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POSTNOTE

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Trends in Agriculture

In the last century, agricultural production intensified, but this increased its impacts on the environment, waste in supply chains and in some regions of the world, disconnected it from people's lives. Projections of global population growth and changing consumption patterns out to 2050 suggest further increases in food production will be needed. This POSTnote outlines key drivers of global agricultural trends and the challenge of safeguarding both food production and environment value in a changing world.

Overview

- Global requirements for food are changing. These include demand for higher quality products in developed countries and for higher protein diets in developing countries.
- Increasing future levels of agricultural production will be challenged by factors such as climate change, declining soil quality and agricultural land availability.
- Attitudes and behaviours of consumers affect production, such as trends in consumption of meat, demand for organic vegetables or locally sourced products.
- Regulation of the use of pesticides and fertilisers, and subsidies for technology will affect farmers' choices, farm productivity, and may drive innovation.
- New agricultural technologies being developed to aid production include robots, drones, satellites and sensors.
- New breeding techniques may produce crops and livestock with novel traits, or accelerate the ability to deploy known traits.

Background

Global agricultural production might have to double in the next 30 years to meet changing food consumption patterns.[1-4] Along with population growth, consumption patterns for some population groups are expected to converge on those typical of affluent countries.[5] Four crops, maize, rice, wheat and soybeans, currently provide nearly two-thirds of global calorie intake.[6] However, yields in these four crops are increasing at less than the 2.4% per year required to double global production by 2050.[7]

Around 37% of global land area is used for agriculture, with a gross production value of almost $US 3000 billion (3.7% of the world GDP). The top ten exporters of agricultural products in 2016 were: the EU, USA, Brazil, China, Canada, Indonesia, Argentina, Thailand, India and Australia.[8] In the case of the UK, farmers produce about three-quarters of domestic food consumption, and exports of agri-food products amount to circa £22 billion annually, 6.4% of UK gross value added. The cost of production is affected by inputs such as fossil fuels, water, fertilisers and pesticides, and regulatory requirements such as those set out by CAP.

More than 3.5 million people work in agriculture (including in the broader agri-food sector like manufacture, distribution and food preparation), about 13% of the total UK workforce. Agricultural land makes up 72% of the total UK land area (17 million ha).[9]

Efficient agricultural production depends on weather, soil quality, farmers' skills and technology. Government and public policy, such as research funding, play a role in ensuring the benefits of technology, such as new breeding technologies, are distributed equally among the population and are accessible by all users. Knowledge transfer and exchange may result in wider uptake, but commentators have highlighted the challenges and complexities for agricultural innovation systems.[10] Infrastructural deployment, such as rural broadband provision (CBP 8200), will help ensure innovation in agriculture has wider and more equitable impacts. This POSTnote outlines the key drivers of change in agriculture and summarises some of the challenges to address it.

Key Drivers of Change

Key drivers of change affecting agriculture can be broadly grouped into: environmental and demographic; economic, social and political; and technological. Some of these trends are global and some are more specific to the UK.

Environmental and Demographic factors

Addressing Environmental Effects

The further intensification of agricultural production to meet growing food demand may increase its environmental impacts.[11] For example, agriculture can have high greenhouse gas (GHG) emissions because of the use of fossil-fuelled heavy machinery, such as tractors, and inputs, such as fertilisers. It is responsible for approximately 24% of global GHG emissions, with transportation accounting for 14%, and electricity and heat production for 25%.[12] Agriculture is the biggest polluter of freshwaters in many countries, with around 115 million tonnes of inorganic nitrogen fertiliser applied to crops annually and 4.6 million tonnes of chemical pesticides sprayed globally. Total nitrogen use is declining in the UK (Figure 1), but less progress has been made reducing other pollutants. In 2016, agriculture accounted for 10% of total GHG UK emissions and for 83% of ammonia emissions (which can in turn affect air and water quality), at an estimated cost of £456 million in terms of human health and environmental impacts.[13]

