to assist in the correct identification of pest and beneficial species relevant to the grains industry. The second part of the workshop went through the major groupings of insects that are relevant in an agricultural ecosystem and includes information on their role in the ecosystem including feeding strategies, habitat, life and reproductive stages etc. Information delivery is supported by photographs and insect specimens that are relevant to grain crops in the northern region of NSW. Throughout this second part of the workshop, questions and discussion among the group was encouraged and facilitated by the presenter and through this process, factors relevant to IPM such as thresholds, impacts of beneficial species, landscape level action such as area-wide management and the development of (or management of) areas of native and certain non-crop vegetation to enhance pest control are covered.

As part of the workshop process there are numerous opportunities to offer a formal evaluation of how practice change is being implemented in response to IPM workshops and activities. Tracking active learning including (McCoy *et al.* 2018) the use of technology including TurningPoint® Audience Response Systems (Keepad Interactive, Sydney) are being increasingly used to assist in quantifying audience knowledge, learning and feedback (Bellati *et al.* 2009; Charleston *et al.* 2009). Through such feedback and evaluation mechanisms, workshops are able to be more effectively targeted to the requirements of workshop participants, provide feedback to researchers and evaluate responses prior to and subsequent to the workshop to ensure that knowledge has improved during the course of the workshop (Baker *et al.* 2015).

In order to ensure that the workshops are suitably targeted to the requirements of agronomists and growers, we incorporated "Keepad" Turning point technology to get instantaneous feedback on workshop content, IPM and insect control issues. From this, we have been able to gauge pre-existing, and subsequent, levels of knowledge from workshop participants. Feedback from growers and agronomists attending *The Sweep Net* workshops has been positive and at the conclusion of the workshops, participants reported greater knowledge and confidence, particularly in identifying beneficial insects and their larvae. In general, we found that although advisors and growers typically have good field-based experience in identification of commonly sighted, prominent species (75%), most had much more difficulty in identifying less prominent pest and beneficial species (24%) (data taken from eight workshops with a total of 71 participants). Moreover, most growers and advisors reported a relatively low level of confidence in identifying pest insects overall with an even lower confidence when asked about beneficial insects in particular (Figure 1). These results are very similar to that of Charleston *et al.* (2009) who found that 75% of consultants were unable to identify 50% of key insects found in mungbean crops with a particular difficulty in distinguishing caterpillars. Similarly, minor pests and natural enemies/beneficial species were not well known or accurately identified by the groups (Charleston *et al.* 2009). Interestingly, a similar lack of confidence in the identification of beneficial species was shown in the *Pest Management in Australian Grain Production survey*, with most agronomists indicating a low-medium (26%) to medium (36%) confidence in their ability. This can be compared with a medium (36%) to medium-high (35%) confidence in pest identification (Spafford 2011).

Clearly, difficulties in identifying pest and beneficial species are persistent amongst grain growers and their advisors (e.g., ladybird pupae, wasps, *Trichopoda* eggs, shield bugs). This presents some obvious difficulties when it comes to successful IPM application. The fact that this was a problem was demonstrated when experienced agronomists who were interested in IPM were not readily familiar with insects such as ladybird pupae in the field. Where agronomists had worked in cotton their knowledge and familiarity with beneficial insects was generally a lot better. Similarly, some of the key weapons within an IPM framework gain much of their benefit from their target specificity and their low or minimal impact on non-target or beneficial species.

Although it is still available in a very much reduced form, workshop participants have regularly identified a perceived reduction in government agency support for insect identification services in northern NSW with approximately 85% of participants suggesting that not only does a specialised insect identification service need to be available to support identification of agricultural pests, but that ongoing formalised training is required to adequately support future IPM activities in the grains industry. Currently, less experienced agronomists consult with more experienced ones

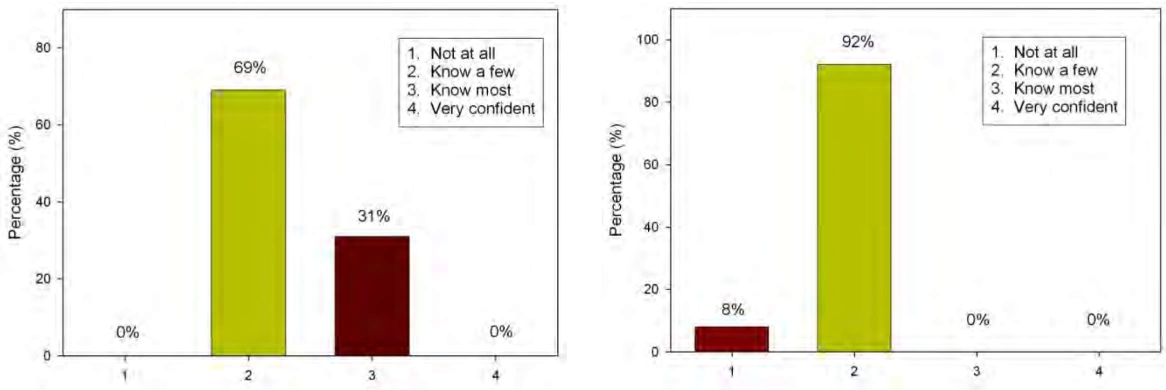

Figure 1. Confidence in identifying common crop insects (left) and common beneficial species (right) prior to commencement of workshops.

