Is sustainable intensification of cropping systems achievable?

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Keywords

- sustainable intensification, sustainability, system change, regeneration, diversification, resilience.

Take home messages

- Sustainable intensification is based on **simultaneous** improvements in productivity and ecosystem health to underpin profitability.
- It is not more of what we are currently doing; it requires **significant system changes** towards greater diversification involving crops, forages, livestock, shrubs and trees.
- Regeneration of soil health; soil nitrogen, soil carbon and other key elements is required.
- Input use-efficiency, water use-efficiency, less energy-rich inputs, integrated pest management and better genetics are all essential components.
- The role of agronomists has changed; productivity, profitability, compliance **and sustainability**.

Background

In writing this paper I am drawing on over 50 years' experience working on sustainable agricultural systems, in Australia and in many countries around the world. When I commenced my career as a scientist in 1967 at Rutherglen, just 150km down the road from here, ley farming was at its peak and considered by many to be one of the most sustainable farming systems in the temperate world. Its implementation varied somewhat from farm to farm but in this region 'a third (sheep), a third (cattle), a third (crops)' was common in higher rainfall areas whilst 60% pasture/livestock and 40% crops, was common to just about every other farm. The system had worked well for over 40 years and at that time, we all; scientists and farmers, believed that it would 'go on forever'. By the end of the 1970s, to the astonishment of many, the demise of ley farming was well underway, for economic reasons; crops were more profitable than livestock and for biophysical reasons, as soil acidification, soil compaction and serious cereal root diseases significantly reduced the productivity and profitability of ley farming.

Since that time, I have witnessed three subsequent system changes:

1. 1970s onwards - Increased cropping but still in a ley farming framework, firstly in the high-rainfall traditional livestock producing regions; a trend which has continued to this day, but subsequently in traditional cropping regions as canola, lupins and field peas were introduced and shown to be complementary to wheat rather than competitive.
2. 1990s onwards - Intensive cropping using zero-till, residue retention, canola-wheat rotations (some pulses), nitrogen fertilisers and pesticides.
3. 2000s onwards – Sustainable intensification (SI) of farming systems, a pathway to more regenerative agriculture.

These transitions have occurred because our farming systems have needed to adapt to the ever-changing operating environment and are a clear example of the 'moving target' of sustainability. We are now at another significant turning point and this presentation makes a clarion call for system changes, underpinned by sustainable intensification, if the Australian grains industry is to remain viable and resilient to future climatic, economic and social shocks.

Grand challenges to food and nutritional security

Based on my extensive experience In Australia and overseas, I have identified five 'grand challenges' (Reeves 2017) to food and nutritional security which require urgent and greater attention from all key stakeholders, they are:

1. Degradation and loss of natural resources – land, water, air quality.
2. Adaptation to climate change – greater variability, extreme events.
3. Nitrogen use-(in)efficiency – N fertiliser efficiency averages around 50% only, this is not sustainable.
4. Food losses and waste – 30+% of food produced is lost or wasted.
5. Neglect of rural communities – farmers are the front line of the food security 'battle' and need a better operating environment and better technologies and 'tools'.

Each of the 'grand challenges' is both a global and a national issue and when combined they contribute to a 'perfect storm' for agriculture. To effectively address these and to nourish a global population still growing at around 150 people/minute and with changing dietary preferences, our current and future agri-food systems must provide more; more nutritious food, but from less land, with less water, less energy-rich inputs, less greenhouse gas emissions and all of this under the spectre of the 'multiplier effects' of climate change. Clearly 'business as usual' will not be acceptable and the world is now looking to the sustainable intensification of its agri-food systems to be able to 'produce more (or sufficient) with less'.

What does sustainable intensification of agriculture mean?

The underlying tenets of sustainable intensification are **simultaneous increases in agricultural productivity/profitability AND ecosystem health** and are largely aligned with other forms of regenerative agriculture. To achieve these dual imperatives, we need to continually improve the efficiency of our current farming systems and to develop new systems to sustainably produce 'more with less'.