Agricultural practices are partly responsible for decreased biodiversity and soil degradation.[14] Overall, projected intensification in agricultural production is estimated to reduce biodiversity by 11% by 2040.[15] However, agriculture's impacts vary greatly between different types of foods. Beef and lamb meat contribute 250 times the GHG emissions per gram of protein that vegetable protein crops do.[16] A recent review suggests beef production has one of the highest overall environmental impacts.[17] However, sustainable grazing on land that is unsuitable for growing crops could provide higher food security and improve soil quality.[18,19] Production of some commodities, such as palm oil, can also have high impacts on biodiversity (Box 1). A possible solution would be to target efforts to spare land (POSTnote 418) in nations that still have areas of high biodiversity value, and promote higher yields from existing agricultural land.[15,20]

Currently, an estimated 29% of all farms globally are involved in initiatives to increase food production without

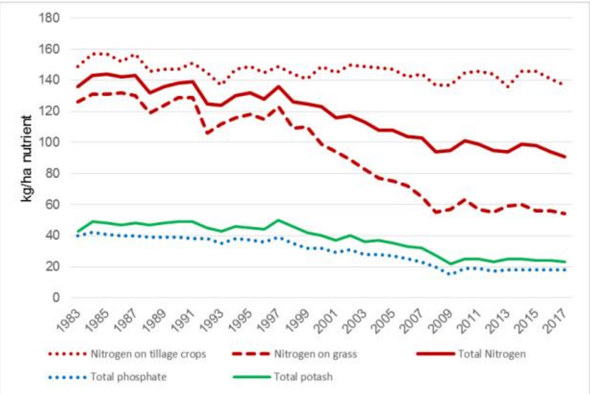

Figure 1. Overall fertiliser use (kg/ha) on all crops and grass, Great Britain 1983 - 2017.[21]

increasing their land use, which amounts to 9% of agricultural land (453 Mha).[22] However, studies have highlighted that such approaches will be insufficient to reduce the environmental impacts without decreases in demand for food and food waste.[22,23,24]

Effects of Climate Change on Agriculture

Climate change will affect agricultural production as: extreme weather worldwide can have unpredictable effects on harvests;[25] water availability will be reduced in some places, including in some areas that rely on irrigation for production;[26] and rates of water use already exceed replenishment in some countries.[27] Addressing climate change is a global challenge, but increasing climate resilience is also an opportunity to improve the efficiency of production and the environment. For example, using fallow periods and natural revegetation to improve soil carbon storage in semi-arid regions could improve yields of crops.[28]

Economic, Social and Political factors

Increased price volatility for agricultural products has the potential to globally affect agricultural revenues,[29] and may discourage recruitment to the industry in developed countries. Commentators suggest climate change and increased linkages between food and energy markets will drive food price volatility in future years.[30] For many UK farmers, input costs are rising and agricultural commodity prices are declining, leading to lower net farm income, with many farmers operating at a loss.[31] Counteracting this trend, an increasing number of skilled farmers are using new technology and farming more cost-effectively on larger scale farms.[32,33] The added effort and expense of enhancing productivity with minimum environmental impact requires investment in new technologies, and may require monetary incentives, since uptake of innovation is highly dependent on income (see Technological section below). The UK Government has stated it wants to help farmers to diversify away from food production,[34] possibly by moving into other aspects of the bioeconomy (Box 2), such as biotechnology.

Shifting Dietary Patterns

Major shifts in dietary patterns over the past 50 years are expected to continue. In addition to continuing growth in the

Box 1: Reducing the Biodiversity Impacts of Palm Oil

About half of oil palm development between 1972 and 2015 was on forested lands, causing biodiversity loss and resulting in GHG emissions, and air and water pollution.[35,36] For example, in Malaysia and Indonesia between 2000–2011, oil palm expansion caused 200,000ha of deforestation per year, associated with 200Mt of CO_2 released per year and high biodiversity losses.[37,38,39] However, biodiversity impacts are lower if only agricultural land is converted to oil palm plantations.[36] Due to its high yields, oil palm produces about 35% of all vegetable oil on less than 10% of the land allocated to oil crops.[36] Certification of palm oil production could improve practices to reduce biodiversity impacts,[39] but thus far has only resulted in marginal reductions.[40,36] In response to criticism of Roundtable on Sustainable Palm Oil (RSPO) standards on deforestation, a number of RSPO companies have made 'no deforestation' pledges and have adopted the High Carbon Stock Approach.[41] However, around 40% of global palm oil production is by smallholders, who have low levels of certification because of the costs and complexities of adhering to the requirements.[42]

