**Introduction**

By 2050, world population is predicted at 9.8 billion, land will be cleared by 1 billion hectares and carbon dioxide greenhouse gas emissions will reach 3 billion tonnes per year (Un.org, 2017; Tilman et al, 2011). Crop production will need to increase 60-70% by 2050 to match demand (Grist, 2015). 33% of the world’s arable land has been lost due to erosion or pollution in the last 40 years (Grantham Centre, 2019). Sustainable agriculture has a difficult challenge to produce greater amounts of high-quality food, while minimising negative environmental impacts and decreasing external inputs (Wittwer et al, 2017). Many world-class scientists and thinkers on agriculture agree on a necessity to update modern, intensive agriculture to more sustainable alternatives (Giovannucci et al, 2012).

**Climate-Smart Agriculture**

Climate change is the biggest biological factor, since it is the main reason for a shift in agricultural systems. 13.5% of the global greenhouse gas emissions are due to current intensive agricultural practises such as the use of manure and synthetic fertilisers, wet rice cultivation and livestock gut fermentation processes (Grist, 2015). There will be increased: frequency and/or severity of extreme events; climate variability; global average temperature; long term changes in rainfalls and incidence/range of plant pests and diseases (Grist, 2015). This will cause: yield decline; crop damage/loss; land degradation and animal loss (Grist, 2015). Slight changes in temperature at critical growth stages will reduce crop yields radically and increase the inter-annual variability of crop yields in many regions (Grist, 2015).

Climate-smart agriculture is an alternate, new approach that combines agroecological and/or more traditional practises with new innovative, technological practises (Grist, 2015). Instead of just focusing on yields and productivity as current agriculture does, climate-smart agriculture will try to increase agricultural productivity and income in a sustainable, site- specific manner, while building resilience to climate change and potentially reducing greenhouse gas emissions (Grist, 2015).

**Agroecology and Organic Farming**

Agroecosystems are communities of plants and animals which interact with environments modified by people to produce human goods for consumption or processing, such as farms (Altieri and Nicholls, 2006). Agroecology studies agroecosystems, factoring in all interrelationships between environmental and human elements (Altieri and Nicholls, 2005). Organic farming is one form of agroecological approach, mostly expressed in the developing world (Altieri and Nicholls, 2006). Organic farming changed inputs of synthetic fertilisers and pesticides to internal/local resources like biological pest controls; solar/wind energy; nitrogen and other nutrients released from organic matter or soil reserves (Altieri and Nicholls, 2006). Organic farming maintains soil productivity/tilth, regulate pests, weeds and diseases and provide nutrients (Altieri and Nicholls, 2006). This is achieved by: biological pest control, crop rotations, legumes, crop residues, animal/green manures and off-farm organic wastes (Altieri and Nicholls, 2006). Animal welfare standards are typically higher due to species-specific animal husbandry, housing and nutrition predicated on breed selection and stockmanship (Stockdale et al, 2001). Organic farming is profitable due to lower variable costs and premium prices (Stockdale et al, 2011). Organic farming’s improvement of biodiversity is dependent on organic-management practises, crop type and specific habitat requirements in the surrounding landscape (Brittain et al, 2010). Organic farming has a lot of political support in the EU through subsidy payments and national government legislation (Hole et al, 2005). By 2016, there are 179 countries with organic activities of which 87 have organic regulations (Niggli et al, 2017). There are 50.9 million hectares of organic agricultural land, with the top three countries being: Australia with 22.7 million hectares; Argentina with 3.1 million hectares and United States with 2 million hectares (Niggli et al, 2017).

Organic farming cannot be considered truly agroeconomic if modern machinery, commercial crop varieties and monocultures are still a part of the farming system (Altieri and Nicholls, 2006). One criticism of organic farming is that yields are typically lower than conventional farming, but this can be improved by changing certain fundamental principles (Röös et al., 2018). Developing novel plant nutrient sources, increasing nutrient recycling, using mineral nitrogen fertilisers from renewable sources and alternative animal production systems will increase yield (Röös et al., 2018). One important factor that is more physical than biological, is to have management that actively mitigate side-effects of these yield increasing strategies (Roos et al, 2018).

