Industry note: New disruptive technologies and mindsets for Asian agriculture in the 21st century

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1 Introduction

Since the first humans settled in fertile deltas to grow crops and tend animals, agriculture has depended on advances such as better crop varieties and animal breeds, together with agronomic or husbandry practices to make big strides in producing more food. In fact, the first agricultural revolution may be attributed to human colonies changing from hunter-gatherer lifestyles to stable farmed areas more than 10,000 years ago (Teng and Foo, 2018). In the modern era as precipitated by the First Industrial Revolution, opportunities to apply modern science and technology led to rapid advances in the agri-food landscape. With the rediscovery of Mendel's laws, modern plant breeding started to produce new crop varieties with higher potential yield in the 20th century and hybrid seed became a major driver of yield increases, as exemplified by maize yields in the USA which increased seven-fold between 1940 to 2000 because of hybrid technology. This enabled the world to have increased animal feed to meet the growing demands for animal protein, especially in Asia. Hybrid maize may be considered as one of the first disruptive technologies (DTs) in modern agriculture.

This paper highlights the important role that DTs have played in assuring that agriculture contributed to food security, and also shares on current and future technologies that will impact on the agri-food landscape in this millennium.

2 Agriculture has a history of continuing innovative, DTs

A DT is one that displaces an established technology and shakes up the industry or a ground-breaking product that creates a completely new industry (Christensen et al., 2015). In the previous century, four innovations 'disrupted' agriculture and helped give rise to the significant increases in crop yields, leading eventually to the Green Revolution in the 1960s which helped prevent mass famine in many parts of Asia. These four DTs were:

- *Genetics (seeds):* In the 1960s dwarf, high yielding wheat rapidly replaced the South Asian subcontinent's hunger with surplus in the 'Green Revolution'.
- *Mechanisation:* Tractors freed up perhaps 25% of extra land to grow human food instead of fodder for draught horses and oxen.
- *Fertilisers:* Fritz Haber's 1913 invention of a method of synthesising ammonia transformed agricultural productivity.
- *Pesticides:* Chemicals derived from hydrocarbons enabled farmers to grow high-density crops year after year without severe loss to pests and weeds.

In the 20th century, the effect of these four innovations was to allow more and more food, feed and fibre to be produced from less and less land. These innovations were 'disruptive' of the status quo but created immense benefit for farmers and consumers through affordable and reliable supplies of the major staples. The four disruptions also depended on governments as well as the private sector (industry) to ensure there was technology transfer to farmers.

Asian agriculture has faced many challenges which lend themselves to technological responses. Food demand is increasing due to population growth, urbanisation and demographic change and changing diets. At the same time, the environment for agriculture is also facing many challenges, such as labour shortages (due to ageing farmers, and rural to urban migration), insufficient capital (increased uncertainties and reduced access), and reduced natural resources (reduced freshwater supplies, reduced arable land, increased climate change phenomena like severe weather events, droughts and floods).

While political and social solutions are possible to meet some of these challenges, experts generally agree that scale-neutral technologies still offer most potential. This agreement has been borne out of the experiences from the first Green Revolution which saw in the 1960s, many large Asian countries grow modern rice and wheat varieties, and together with modern agricultural inputs, increased yields. India and China staved off mass starvation. If not for the positive impact of these disruptive innovations, Asia would not have had the food security necessary for economic development. However, technology has to be appropriate and suited to different groups of farmers, from smallholders farming less than 2 ha to large farms, in order to provide solutions to the many challenges (Teng and Foo, 2018).

3 DTs for the 21st century

The 'first wave' of technological innovations was expressed through Green Revolution technologies of improved seed, fertiliser, pesticides, irrigation and mechanisation, starting in the 1950s. A 'second wave' was discernible when biotech (genetically modified) crops were first planted by farmers in 1996 (ISAAA, 2018). Agriculture is now undergoing a 'third wave' which is strongly influenced by the so-called 4th Industrial

Revolution digital technologies and started having impact in the 2010s. The term 'agtech' or agricultural technology has come to now represent this milieu of exciting new technologies like drones, sensors and intelligent robots, sometimes united by the 'internet of things (IoT)', and is joined by new 'fintech' or financial tools to help farmers access credit and markets. This author has also suggested that a 'fourth wave' has started to produce food (and feed) without agriculture, basically in laboratories (Teng et al., 2019).

The new agtech represents a set of powerful DTs that have already started to make a difference to small farmers in Asia! These include the following:

- Agronomy and agricultural biotechnology to innovate inputs for crop and animal agriculture such as seeds, pest control, seeds with new genetics, microbiome and animal health.
- Mechanisation, robotics and equipment such as on-farm machinery, automation, drones guided by GPS or GIS systems, environmental sensors and growing equipment.
- Farm management software, IoT systems with sensing and intervening – these include environmental, farming data capture devices, decision support software, big data analytics and miniaturised portable applications.
- Novel farming systems such as indoor farms, plant factories with controlled environment, aquaculture systems, and grow-out facilities for insects, algae and microbes.
- Bioenergy and biomaterials such as on-farm waste processing systems, bio-digesters and biomaterial production for valorisation.
- Agribusiness marketplaces to allow smallholders to be included in supply chains, such as commodities trading platforms, online input procurement, contracting services.

In countries like China, the Philippines and India, smallholder farmers are already accessing digital agtech devices like sensors and drones for managing nutrition and pests in crops like wheat, corn and rice. Many of these are offered through young entrepreneurs to farmers as part of a consulting service to make profits, and represent a form of 'smart farming' in which up-to-date data on crop and environment are linked through IoT systems to provide timely action, an example of a positive impact from the so-called 4th Industrial Revolution.