There are five components of sustainable intensification which need to be effectively combined for maximum impacts. They are:

1. Conservation agriculture (CA) – minimum soil disturbance, mulches, integration of crops, forages, livestock, trees/shrubs/
2. Healthy soils – integrated soil nutrition management, building soil carbon (C) and nitrogen (N).
3. Improved crops/varieties/livestock/breeds – high productivity, input-use efficient, resistant/tolerant to abiotic and biotic stresses, more nutritious products.
4. Efficient water management – 'more crop per drop', reduced water use, system/landscape efficiency.
5. Integrated pest management – diverse systems, genetic resistance, judicious use of safer pesticides at the system, farm and landscape levels.

It could be argued that many of our farms are well advanced in these practices, and for some elements of CA for example, this is true. However, there are also many aspects where changes are needed; many cropping systems now lack diversity and the dominant canola-wheat rotation is highly likely to be unsustainable. Livestock are now absent on many farms; legume use has diminished, and whilst resultant N fertiliser use has increased, accumulated N deficits are steadily increasing in many soils across Australia. Soil C is also being depleted on many cropping farms and this combination of diminishing soil C and soil N levels needs urgent attention. For other components of sustainable intensification, genetic gains have slowed in some crops and forages; water-use efficiency still averages around 40% on many cropping farms; and resistant weeds and diseases are indicative of systems that are too dependent on pesticide use.

Enhancing sustainable intensification practices

Each component of sustainable intensification is important and can bring individual benefits, but it is their effective combination and integration that results in 'the whole being greater than the sum of the parts' or as Dr John Kirkegaard (2019) has described it, in 'incremental transformation'.

How can we further improve the five components of SI and integrate them more effectively?

Conservation agriculture

Australia has been and remains a leader in the development, adaptation and adoption of CA systems (NLA Trove 2016). However, there are clear signs that new and different directions need to be taken if CA is going to continue to effectively contribute to sustainable intensification. Greater system diversification is required. Canola-wheat rotations which now dominate southern cropping farms are not a diverse system. In addition, nitrogen use-efficiency still averages around 50% with the application of nitrogen fertilisers, and some of these losses are contributing to emissions of potent greenhouse gases. Recent research has shown that these losses can be reduced by the utilisation of more biologically fixed N from legumes; both pastures and pulses, as legume-fixed N is generally a less emissive form of N input than fertiliser N (NANORP 2012-2015). Pasture rotations which help to re-build soil C levels and in so doing sequester carbon dioxide, are absent from many farms and yet without them there is clear evidence that soil C/ organic matter (OM) levels are steadily declining in our farming systems.

Management options for greater, 'modernised' system diversification include:

- Improved soil management with minimal disturbance, surface and subsoil amendments where appropriate with lime, gypsum, organic materials and major macro-nutrients to stimulate soil biological activity and overall soil health.
- Greater range of crop options – wheat, barley, oats, triticale, millets, sorghums, maize, canola and various pulses and other legume options.
- More diverse crop varieties/species – range of planting times, flowering times and crop maturities, and with greater resistance to biotic stresses and tolerance of abiotic stresses (dryness, heat, frost).
- More diverse crop management – differential grazing/defoliation regimes, N timing and forms including more biologically fixed N, cover crops/mulches, differing stubble heights and spreading.
- Livestock integration for enhanced crop, residue, weed and pasture management and N cycling and for diversification of farm income streams.
- Incorporation of trees and shrubs to provide a range of ecosystem services, including shade and shelter for livestock as the incidence and magnitude of heat stress for animals is increasing as our temperatures rise and more 'high heat' days are experienced. Re-invigoration of 'adaptive agroforestry'.
- More innovative ideas that will require more research and evaluation, could include; sowing 'shandies' of crop varieties; companion cropping; strip cropping – alternate strips, of say a cereal and a pulse, side by side across the paddock, inter-cropping – different crops in different rows, 'fan' drones to aid frost protection, biopolymers for soils to reduce evaporation (and perhaps one day, to protect crops). Too futuristic? So were smart phones around 15 years ago...