Another criticism is that organic farming does not benefit biodiversity. When looking at pollinator activity, it was made clear that the natural habitat diversity was the cause of the higher pollinator abundance in organic farms over conventional farms, not the organic farming practises (Chateil and Porcher, 2015). To promote biodiversity, diversification schemes that optimise crop and animal synergism should be implemented. One way is intercropping using a push-pull system (Altieri and Nicholls, 2006). This has been tested in 450 farms in Kenya with Maize, Napier and Desmodium, resulting in a 15-20% increase in maize yield (Altieri and Nicholls, 2006). Grade cows can be supported by the fodder crops which increases milk yield, causing a greater return for every dollar invested than just using maize as a monocrop (Altieri and Nicholls, 2006). one study showed that complimenting cover crops with reduced tillage can improve crop yield by 24% (Brittain et al, 2010). Finally, introducing flowering plants as strips within crops is a way to enhance pollen and nectar availability for natural enemies of pests (Altieri and Nicholls, 2006). *Phacelia tanacetifolia* strips planted next to wheat, sugar beets and cabbage crops, lead to more aphid-eating predators like syrphid (Altieri and Nicholls, 2006). Beetle banks sown with perennial grasses led to higher numbers of predators in two years (Altieri and Nicholls, 2006). Increasing biodiversity is a major factor to improving organic farming as it would lead to more effective pest control and pollination, tighter nutrient cycling, and, most importantly, stabilise crop productivity and lower yield risks (Altieri and Nicholls, 2006).

**Technological alternatives**

**Climate-resilient crops**

Agrobiodiversity is vital for sustainable agricultural development as knowledge on crop genome allows adaptability to sudden changes in agricultural production (Jacobsen et al, 2013). Development of climate-resilient crops is an important focus for agricultural biotechnology corporations (Saab, 2015). and proteomic research on the plant stress signalling network has led to important discoveries for biotic and abiotic stresses affecting plants (Dhankher and Foyer, 2018). Glyoxalase-overexpressing rice plants showed enhanced stress tolerance and better protection of photosynthesis by preventing methylglyoxal accumulation (Gupta et al, 2017; Dhankher and Foyer, 2018). Novel stress-associated proteins (SAPs) can provide tolerance to multiple abiotic stresses; transgenic Arabidopsis lines overexpressing AtSAP13 had greater tolerance to drought and salt stresses as well as toxic metals (Dixit et al., 2017; Dhankher and Foyer, 2018). AtSAP13 and homologs in other crops can be used to develop climate resilient crops. High temperature stress tolerant lines are being identified and will be useful to develop parental lines or hybrids with high temperature tolerance (Dhankher and Foyer, 2018). Recent advances in phenotyping platforms and high-throughput sequencing, allows for genomics-assisted breeding which has the prospect of improving climate change resilience in crops (Iorizzo et al, 2015). Model organisms that carry out C4 photosynthesis such as foxtail millet and green foxtail are used to decipher traits with the hope of implementing into crop plants in the future (Iorizzo et al, 2015).

**Precision farming**

Precision farming is a modern farming management concept involved in monitoring, measuring and responding to inter and intra-field variability in crops, allowing for fertilisation or harvesting strategies to be adapted to suit the individual farmer’s needs (Zarco-Tejada et al, 2014; Schrijver et al, 2016). Precision agricultural technologies (PATs) are a set of technologies aimed at managing spatial and temporal variability by using sensors, satellite navigation and positioning technology, alongside the internet (Barnes et al, 2019; Schrijiver et al, 2016). Optimum operation of PATs may increase on-farm profitability; improve yield and quality; decrease inputs and minimise environmental impacts (Barnes et al, 2019). The challenges towards precision farming are the prohibitive costs of PATs; uncertainty of outcomes limiting accurate predictions on returns and low levels of trust in the technology (Barnes et al, 2019). One paper details a survey where they adopt a count regression modelling approach and a qualitative analysis on the reasons behind why farmers will adopt precision farming (Barnes et al, 2019). They claimed there was a gradient of adoption in European arable farming systems and advised policy makers to lead cost-effective interventions to maximise uptake, generate good returns to farmers and still meet the desire for sustainable agricultural production (Barnes et al, 2019). Precision farming can be used to mitigate the effects of climate change and there are already precision agriculture investment opportunities in the private sector such as: digital advisory services, drip irrigation, solar pumps and crop/soil monitoring (Aisenberg, 2017).

