THE LIVESTOCK PHENOTYPE REVOLUTION: ENABLING A STEP-CHANGE IN FARM MANAGEMENT AND SCIENTIFIC DISCOVERY

C.E.F. Clark[1], S.C. Garcia[1], K. Marshall[2], J.E. Pryce[3,4], P. Greenwood[5,6] and S. Lomax[1]

[1]School of Life and Environmental Sciences, Faculty of Science, University of Sydney, Camden, NSW, 2570 Australia
[2]School of Environmental and Rural Science, University of New England, Armidale, NSW, 2351 Australia
[3]Agriculture Victoria Research, AgriBio, Bundoora, Victoria, 3083 Australia
[4]School of Applied Systems Biology, La Trobe University, Bundoora, Victoria, 3083 Australia
[5]New South Wales Department of Primary Industries, Armidale Livestock Industries Centre, University of New England, Armidale NSW, 2351 Australia
[6]CSIRO Agriculture and Food, FD McMaster Laboratory Chiswick, Armidale, NSW, 2350 Australia

SUMMARY

Risks and challenges for the global agricultural industry are arising alongside well defined societal and environmental trends. Whilst genomic selection has historically enabled rapid genetic progress, new phenotypes are now required to fully unlock the power of genomics enabling the creation of robust, high welfare, agricultural systems. Here we reveal why technology is being adopted by industry to drive on-farm value, how these data are now generating new phenotypes and what phenotypes are being created now for the future. We propose to leverage these data to revolutionise current surveillance techniques enabling early warning of potential pest and disease outbreaks whilst also focusing industry extension to improve animal health. How the diversity in new phenotypes can be used for scientific discovery will also be revealed.

INTRODUCTION

Consumers now base their consumption decisions on a range of factors with a significant emphasis on provenance and animal welfare (Taylor and Signal 2009). Alongside these societal changes has been a shift towards larger, more intensive production systems. Technology is well placed to focus farmer attention to individual animals requiring intervention earlier than by visual diagnosis. Technology now not only has the capability to 'learn' from humans to 'observe' discrete behaviours but to remotely monitor individual plant and animal physiology and morphology. In this paper we describe how livestock phenotypes have evolved through time alongside those that are required for the sustainability and competitiveness of the Australian agricultural industry. Such phenotypes will revolutionise biosecurity surveillance and on-farm management in both developed and developing nations, and when collected and collated, enable significant scientific advancement and the creation of new advanced traits through genetic/genomic selection.

CONSUMER, LIVESTOCK INDUSTRY AND ENVIRONMENTAL TRENDS

'Resilient, profitable and competitive agricultural and rural industries need to actively consider what is coming and be well placed to respond' (Hajcowitz and Eady 2015). This review of the trends likely to impact rural industries over the next 20 years introduces the megatrends impacting Australian rural industries, namely the growing demand for food and fibre, climate and environmental change and the associated risk profile, increasing middle class wealth and shift in diet towards animal proteins, information empowered consumers and expectations and the rapid advances in digital technology and genetic science. Our global agricultural industry is thus tasked with increasing agricultural output by 70% to 2050 on a reduced land area due to urbanisation and desertification (Alexandratos and Bruisnma 2012). In value terms, the Australian Agriculture industry, through the National Farmers Federation, has set itself a target of increasing whole industry gross value from the current ~$60 billion to over $100 billion by 2030 (EY 2019). The same industry is consolidating into larger entities whilst rapidly moving towards a highly interconnected, globalised, production environment between consumer and producer. As such, the red meat industry has calculated a 3.5 billion risk related to the loss of society freedom to operate (RMAC 2017).

Alongside these risks and challenges will be the continued development of digital technologies enabling the detailed monitoring of livestock 24h per day (Molfino *et al*. 2017) and such technology will continue to rapidly reduce in cost. As an example, the generation of a watt through solar photovoltaics has reduced from $1,910 USD in 1956 to $0.82 in 2013 with a continued halving of cost every 5 years (Farmer and Lafond 2016). Such advancements in technology will be required to meet the complex, intersecting challenges posed above and at the forefront of these challenges will be the requirement for robust, high welfare, agricultural systems. These systems will be enabled through the creation and use of new phenotypes.