Box 2: Bioeconomy
Six key components make up the core of the bioeconomy: industrial biotechnology, forestry, water supply, agriculture, fishing and manufacture of food products. As well as being a distinct category, agriculture is impacted by or feeding into each of the others. The UK bioeconomy provides £36.1 billion GVA (2% national total) to the economy. Agriculture is critical for the UK bioeconomy; the processing of food products accounts for 56% of the GVA. Different regions of the world have different bioeconomic priorities, defined by factors such as their technological base, land use trends, and access to markets. Key drivers of the bioeconomy are raw material supply, technological development and the environment.[43]

global population, people in developing countries are eating more calories per head as rising wealth allows them to buy more meat and processed food.[44] Meat consumption is expected to increase by 26% from 2007 to 2050, with developing countries accounting for 80% of this growth (POSTnote 499). There is also a transition for some population groups in both developed and developing countries towards diets high in processed foods and refined sugars, leading to rates of associated illnesses rising globally.[45] In contrast to such trends, some consumers in developed nations are eating less processed food and fewer animal-sourced foods. This could have health benefits in terms of decreasing rates of obesity or diabetes.[46,47,44] Studies suggest shifts towards healthier and more balanced diets would deliver the largest benefits per individual in developing countries.[48] In high- to middle-income countries, which have an established health system, benefits would accrue to the country as a whole.

Price Volatility and Food Security
After a period of relatively stable global agricultural markets, several price spikes have occurred in recent years. Food security can affect political stability;[49] for instance, recent political changes and conflicts in some countries may have partly been linked to food shortages.[50] Adapting to price volatility may require investment from the public and private sectors to stabilise domestic food prices, but this can disrupt international market prices. In developing countries, stable food prices prevent poverty for farmers and consumers and promote farm-level investment, helping social stability.[51]

Tariff and Non-tariff Barriers to Agricultural Trade
The House of Commons Environment Food and Rural Affairs Committee (EFRA) has highlighted that high tariffs on imports would raise the cost of food for consumers.[52] Removing tariffs may lower consumer costs, but could affect the long-term viability of the UK's agricultural industry. Non-tariff barriers include differing standards such as plant health and animal welfare standards.[53] Although standards can increase the costs of production, consumer demand is increasingly for high product standards, suggesting that UK farmers will need to adhere to high welfare and biosecurity standards.[54] The House of Lords EU Select Committee has recommended that the UK Government should consider the effect of increasing standards following EU withdrawal**.**[55]

Increasing Supply Chain Complexity
Human societies are becoming increasing urbanised; 54.3% of humans lived in urban areas in 2016,[56] and in some regions consumers are distant from agricultural systems and unaware of their environmental impact.[57] Requirements for transparency in how food is produced and supplied from farm to fork are increasing, along with consumer demands for high quality, healthy and traceable food.[48] Novel initiatives can help food companies be more transparent about the origins of their products, such as Provenance, a social enterprise project in the UK that uses distributed ledger technology (POSTbrief 28) for food traceability.[58]

Changing Attitudes
In wealthier countries, changes in consumers' attitudes are playing an increasing role in shaping food and farming systems.[59] For example, a UK public survey has suggested that some British adults recognise that the food system is a contributor to climate change.[60] Regulation of the use of pesticides and herbicides is informed by scientific studies and advice,[61] but the acceptability of their use is influenced by public perception of risk (POSTnote 564). For example, the effects of neonicotinoid pesticides on pollinators was regulated following European Food Standards Agency advice and NGO campaigns.[62,63]

Technological
Increases in yields may be limited unless different approaches and technologies are adopted. Plants are increasingly resistant to pesticides and herbicides. Studies in 70 countries show that, to date, almost 500 types of herbicide resistance were detected across weed species in over 90 crop varieties.[64] Approaches such as integrated pest management (POSTnote 501) may reduce the rate of increase in resistance to herbicides. Innovation and technological advances, such as data-enabled precision agriculture, may be another way to increase yields with lower inputs. Identification of beneficial traits in crops' genomes from long-term improvement projects or gene editing may also be needed to increase yield,[65,66] but the costs of adopting technologies and their environmental benefits will vary between locations.[67] The UK's Agri-Tech strategy has created four centres for agricultural innovation, but their future funding is uncertain.[68] An investment of £90m for agri-tech innovation was also announced under the Industrial Strategy Challenge Fund.[69]