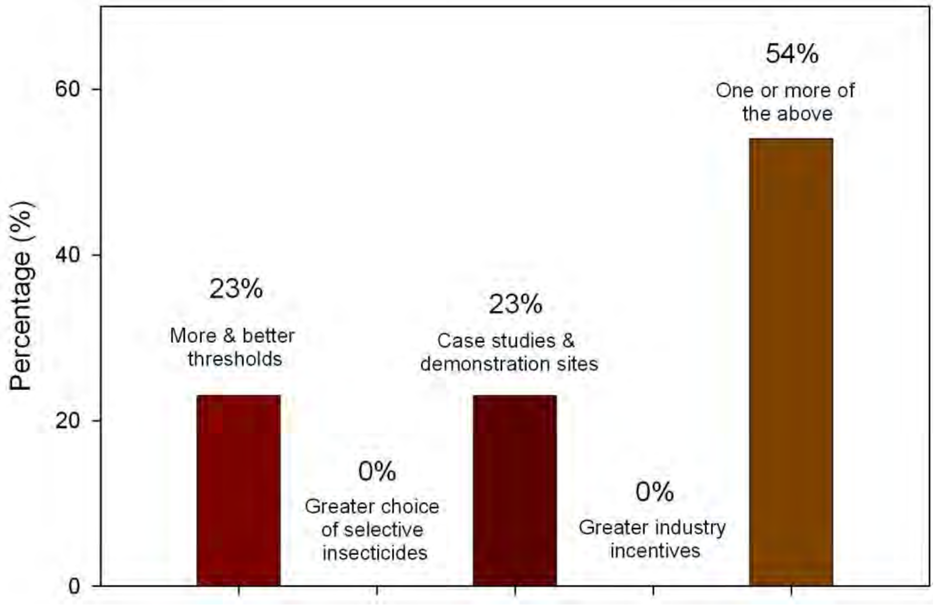

Figure 2. Support requirements for IPM strategies in the northern NSW grain-growing region. Percentage of workshop participants.

rather than going to an expert (Carol Sanson *pers. comm.*) and although this is an effective strategy immediately, it is clear from the workshops that many of the more experienced agronomists are barely familiar with very small predators such as pirate bugs, damsel bugs, big-eyed bugs and small parasitic wasps, and that workshops run by specialists are invaluable in allowing agronomists (experienced and otherwise) to get their "eye in" to these small insects. There are opportunities for an accreditation-style program that allows for advisors and growers to progress through increasingly detailed or specifically targeted programs, however, it is possible that the level of interest, at least in northern NSW, is insufficient to warrant this.

Insect identification services and IPM support

Despite such problems, approximately 43% of growers and advisors surveyed in the workshops have had either rudimentary formal training in insect identification, or have received some degree of on-going training or support within in the past five years. Most people have volunteered that even with reasonable recent formal training, it is valuable to get a revision as well as a training course that has directly applicable content. There are, as such, numerous opportunities to build-on and direct existing baseline knowledge in the form of insect identification workshops that consolidate or update growers and advisors as part of ongoing programs offering IPM support. As part of this we have found that it has been helpful to offer workshop participants an overview of insect orders and key morphological features in order to aid identification prior to presenting details on how this knowledge can be incorporated to an on-farm IPM framework.

Following these results, workshop participants were asked to indicate areas where they felt they needed more information or where additional IPM-related training and industry support would be desirable. Key areas of interest include assistance with IPM-based decision making, more and better economic threshold information including pest to beneficial ratios, support for insect identification, case studies and demonstration sites and more information on interactions between pests and beneficial species at a whole community level. When surveyed workshop participants identified key support requirements as the provision of more and better economic thresholds, more case studies and demonstration sites or ideally, a combination of these (Figure 2). Additionally, verbal responses to the idea of a Smartphone application, such as MyPestGuide (https://www.agric.wa.gov.au/pests-weeds-diseases/mypestguide) for insect identification have been welcomed with enthusiasm.

Extension activities

Through the course of *The Introduction and Extension of IPM in northern NSW* project, we found that targeting smaller areas with workshops of short duration (3-4 hours) in a small group worked extremely well. One of the barriers to training people was that of competing with other demands on their time, particularly agronomists. This is especially true with cropping because of the need to be adaptable with activities in response to weather; and especially so in the northern region because of the double-cropping nature of the region. Workshops are one of the key ways that farmers prefer to receive up-to-date information (Arbuckle 2016; Archibald *et al.* 2017).