Angus et al. (2015) provided an excellent review of the impacts of break crops on wheat yields based on more than 900 comparisons conducted across Australia and elsewhere and it is well worth reading.

Healthy soils

Soil health is defined as 'the capacity of the soil to function as a living system that sustains plant and animal productivity, maintains or enhances water and air quality, and promotes plant and animal health' (Doran and Zeiss 2000). Soil health and fertility are the 'engine room' of productivity, profitability and sustainability on farms and yet there are signs that our current intensive cropping systems are steadily depleting both soil N and soil C levels (Sanderman et al., 2010; Sanderman and Baldock, 2010; Lake 2012b). These are critical indicators of sustainability for our farming systems as the benefits arising from fertile, healthy soils are well recorded. In relation to soil C levels under intensive cropping, Baldock (2019) made the following salient points:

- Stocks of soil organic matter (SOM) and N are limited resources and current trends across Australian agricultural soils indicate that these are declining (Luo et al. 2010).

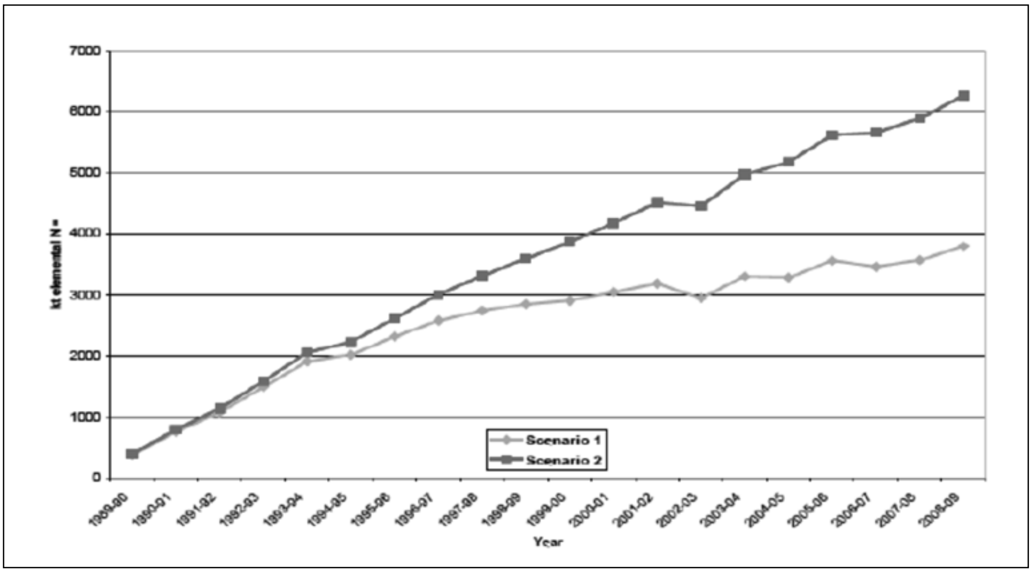

Figure 1. Accumulated nitrogen (N) deficits expressed as elemental N fertiliser equivalent in Australian temperate crop soils as estimated by two scenarios, Scenario 1 being the best possible case of N fertiliser usage on those crops and Scenario 2 being a more realistic assessment of likely N usage levels (Source: Lake 2012).

- Taking a long term (decadal) view on the economic implications is critical to ensure future productivity will not be compromised in an effort to maximise short term (annual) profits.

In addressing the steady and relentless decline in soil N (Figure 1) across our farming systems (Lake 2012b), Peoples et al (2017) and Lake (2012a) have both described the importance of including more legumes in these intensified systems, with the greatest impacts on soil N accretion resulting from pasture legume phases or 'brown manuring' of grain legumes.