Gathering and Using Data
Currently, it takes on average 10 calories of fossil fuel to produce 1 calorie of food,[70] but better data may help to improve this ratio.[71] For example, drone technology now allows for real-time data gathering and processing, such as on soil analysis and crop growth, which can inform irrigation, fertilisation and protection management. Data from Earth observation (POSTnote 566) are also used to identify and map soil composition and hydrological state, types of crops and proximity with wild relatives, which can affect pollination levels, plant diseases and gene flow.[72] Satellites can also provide a predictive capability for environmental factors at scales relevant to farming.[73] This information can aid a range of different agricultural challenges, from choosing the best crop for a land type to studying pollinator patterns. In the livestock sector, the adoption of monitoring technology can improve the welfare of animals, as well as reducing environmental impacts and increasing revenues. For example, the connecting of devices over the internet (so

they inform us and each other, the Internet of Things) has been used for monitoring the feeding and well-being of pigs, and electronic identification systems for cows is used for robotic milking (POSTnote 505).

Automation and Robotics
Precision agriculture (POSTnote 505) combines technology with livestock and crop science to increase production, improve quality and cut costs, as well as reduce environmental impacts and improve animal welfare. For instance, drones can be used to perform physical tasks more efficiently such as planting, irrigating and spraying,[74] and fully automated approaches to farming are now in development, referred to as 'robotic farming' (Box 3). In 2017, the Harper Adams University's Hands Free Hectare project harvested spring barley without any human intervention, using drones, soil samplers and autonomous tractors and combine harvesters. The horticulture sector is also increasing automation in the harvest of many different vegetables, particularly in the Netherlands, where the sector has an average growth rate of productivity of around 3.9% (compared to 0.9% in the UK).[75,76,77,68] The sector is also adopting new technologies, such as hydroponics and vertical farms (POSTnote 499), which control the growing environment, reducing the need for inputs.[78,79]

New Technologies and New Products
New plant breeding techniques (POSTnote 548) allow for genetic manipulation to produce key nutrients or other compounds, such as pharmaceuticals (POSTnote 424),[80,81] and are likely to play a key role in the bioeconomy (Box 2). These techniques can also be used to create novel food crops,[82] or to adapt crops to grow in extreme weather or adverse conditions, allowing production in difficult areas.[83,84] Genetic breeding to improve ruminants and gene editing techniques are being tested in livestock, for example to reduce bovine and porcine susceptibility to infections.[85,86,87] Novel types of fodder for livestock, including insects, are also being tested, as this feed could reduce the amount of land used for grazing or to produce grass. Commercially viable production of cultured meat, grown in laboratories (POSTnote 499) may be possible in future, but would need to gain consumer acceptance.[88]

Box 3: Robotics in Agriculture
Market forecasts suggest agricultural robots and drones will transform agriculture over the next decade,[89] including: dairy farm robotics; autonomous tractors; robotic horticultural harvesters; robotic implements, such as pruners; autonomous small robots for tasks such as weeding; and agricultural drones. For example, the EU 'Flourish' project, funded through Horizon 2020, is developing robots to transform farming.[90,91] Consortium partners in Germany, France and Italy have developed an autonomous farming system, where drones and robots work together to monitor the crop and remove weeds. An unmanned aerial vehicle equipped with a camera, various sensors, GPS and statistical software, can distinguish between crops and weeds; advanced algorithms enable it to optimise its flight path.[92] Once it has gathered this information, it communicates with an unmanned ground vehicle that can autonomously navigate its environment, spraying pesticides or mechanically removing weeds.[93]

Meeting the Challenges
Several major challenges arise from the drivers of change outlined above. Meeting the dietary needs of the world's rapidly growing population will be exacerbated by climate change, influencing extreme weather events and the predictability of yields. Moving to a more climate-resilient agricultural system would be needed to avoid increased price volatility and economic uncertainty affecting food security. A recent study suggests increasing technologies, changing dietary habits and reducing waste will all be necessary interventions to achieve planetary sustainability.[11] To sustain the natural resources on which agriculture depends; such as soils, water, climate and biodiversity; inputs into agricultural systems need to be reduced per unit area of land, along with reducing food waste and demand.