PHENOTYPES ENABLING A STEP CHANGE IN FARM MANAGEMENT

A phenotype is a set of observable characteristics of an individual resulting from the interaction of its genotype with the environment; which relates well to the origins of the word being to 'show type'. However, we have come from a time where the description of such phenotypes were derived from visual observation through to a time now where advancements in science and technology are now automating those processes and allowing new phenotypic data to be collected (Clark and Garcia 2016). New phenotypic data can be collected as technology now monitors the structure and function of the individual over durations that exceed human capability. For instance, small, frequent changes in a variable, changes occurring over considerable time periods or the internal function of the animal. Thus, we need to rethink the definition of phenotype. 'Observable', from physics, is a physical quantity that can be measured, so here we describe a phenotype as the set of physical quantities that characterise an individual resulting from the interaction of its genotype with the environment. In other words, data describing the structure and/or function of a body.

Such technology derived data required to generate new phenotypes is already being collected on farm. Lyons *et al*. (2016) highlights the vast differences in the type of technology adopted with technologies that collect and collate data and automatically implement actions such as automatic cup removers were more prevalent than those that generate data with no clear action, outcome or decision support system directly linked. These findings together suggest that it is not the technology *per se* that is limiting adoption by famers but the lack of decision support systems around them and the value that is derived from this technology on farm.

In the next 10 years we will also see new technologies implemented on farm in line with the advances made using machine learning and other techniques to reveal valuable new phenotypes. Gardenier *et al*. (2018) recently presented a robust, cost-effective perception system suitable for automatic lameness detection in dairy cattle. This system detected and localised performance for carpal/tarsal joints and hooves, along with tracking performance for hooves showing the capability of such techniques to autonomously record the structure and function related to the movement of animals.

Whilst this paper has so far focused on the value of new phenotypes using data from developed countries, phenotyping tools that are cheap, reliable and easy to use are required for developing countries. The use of such technologies would enable a step-change in farm management in developing countries shifting decades of agricultural research to such farms overnight. Wearable devices for remote recording of livestock health, movement and reproductive status are being tested in African systems but these are currently unaffordable by most farmers (Marshall *et al*. 2019). Increasing animal protein price due to increased population demand and wealth coupled with a rapidly declining technology price will create the opportunity to dramatically advance developing country livestock systems in the near future. Irrespective of whether the country be developed or developing, management value will continue to drive technology adoption on individual farms. A dedicated programme to collect and collate these data will enable the creation of new phenotypes not only for genetic selection but also for scientific discovery and biosecurity.

SCIENTIFIC DISCOVERY

The collection and collation of data to create new phenotypes presents a new approach to scientific discovery. Differences in phenotypes between animals has, and will continue to be, discovered through building the processes of an animal from the ground up; for instance, understanding metabolic and cell processes and interactions leading to differences in structure and function between individuals. Garner *et al*. (2016) provides an example of a different approach, where phenotypic diversity is firstly determined through the collection and collation of data. Extremes in phenotype are then sourced to enable break-through metabolic and physiological discoveries as to why these differences occur. The aforementioned study used the rate of decline in milk production with increasing temperature humidity index to create a heat tolerance phenotype and then with these data genomics predictions for the trait (Nguyen *et al*. 2016). These genomics predictions were then used to source cattle with trait extremes that were then exposed to heat-stress conditions in controlled-climate chambers to discover why the cause of differences. In this regard, Garner *et al*. (2016) revealed superior thermoregulatory ability enabled through improved vasodilation, with further work proposed determine differences in thermal physiology. Using a similar approach, Molfino (2019) used data generated by automatic milking systems to create groups of cows associated with efficiency in the context of voluntary cow traffic. The more ‘efficient’ cows produced 9% more milk with 5% less milkings per day than ‘inefficient’ cows, which in practice could allow more cows per robot unit and therefore improve whole system performance. Furthermore, in a subsequent study, the same author showed that efficient cows significantly spent 40 min more per day grazing ($P = 0.04$), 42 min more per day ruminating ($P < 0.001$) and 55 min less resting ($P = 0.004$) in comparison to inefficient cows, providing strong evidence of phenotypic differences between animals. Although the implications are yet to be investigated, this is an example of a ‘phenotype’ that was neither relevant nor detectable previously, but that with the advancement of technology could be detected and used to not only improve farm efficiency but also for scientific discovery. We propose that the approach of Garner *et al*. (2016) and Molfino (2019) will form the basis for scientific discovery as to the structure and function of livestock into the future and rapidly enable the selection of more robust animals for our future environment.