This decline in soil N and C levels has stimulated me to look back at lessons from the past and in doing so reflect on the outstanding work on soil fertility of my long-time, now sadly passed colleague, Tony Ellington. His work at Rutherglen in the 1960s and 1970s, on soil N and OM accretion under clover pasture leys and its subsequent use by successive cereal crops reminds us that we have a number of well proven options to increase soil N, as Baldock (2019) has re-affirmed. I have reproduced here an original figure (Figure 2) (Ellington et al. 1979) and it is interesting to note that the clover-ley system that he used actually resulted in a 'spiralling up' of soil N levels despite the growing of four successive wheat crops after the five year pasture phase. This is in contrast to the 'spiralling down' trend that we are now experiencing on many farms; one could argue that these steady losses of soil N and C levels are a slow path to financial demise, where the largest impacts are likely to be endured by the next generation. Of course, as previously outlined, we know that the ley system broke down due to a number of biophysical and economic reasons. However, we now have ready solutions to these bio-physical problems and the economic returns from livestock have well and truly risen. There is evidence that in many regions, crop-livestock producers have fared better than crop-only producers during the tough seasons experienced in recent years as livestock have been a source of economic diversity and have helped to offset climatic and market risks, as well as helping to enhance soil health.

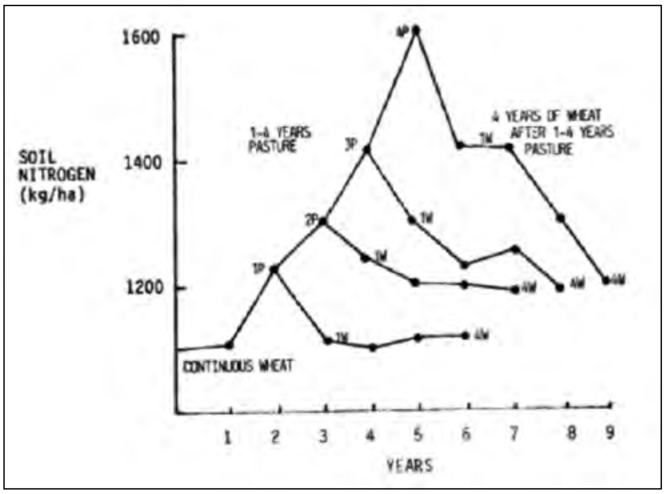

Figure 2. Soil nitrogen accretion under legume pastures (Source: Ellington et al. 1979).

Sustainable intensification and the future of farming is highly dependent on fertile, healthy soils and if we are to achieve the dual imperatives of enhanced productivity and ecosystem health then greater attention to our key resource, the soil, is urgently required.

Improved crops (and livestock)

Improved crop varieties are invariably used in our current systems and are an important component of sustainable intensification, now and in the future. It is however critical that greater emphasis is given to those genetic attributes that will boost the success of sustainable intensification systems. These include the continuing development of durable resistance to biotic stresses. For other important crop traits, the development and adoption of early sown winter wheats (Hunt et al. 2019) has been an exciting development and highly beneficial in helping many crop producers to adapt to changing climatic conditions, particularly the changed rainfall patterns of the past 25 years or so, where autumn and winter rainfall has declined and summer rainfall increased, in many parts of southern Australia.

However, the work of Flohr et al. (2018) is a reminder that constant attention is required to meet the changing needs of our evolving farming systems as she and her colleagues found that the rates of wheat variety yield increases in New South Wales (NSW) had plateaued since the 1980s; that flowering time was less stable in the modern varieties; and that vernalisation could become a more important trait in our wheat breeding programs. As perhaps a support to their conclusions that the rate of wheat yield increase had declined possibly due to an emphasis on quality related traits rather than yield per se, the performance of several imported feed quality wheats (Poole et al. 2018) has been quite remarkable in some regions.

Another important aspect of the use of a range of crop varieties for sustainable intensification and as a source of genetic diversity on farms, is the diversity between farms in a district or region. The genetic diversity between farms is often limited; for example, a single canola variety dominated around 70 to 80% of the planted area in north-east Victoria in 2018. From an industry perspective this is undesirable in terms of risk management and adds complexity to the decision making by growers and agronomists when selecting varieties. For sustainable intensification, decision making must move from paddock productivity, to system and farm productivity, and the latter also needs to take into account the landscapes and ecosystems in which the farm is located. Crop varieties/species with enhanced resistance/tolerance to abiotic and biotic stresses, with greater input-use efficiency; water, nutrients and elevated carbon dioxide, with greater adaptability to mixed farming systems; for example, graze and grain crops, and with greater nutritional value, are all required as a key component of sustainable intensification.