The 2017-2019 UK Agriculture Bill is proposing financial support for farmers and land managers to provide public goods, such as increased carbon sequestration, in England, Northern Ireland and Wales (CBP 8405).[94,95] However, it is not clear if the support will encourage approaches that integrate ecology into agricultural practice, such as agroforestry to increase soil carbon.[96] An international report has highlighted the need for a systems approach to agriculture to tackle these interconnected challenges and the provision of the metrics and knowledge to support this.[97] For example, a recent review of studies on increasing agricultural productivity found that they rarely measure the full range of outcomes needed to sustain ecosystem services and human well-being.[98]

Productivity, Technology and Innovation
In 2018, the EFRA Select Committee recommended that the Government produce a plan to improve UK farm productivity. This plan would require policies to address constraints, including the capital cost of new technologies, infrastructure in rural areas, and support for transfer of independent evidence and advice to farmers. Constraints to adopting technology may arise from the difficulty in integrating data between different platforms,[99] or poor rural internet connectivity (CBP 8200). The high cost of many of these technologies, such as robotic and autonomous systems, may be a constraint as well as lack of expertise.

Increased agricultural productivity relies on innovation throughout the food chain.[100] Strategic approaches to co-ordinating new agricultural technology, social (consumer) attitudes, and research and development advisory organisation activities are usually referred to as 'Agricultural Knowledge and Innovation Systems'.[101] Studies have shown the importance of co-creation of agricultural knowledge to allow for adaptation of innovative practices and technology.[22] In 2011, the House of Lords EU Committee highlighted that this requires: better cooperation between farm businesses, advisory bodies and scientists; improved interdisciplinary research; and farmers becoming actively involved in setting agricultural research agendas.[100]

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Endnotes (fully referenced version available online)