Where workshops were kept small and informal, it required less preparation time, less logistical costs such as the hiring of large venues, and if people were unable to make it at the last minute, they did not feel awkward about pulling out as it was still worthwhile to run a workshop for small groups. This resulted in ongoing positive communication between extension people and agronomists/growers and ensured that workshops were run regularly. Another advantage of conducting smaller workshops for targeted groups of interested growers and advisors is that each workshop can be targeted to individual groups in terms of content and delivery method. There are also opportunities to do follow-up extension activities that incorporate field-based practical components and in-crop visits into the workshops, and this remains specific to a particular local area. These have been run on an "as required" basis in the Glen Innes and Dubbo regions.

Reflections on the project

Whilst growers and agronomists were in general very favourable about maintaining an insect identification service for the northern grain growing region (85% of those surveyed), when such a service existed, there were in fact very few specimens actually submitted to *The Sweep Net* for identification (n = 8). Having an insect identification service available appeared to be something that was perceived to be important "just in case". Whilst this makes sense from a biosecurity point of view, such a service may only be sustainable if significant gains in terms of additional IPM support ("value-adding") can be made. In western Nebraska, USA, farmers more often relied on crop consultants to identify insects and have an understanding of management implications, than to learn themselves (Archibald *et al.* 2017). For this project, we found that having an insect identification service available worked well where there were existing relationships with growers or agronomists. Indeed, although there is a perceived reduction of government agency support for insect identification services there appeared to be little impetus for growers and agronomists to actively seek out services themselves through internet searches, in response to media articles and promotions, or even word of mouth. Additionally, there appeared to be significant barriers for growers and advisors to physically collect specimens to send in for identification. This particular issue was addressed in part in the workshops simply by showing an example of a very simple, small glove box style insect collecting kit. It was much more common for photographs to be sent in, rather than samples. This appeared to be in part in response to a lack of collecting material out in the field, but also likely to do with an expectation that most common pest species would be able to be easily identified through their gross appearance rather than through finer morphological differences. This is perhaps in part the result of a lack of understanding of the fine examination of morphological and taxonomic details needed for correct identification of many species. Again, this issue could be addressed/discussed during the workshops.

Another benefit of the shorter, more informal approach to workshop delivery was that there was less tendency to overload attendees with excessive information. Indeed Charleston *et al.* (2009) commented on this stating that "top-down" research approach of delivering material on thresholds, monitoring, identification, biology and ecology tended to overload workshop participants with too much information. In *The Sweep Net* workshops simple, essential material provided the backbone of the session and further details were often "fleshed out" with informal discussions in the more structured part of the workshop and/or around a cup of tea. Again, having a smaller group generally meant that people were more comfortable participating in discussions. Interestingly, people in the group who were the most sceptical about IPM frequently initiated the most effective discussions.

Importantly, once people had gained a "point of contact" from the workshops, it was often the case that they would make phone or email enquiries later on. Other areas of interest for more information included decision-making, pest beneficial ratios, and whole community information.

From the workshops, it is apparent that there are many growers/agronomists who would like to use more sustainable pest management techniques, but require: a) a simplified message for IPM and TAFE; and b) appropriate tools such as greater availability of selective insecticides. As part of this, support for monitoring in the early stages of IPM implementation by services such as *The Sweep Net* is also needed in order to counter the initial inertia associated with putting in place a comprehensive on-farm monitoring strategy.

Something that was very apparent through the course of the project was the importance of building networks and trust and confidence in service personnel. By mid-2011 (the final six-months of the project) it was clear that people were enthusiastic about the service and we were able to run twelve workshops during that time.

RESEARCH GAPS

IPM is often already incorporated into management of crops in some form without being formally identified, but if a fully developed IPM plan is developed, it is often considered to be too hard or too much of a complete pack to incorporate into day to day practices. This is where IPM would potentially be better re-labelled as "best practice" or something similar. If discussing 'IPM' to growers, usig this particular label can put its usage into a category where growers think that IPM is just one more thing they need to learn; whereas if labelled 'best-practice', growers are given a sense that they're probably already on the road to doing it. Most farmers and agronomists are already aware about IPM as well as AWM and aware that everyone needs to be involved. Good management practices introduced independently. Areas of interest then feed into a research strategy.