A second DT is through biotechnology, in the form of crop varieties developed using any of a milieu of biotechnology techniques, including genetic modification (GM). Asia in 2018 already grew 11% of the world's biotech (GM) crops, about 19 million hectares in nine countries (ISAAA, 2018). The crops are cotton, papaya, canola, maize, eggplant and sugarcane, benefiting millions of smallholders and in some cases, allowing crops to be grown in areas which hitherto had to be abandoned due to insect pest pressure and the ineffectiveness of insecticides. Since its introduction in 1996, a cumulative area of 2.5 billion ha of biotech crops have been grown with an unblemished record of safety. Going forward, a new biotechnology called gene-editing is likely to have even greater impact.

In response to urbanisation, climate change and increased demand by consumers to have vegetables grown close by, a third DT has arisen in the form of 'plant factories with artificial light (or PFALs)' which are essentially enclosed, environment-controlled greenhouses in which vegetables are grown in tiered trays (Kozai et al., 2015). These PFALs generally have no need to use insecticides and can produce many times more per unit areas using LED lights. In Asia, there were reportedly over 450 PFALs as of 2016 and the number is growing in countries like China, Japan, S. Korea, Taiwan and Singapore. These will increase the 20% of food that the FAO, UN has estimated is produced in urban area.

Many developing countries are already benefiting from DTs but many more are not even starting to use them – leaving much untapped potential to increase food production and promote entrepreneurship. Some of the technologies yet to mainstream are plant-based protein, cellular meat, insects for food and feed, alternative vegetables, gene-edited genotypes, customised medicinal food with demographic indexing and intelligent drones and sensors. Another high potential DT is blockchain technology that safeguards the integrity of food supply from farm to consumer. Blockchains are also spawning the development of techniques to quickly detect food fraud or guarantee food identity.

Countries need to ask themselves to what extent they want to be part of the revolution in technology-enabled food production and processing. The economist, J. Sachs, famously stated in 2000 that a third of the world's population is technologically disconnected, neither innovating at home nor adopting foreign technologies. As a continent, Asia cannot afford to be part of this third.

4 Education for a new agriculture: STEM and knowledge intensive agriculture

Concomitant with the growing developments in DT in Asia is also the recognition by many educators that science and technology are foundations which drive innovation in many sectors of the economy, including the agri-food sector. This recognition has been translated into increased importance being paid to STEM education, which is generally accepted to be made up of elements from science, technology, engineering and mathematics; and yet is also generally accepted to not mean taking all four in to and combining them into a single mega-discipline. In many respects, STEM education is the education community's response to meet the demands for 21st century competencies for children but also to interest them in career pathways that are linked to science, such as agriculture.

STEM education helps accomplish the following (Teng, 2018):

- Grounding students in the processes and attitudes of mind associated with science and mathematics, and engineering and technology.
- Inculcating the ability to take an integrative, interdisciplinary approach to problem-solving.
- Acquiring competencies and character qualities for a work force of the future.

For countries in which the agri-food industry remains important, it will be important to ensure that students continue to show interest in colleges of agriculture so that the demands of industry in the future can be met with sufficient human resources.

Agriculture in the 21st century, apart from the impact of DTs, is also requiring better use of knowledge to directly ensure that the potential of the DTs is properly captured by farmers, especially smallholder farmers. Modern farming depends on technology but it has become increasingly clear to scientists, policymakers and development agencies that physical inputs alone do not guarantee that farmers can make best use of these inputs. Knowledge is required to make farms productive, farming practices efficient and farm productivity more targeted.

Additionally, a new impetus for knowledge-intensive agriculture is the increase in myriad tools to practise 'data-enabled agriculture' – environment sensors, mobile computing, satellites and imaging, drones, wireless communication and even genetics (Teng, 2017). All of which are DTs. The growth of knowledge in digital form, and the increasing capacity of small farmers to access digital information provide opportunities not possible before to share timely information on farming environments and the required management knowledge. As experts at an Asian Development Bank Workshop in June 2018 noted, knowledge-intensive agriculture has the potential to become the latest and most impactful game-changer because it 'connects the dots' to link technology, knowledge, the farmer and the financier.

DTs are further helping to create a new class of young entrepreneurs, called 'agropreneurs' who are contributing to the revitalisation of agriculture (Ahmed et al., 2019). These often young people use Knowledge tools like computer programs called 'apps' to help farmers decide when and how much input to apply by practicing knowledge intensive agriculture. Experts from the Asian Development Bank, Manila have argued that education systems throughout Asia need to be reformed to provide training of these agropreneurs so that farming and food production can make full use of the potential inherent in DTs. This is the future for Asia.

5 Concluding remarks: sustainability and social license

Teng and Foo (2018) noted in 'food matters' that, for the world to even dream of achieving a state of sustainable development, the food imperative, in the form of stable supply and access, has to be guaranteed. This food imperative, now more than at any other time in human history, has to be based on scientific knowledge that can assess, diagnose and address the increasingly complex challenges facing food production (through agriculture or otherwise), its journey from farm to consumer, its safety, and its contribution to human nutrition and health. These challenges, on top of a growing human population expected to reach almost ten billion by 2050, highlight the need to produce more food of higher quality but with less land, less water, less labour and less environmental impact. Science and its progeny, technology, helped humankind survive one of its difficult periods after the Second World War, through the 'Green Revolution'. Science and technology, but now coupled with ethics and vision, are needed again to meet the new challenges in this new millennium. Social license, which is getting society to accept the new food products from novel technologies such as vegetables produced in plant factories, plant-based meat, genetically modified food, is an important aspect of creating public awareness in society and also educating the young about science and technology.

This is where agriculture has to address the Sustainable Development Goals (SDGs), of which the eradication of hunger (SDG 2) and poverty (SDG 1) are important goals.

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