1 OECD Data, Meat consumption, 2018
2 OECD Data, Population, 2018
3 OECD Data, Meat consumption, 2018
4 OECD Data, Population, 2018
5 Pretty, J, 2013, *Environ Resource Econ*, 55 (4), 475–499
6 Zhao, C, *et al*, 2017, *PNAS*, 114 (35), 9326-9331
7 Ray, D, *et al*, 2013, *PLOS One*, 8(6): e66428
8 WTO, 2017, *World Trade Statistical Review*
9 UK Government, 2017, *Agriculture in the United Kingdom 2017*
10 EU SCAR, 2012, *Agricultural knowledge and innovation systems in transition – a reflection paper*, Brussels.
11 Springmann, M, *et al*, 2018, *Nature*, 562, 519-525
12 IPCC, 2014, *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*
13 Committee on Climate Change, 2018, *Chapter 6: Agriculture and land use, land-use change and forestry, In: 2018 Progress Report to Parliament*
14 UN FAO, 2018, *More people, more food, worse water?*
15 Egli, L, *et al*, 2018, *Glob Chang Biol, 24(5): 2212-2228*
16 Tilman, D, and Clark, M, 2014, *Nature*, 515: 518-522
17 Hilborn, R, *et al*, 2018, *Frontiers in Ecology and the Environment*
18 Larcom, S, and van Gevelt, T, 2018, *Environmental and Resource Economics*, 1-24
19 de Faccio Carvalho, P, *et al*, 2010, *Nutrient Cycling in Agroecosystems*, 88: 258-273
20 Phalan, B, *et al*, 2018, *Science*, 351 (6272), 450-451
21 *Figure from British survey of fertiliser practice 2017 - statistical notice* (Defra and ONS July 2018)
Winter, M, 2018, *Changing Food Cultures: Challenges and Opportunities for UK Agriculture*, Exeter: University of Exeter and Nuffield Farming Scholarships Trust
22 Pretty, J, *et al*, 2018, *Nature Sustainability*, 1, 441-446
23 Government Office for Science, 2011, *The future of food and farming foresight report*
24 Bajželj, B, *et al*, 2014, *Nature Climate Change*, 4, 924–929
25 Leng, G, and Huang, M, 2017, *Scientific Reports*, 7: 1463
26 Reardon T, and Zilberman, D, 2018, *Climate Smart Food Supply Chains in Developing Countries in an Era of Rapid Dual Change in Agrifood Systems and the Climate*, In: Lipper L., McCarthy N., Zilberman D., Asfaw S., Branca G. (eds) Climate Smart Agriculture. Natural Resource Management and Policy, vol 52. Springer, Cham
27 Rodell, M, *et al*, 2018, *Nature*, 557, 651–659
28 Robertson, A, *et al*, 2017, *J. Environ. Qual.*, Vol. 47 No. 4, p. 684-694
29 UN FAO, *Price volatility in agricultural markets*
30 *Global Food Security, Public Engagement*
31 UK Government, 2017, *Farm Business Income by type of farm in England, 2016/17*
32 Satellite Applications Catapult, 2017, *Agricultural Technology – Market Review*
33 Wach, E, 2018, Rise of the 'megafarms': how UK agriculture is being sold off and consolidated, The Conversation
34 UK Government, 2018, *Health and Harmony: the future for food, farming and the environment in a Green Brexit*
35 Koh, L, and Wilcove, D, *Conservation Letters*, 1: 60-64
36 Meijaard, E., *et al*, 2018, *Oil palm and biodiversity. A situation analysis by the IUCN Oil Palm Task Force*.
37 Savilaakso, S, *et al*, 2014, *Env. Evidence*, 3 (1), 4
38 Henders, S, *et al*, 2015, *Env. Res. Lett.*, 10 (12), 125012
39 Lucey, J, *et al*, 2017, *J. Appl. Ecol.*, 54(3), 731-736
40 Carlson, K, 2018, *PNAS*. 115 (1) 121-126
41 High Carbon Stock Approach
42 Brandi, C, *et al*, 2015, *J Env. and Devt*, 24 (3), 292-314
43 Capital Economics, TBR and E4tech, 2016, *Evidencing the Bioeconomy, Report for the Biotechnology and Biological Sciences Research Council and the Department for Business, Innovation & Skills*
44 Winter, M. (2018) *Changing Food Cultures: Challenges and Opportunities for UK Agriculture*, Exeter: University of Exeter and Nuffield Farming Scholarships Trust.
45 Hawkes, C. 2006, *Globalization and Health*, 2(4)
46 Mason, P, and Lang, T, 2017, *Sustainable Diets*, Lond, Routledge
47 Global Burden of Metabolic Risk Factors for Chronic Diseases Collaboration, 2014, *The Lancet Diabetes and Endocrinology*, 2, 634-647
48 Godfray, C. et al. 2010, Science, 327(5967): 812-818
49 UN, 2011, *The Global Social Crisis, Report on the World Social Situation 2011*
50 Extreme weather and resilience of the global food system (2015). *Final Project Report from the UK-US Taskforce on Extreme Weather and Global Food System Resilience*, The Global Food Security programme, UK
51 Desai, R and Rudra, N, 2018, *European Journal of Political Economy*, In Press