BIOSECURITY

Of the 91% of Australian dairy farmers that report unusual health events to their veterinarian, only 6% contact their state department of primary industries (Dairy Australia 2012). It is clear that silos of information related to the potential spread of pests and diseases are maintained across Australia, which is a concern given our increasingly interconnected, global production environment. In this regard, Newell *et al*. (2017) reported 83% of veterinarians to hold data within their practice without sharing with state organisations or other veterinary practices and almost all veterinarians (89%) identified cases of reduced health or abnormal appearance that remained undiagnosed. This presents a large risk to the ongoing health of Australia’s livestock industry. Despite this, 71% of respondents were willing to share data with a centralised database provided a streamlined process was in place. The collection and collation of these data into a centralised system would enable the creation of phenotypes associated with pests and diseases as per the creation of the aforementioned heat stress trait (Nguyen *et al*. 2016). This would revolutionise current surveillance techniques enabling early warning of potential outbreaks whilst also focusing industry extension

CONCLUSION

Risks and challenges for the global agricultural industry are arising alongside well defined societal and environmental trends. Whilst genomic selection has historically enabled rapid genetic progress, new phenotypes are now required to fully unlock the power of genomics enabling the creation of robust, high welfare, agricultural systems. Technology that collects and collates data and automatically implement actions is adopted by industry as these technologies typically drive on-farm profit. In the next 10 years we will also see new technologies implemented on farm in line with the advances made using machine learning and other techniques to reveal valuable new phenotypes. Increasing animal protein price due to increased population demand and wealth coupled with a rapidly declining technology price, will create the opportunity to dramatically advance developing country livestock systems in the near future. We propose to leverage these phenotypic data to revolutionise current surveillance techniques enabling early warning of potential pest and disease outbreaks whilst also focusing industry extension to improve animal health. A new approach is also proposed for scientific discovery whereby the causes of livestock structure and function are determined by animal population phenotypic screening to determine the causes of diversity.

REFERENCES

Alexandratos N. and Bruinsma J. (2012) 'World agriculture towards 2030/2050: the 2012 revision.' (FAO: Rome).

Baquet A., Hambleton R. and Jose D. (1997). 'Introduction to risk management.' (1st ed.) Washington: USDA.

Clark C.E.F. and Garcia S.C. (2016) 67th Annual Meeting of the European Association for Anim. Prod. Belfast, Ireland.

Farmer J. and Lafond F. (2016) *Res. Pol.* **45**:647.

Dairy Australia. (2012). 'Dairy 2012: Situation and Outlook' (pp. 67). Victoria, Australia.

EY (2019). 'Summary Report.' Ernst and Young, March 2019; 41p.

Garner, J.B., Douglas, M.L., Williams, S.R.O., Wales, W.J. Marett, L.C. Nguyen, T.T.T., Reich C.M. and Hayes B.J. (2016) *Sci. Rep.* **6**:34114

Gardenier J., Underwood J. and Clark C.E.F (2018). International Conference on Robotics and Automation. Brisbane, Australia.

Hajkowicz, S. and Eady, S. (2015). 'Publication No. 15/065'. Rural Industries Research and Development Corporation

Lyons N.A., Eastwood C.R., Dela Rue B.T. and Kerrisk K.L. (2016). Precision Dairy Conference. Netherlands.

Marshall K., Gibson J.P., Mwai O. Mwacharo J.M., Haile A., Getachew T., Mrode R. and Kemp S.J. (2019) *Front. Genet.* **10**:297.

Molfino, J. (2019). PhD Thesis. The University of Sydney. 147 p.

Newell E., Lyons N., Ryan D., Ward M., Lomax S. and Clark C. (2017) 8th European Conference on Precision Livestock Farming. Nantes, France.

Nguyen T.T., Bowman P.J., Mekonnen H.M., Pryce J.E. and Hayes B.J. (2016) *J. Dairy Sci*. **99**:2849.

RMAC (2017). 'Meat Industry Strategic Plan.' Canberra: Meat Industry Advisory Council.

Talukder, S., Thomson, P. C., Kerrisk, K. L., Clark, C. E. F., and Celi, P. (2015). *Therio*. **83**:739.

Taylor N. and Signal T.D. (2009) *J. Appl. Anim. Welf. Sci.* **12**:345.