Efficient water management

Water use-efficiency on many Australian farms is high, but nationally, crop yield gaps; between potential water limited yields and actual yields, average around 30 to 40% (Kirkegaard et al. 2014) and so there is still significant scope for improvement, albeit with the need to take risk management into account. In his 2017 Farrer Oration (now also published as Kirkegaard 2019), John Kirkegaard emphasised the need for an integrated approach to enhancing water-use efficiency, citing that the combined impacts of better varieties adapted to earlier sowing and improved agronomy are necessary to achieve these greater efficiencies (Kirkegaard and Hunt 2010). These are also the principles of sustainable intensification, where system productivity and sustainability are the aims, rather than maximising the performance of one crop or livestock unit. An excellent example of system adaptation to achieve efficient water management is the widespread adoption of summer weed control in the rainfed cropping regions of southern Australia. (Hunt and Kirkegaard 2011).

Another even more recent example of system adaptation to rainfall changes is the re-introduction of long fallows into intensive cropping systems in a number of regions in southern Australia. The early adopters believe that the benefits of more timely seeding and management of the paddocks to be planted with crops and the 'income smoothing' effects resulting from fallowing are more than enough to offset 'lost production' incurred during the fallow period (pers comm; D. Cann and J. Hunt, GRDC Research Updates 2018). There is still further scope to improve water-use efficiency on farms through efficient combination of all of the components of sustainable intensification and this applies to both crop and livestock systems. Whilst, as described above, many cropping farmers have effectively utilised the increased falls of summer rainfall, there is less evidence of such adoption in some of the livestock industries.

Integrated pest, disease and weed management

The ever-increasing problems of herbicide resistant weeds are indicative of the need to further improve our integrated weed/pest management strategies and practices if sustainable intensification is to be successful. A weakness of our CA systems in Australia that underpin sustainable intensification, is the extensive reliance on herbicides to manage weeds, which has not only caused extensive resistance problems but also raises concerns over soil residues, environmental impacts and in some cases, the health of operators. In other regions of the world much more attention has been given to other ways of controlling weeds through the use of cover crops and other techniques such as relay-cropping (Rodriguez et al. 2013). We continually need to look at other options for weed management that involve more judicious use of herbicides.

Innovative research on microwave (MW) treatment of weed seed banks by my colleagues at the Dookie Campus of the University of Melbourne, may add to future options for resistant weed/weed seedbank management and for non-chemical weed control in mixed farming systems (for example, Khan et al. 2018). This work led by Dr Graham Brodie (Brodie et al. 2017) has been investigating the role of MW weed and soil treatments in agricultural systems for over a decade. Results have been very positive with significant reductions in weed seeds and weed numbers, beneficial impacts on soil fertility, and resultant wheat yield increases of around 25% after MW treatments. The technology is now being commercialised (with GRDC support) and likely to be available in the next couple of years.

Conclusion

In this paper I have addressed issues with current practices and identified potential solutions for their improvement and better contribution to sustainable intensification of our agricultural systems. These changes are necessary if our farms are to remain productive, profitable and sustainable. The clear message from my long experience is that agricultural sustainability is a 'moving target' and that no single system has remained sustainable, for one reason or another and nor will it, now or in the future. It is equally clear to me that a new 'revolution' of diversified farming based on the effective integration of crops, pastures, livestock, shrubs and trees together with diverse practices, is required to make farms more resilient financially, and to the increasing challenges of climate change and climate extremes. To achieve this resilience, it is also an imperative to build soil C and N content and soil health generally.

It also raises a further important point for those of us who are agronomists, where the role has evolved from a productivity focus in the past, to the current and future emphases on productivity, profitability, compliance **and sustainability**.

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Useful resources

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