52 House of Commons EFRA Select Committee, 2017, *Brexit: Trade in Food*, Third Report of Session 2017–19
53 House of Lords European Committee, 2018, *Brexit: plant and animal biosecurity*, 21st Report of Session 2017–19
54 *Ethical Markets Report 2017*
55 House of Lords European Union Committee, 2017, *Brexit: farm animal welfare*,
56 World Bank Statistic, *Urban Population as % of Total 1960-2016*
57 Dalin, C, and Rodriguez-Iturbe, I, 2016, *Environmental Research Letters*, 11(3)
58 Project Provenance Ltd
59 Lusk, J, and McCluskey, J, 2018, *Applied Economic Perspectives and Policy*, 40 (1),5-21
60 ComRes, Global Food Security, 2017, Public attitudes to climatic shocks and their interaction with the food system
61 European Food Safety Authority, Pesticides
European Food Safety Authority, 2016, *How Pesticides are Regulated in the EU, EFSA and the assessment of active substances*
62 *Evaluation of the data on clothianidin, imidacloprid and thiamethoxam for the updated risk assessment to bees for seed treatments and granules in the EU*
63 Andersons, 2016, *The Future Availability and Efficacy of Plant Protection Products – Potential On-Farm Implications*, Report for AHDB
64 *International Survey of Herbicide Resistant Weeds*
65 *Vegetable Genetic Improvement Network*
Pulse Crop Genetic Improvement Network
Oilseed Rape Genetic Improvement Network
Wheat Genetic Improvement Network
66 Miao C., *et al*, 2018, *PNAS* 201804774
67 Khanna, M, *et al*, 2018, *Applied Economic Perspectives and Policy*, 40 (1), 38–59
68 House of Commons EFRA Select Committee, 2018, *The future for food, farming and the environment*
69 UK Government, *Transforming food production: funding and events*
70 Professor Ian Boyd, personal communication
71 Koble, C, *et al*, 2018, *Applied Economic Perspectives and Policy*, 40 (1), 79–96
72 Bach, H, and Mauser, W, 2018, *Sustainable Agriculture and Smart Farming*, In: Mathieu PP., Aubrecht C. (eds) Earth Observation Open Science and Innovation, ISSI Scientific Report Series, vol 15. Springer, Cham
73 Fritz, S, *et al*, 2018, *Agricultural Systems*, In Press
74 Mazur, M. 2016, *MIT Technology Review*
75 Robotics Review, 2016, *Dutch Agricultural Robots to Reap Research Benefits*
76 TNO, *Greenhouse Horticulture: TNO supports suppliers with technical innovations*
77 National Geographic, 2017, *This Tiny Country Feeds the World*
78 Business Green, 2018, Green growth: British soil-free farming start-up prepares for first harvest
79 Vincent, J, 2018, *The robotic farm of the future isn't what you'd expect*, The Verge
80 Ricroch, A. *et al*. 2017, *Emerging Topics in Life Sciences*, 1(2): 169-182
81 Yao, J. *et al*. 2015, *International Journal of Molecular Sciences*, 16: 28549-28565
82 Zsögön A. *et al*, 2018, *Nature Biotechnology*
83 Areal, F, *et al*, 2015, Research Review No. 82: *An evidence-based review on the likely economic and environmental impact of genetically modified cereals and oilseeds for UK agriculture*, Agriculture and Horticulture Development Board (ADHB)
84 Baghri, D, *et al*, 2018, *Plant Science*, 272, 267-275
85 Lillico, S. et al, 2013, *Nature Scientific Reports*, 3: 2847
86 Proudfoot, C. et al, 2015, *Transgenic Research*, 24(1): 147-153
87 Tan, W. et al, 2013, *PNAS*, 110(41): 16526-16531
88 Gaydhane, M, *et al*, 2018, *Biomanufacturing Reviews*, 3:1
89 Robohub, 2017, *Farming (r)evolution*
90 Lottes, P. *et al*, 2016, *IEEE International Conference on Robotics and Automation* (ICRA)
91 Liebisch, F. *et al*, 2015, *Plant Methods*, 11:9
92 Albani, D. *et al*, 2017, *IEEE International Conference on Intelligent Robots and Systems* (IROS)
93 Fleckenstein, F. *et al*, 2017, *International Conference on Robotics and Automation* (ICRA)
94 Agriculture Bill (HC Bill 266)
95 UK Government, 2018, *Health and Harmony: the future for food, farming and the environment in a Green Brexit*
96 De Stefano, A and Jacobson, N, 2018, *Agroforestry Systems*, 92 (2), 285–299
97 The Economics of Ecosystems of Biodiversity (TEEB) 2018, *Measuring what matters in agriculture and food systems: a synthesis of the results and recommendations of TEEB for Agriculture and Food's Scientific and Economic Foundations report.*
98 Rasmussen, L, *et al*, 2018, *Nature Sustainability*, 1, 275-282
99 Wolfort, S. *et al*, 2017, *Big Data in Smart Farming – A review, Agricultural Systems*, 153: 69-80
100 House of Lords European Committee, 2011, *Innovation in EU agriculture*
101 European Commission Standing Committee on Agricultural Research (SCAR), 2016, *Agricultural knowledge and innovation systems towards the future*, A Foresight Paper