With the long-term development of cotton research in the northern region over the last few decades there has already been a lot of research carried out (e.g. CRDC 2019) where knowledge transfer can be integrated into grains insect pest/beneficial research. Some additional specific areas of research that would be promising:

1. Impact of no tillage practices on pest and beneficial insect populations – currently there is a generalised perception that no till increase populations of some insect pests. However pests such as millipedes (CESAR 2017) and European earwigs (CESAR 2019) are known to become pests in no-till systems in the southern grains aeras of Australia. Clearly an assessment of species and population numbers need to be assessed in no-till areas to identify the benefits/ costs of no-till. eg. Does no-till support slugs and crickets more than predators and parasitoids, or is the balance tipped the other way?

2. Are aphids developing resistance to Neonicotinoids? Chemical resistance is always a huge problem, and the amount of resistance within and across populations needs to be identified, so remedial management can be implemented (if quickly enough) to reduce rapid resistance occurring throughout populations. Green Peach Aphid resistance to neonicotinoid insecticides was detected in the southern grain systems in 2017 (Macdougall 2018), and neonictinoids are being found carried in dust, water runoff, and buildup in bee hives (Thomas Heddle pers comm).

Specifically, growers identified a number of dominant themes and questions from the workshop presentations:

- Increasing confidence in IPM could be achieved through the development of case studies;
- People want to know about beneficial to pest ratios and want specific figures to work with;
- Concerns about Rutherglen bug and other sucking pests and in particular the lack of non broad-spectrum control agents;
- Information on the effectiveness of parasitoids and beneficial insects in cropping systems;
- Concerns about other emergent pests;
- More IPM information about plant diseases and their insect vectors; and
- More information that better encompasses pest assemblages and multi-pest interactions into IPM thresholds.

Initial areas of interest include sucking pests in broadleaf crops, emergent pests, resistance issues, pest thresholds, the role and effectiveness of parasitoids and beneficial insects in cropping systems. Developing thresholds for pests is one of the biggest areas that growers identify as the greatest restrictions to implementing IPM. So enhancement of threshold information and the use of case studies where they are implemented and natural enemy interactions are developed would be most useful for direct implementation of IPM for growers.

CONCLUSIONS

The Northern NSW grain-growing region has a strong history of Integrated Pest Management (IPM) and extension within the grains industry. Despite this, there is a persistent perception that on-farm implementation of IPM strategies is too complex for routine adoption across multiple crops and across the whole farm system. This situation is exacerbated by environmental variability, changes to farming and land management practices, as well as the overarching impacts of climate change. If increases in the adoption of IPM in the grains industry are to be achieved, it is imperative that agronomists and growers are supported by simplified messages, up-to-date information on emergent pests and assistance in incorporating IPM into existing farming practices.

Key to the successful practice of IPM is the ability of advisors and growers to be able to monitor pest activity below threshold levels and have the knowledge and tools necessary to quickly identify the pest, beneficial or neutral insects within cropping systems. With this information, growers can reduce reliance on prophylactic broad-spectrum insecticides as well as increase their understanding of a "whole system" management approach in managing pest insects. This will be invaluable in understanding potential changes in pest assemblages in response to differing management practices and a changing climate.

In order to support advisors and growers in the Northern NSW grain growing region, *The Sweep Net*, held information sessions on insect pest identification and the role of beneficial insects within cropping systems. These sessions had a focus on the ways in which this information can assist in the implementation of on-farm IPM strategies. Sessions were targeted mainly at agronomists, but interested growers were also welcome. The natural evolution of these workshops were practical assistance for on-farm insect identification and monitoring within cropping seasons.

The Sweep Net offered an insect pest identification service and a web-based information service and "blog" called *The Sweep Net*. This was a free service to grain growers and advisors. *The Sweep Net* website and blog gives a point of contact for the insect identification service and provides information on emergent pest issues, beneficial insects and IPM to advisors and growers. *The Sweep Net* supported the expansion of advisor and grower networks to facilitate information- sharing and extension activities between agronomists and grower groups and offers a platform for advisors and growers to submit or obtain information on emergent pests or issues relevant to IPM.

The communication and research strategy has identified areas that are not fully developed within the context of IPM, changing land management practices and climate change. As part of this strategy and in order to ensure that the workshops and extension activities are meeting the needs of advisors and growers, the project has identified opportunities for research that offer targeted scientific support to IPM strategies. Feedback from users of the service has indicated that more "case study" style examples, and therefore confidence, of the benefits of IPM are needed. To this end we conducted research in three main areas: (i) a field-based monitoring study of beneficial insect activity in soy and sorghum crops; (ii) an investigation into important food-web interactions underlying IPM systems (assessing beneficial insects: pollinators and parasitoids); and (iii) assessment of pathogens and parasitoids on a major pest species (Rutherglen Bug) under a variable climate. Future research into better understanding and implementation of pest thresholds, the benefits of Area Wide Management, pollinators and threats to their efficiency, and the biological responses of pests and natural enemies to a rapidly changing climate were identified as key research areas into the future of IPM in northern NSW.

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