**Alternatives to pesticides**

Modern agriculture involves selecting high yielding, palatability crops, sacrificing strains that have greater natural resistance to stresses (Altieri and Nicholls, 2006). Despite substantial high level of pesticides being used, about 500 million kg worldwide, the world’s crop yield has been reduced by 40% due to pests (Altieri and Nicholls, 2006; Chandler et al, 2011). Current EU policy significantly reduce pesticide use and support implementation of integrated pest management (IPM) (Hillocks, 2012). Only low-risk synthetic pesticides with high levels of selectivity are used e.g. synthetic insect growth regulators (Hillocks, 2012). Other practises of IPM are cultivating crops with partial or total pest resistance and implementing crop rotations, intercropping and undersowing, alongside using physical methods like mechanical weeders (Hillocks, 2012). IPM utilises biopesticides and biological control to combat pests (Hillocks, 2012). Bacteria, fungi, oomycetes, viruses and protozoa are all used as biological control of insects, plant pathogens and weeds (Hillocks, 2012). An insect pathogenic bacterium *Bacillus thuriginesis* (Bt) produces an endotoxin that causes lysis of gut cells in insects (Hillocks, 2012). Microbial biopesticides were mass-produced using fermentation tasks utilising the Bt endotoxin and formulated into a sprayable biopesticide (Hillocks, 2012). Semiochemicals are a type of higher plant secondary metabolite that can alter behaviour and life cycle of insect pests without killing them (Dubey et al, 2010). One example is beta-asarone extracted from rhizomes of *Acorus calamus*, that has antigonadial activity causing complete inhibition of ovarian development in different insects (Dubey et al, 2010). Botanical pesticides are eco-chemical and sustainable alternatives to manage pests and with governments continuing to impose IPM, more research can be carried out on biopesticides to make crop production more sustainable (Hillocks, 2012).

**Alternatives to fertilisers**

By 2050, nitrogen use will be around 250 million tonnes per year (Un.org, 2017). Wasteful application and crops inefficiently using fertilisers lead to 50-70% of conventional chemical fertilisers lost to the environment by leaching, runoff, emissions and volatilisation in soil, water and air. (Singh et al, 2017; Altieri and Nicholls, 2006). If the fertiliser nutrients enter surface waters, eutrophication and algal bloom will end up killing plants at the bottom of the lake, reducing oxygen content and destroying animal life in the water (Altieri and Nicholls, 2006). Furthermore, nitrogen, phosphorous and potassium (NPK) fertilisers depletes soil organic matter in the long decreasing soil productivity and the efficiency of nitrate fertiliser, resulting in more intensive practises and greater use of fertilisers (Kotschi, 2013). Some eco-friendly alternatives to fertilisers are organic manure and bio-fertilisers, but this is not viable due to limited availability; bulk transport of manures; and low efficacy (Singh et al, 2017). Slow (controlled) release fertilisers (SRFs) release nutrients slowly or synchronise with growth rate and physiological need of plants (Singh et al, 2017). This increases nutrient recovery and decreases nutrient loss to the environment (Singh et al, 2017). However, the cost effectiveness of commercial SRFs and lack of knowledge on adverse effects of chemical fertilisers limited the replacement, especially in the developing world (Singh et al, 2017). Nitrogen-based SRFs use biodegradable, non-toxic and locally available agro-waste/agro-products that are low cost, highly efficient and eco-friendly to enhance crop productivity and soil fertility (Singh et al, 2017). Using biotechnology and nanotechnology, smart fertilisers can be created that control nutrient release with bioformulations based on bacteria or enzymes (Calabi-Floody et al, 2017). Also, several materials like clays, nondegradable/degradable polymers and agricultural wastes can be used to act as carrier matrices for nutrients and bacterial inoculants (Calabi-Floody et al, 2017). To meet sustainable development, chemical fertilisers must be reduced, and further research should be carried out on these alternatives.

**Conclusion**

Physical factors such as agricultural policy is vital for the future of sustainable agriculture and the UN supports climate-smart production systems as a necessary adaptation (Giovannucci, 2012). Current agroeconomic practises in climate-smart agriculture are intercropping; smart use of chemicals and biological pest control; crop rotations and integrated crop-livestock management systems. For technological innovations, climate-resistant crops are used and the desire to monitor crops and the environment can be fulfilled by precision farming. Pesticides and fertilisers are chemical factors that have had major negative environmental impacts, but now sustainable alternatives are available or being researched. Climate-smart agriculture is not limited to a single type of agriculture like organic farming which means multiple sustainable factors can work together on the same agroecosystem. Current agriculture is too ingrained into society for any rapid changes, and while the issues of current agriculture is well-documented, many unknowns remain regarding the impact of the sustainable alternatives. Long-term studies on the impacts of the alternatives will need to be carried out to study effectiveness and ensure no adverse effects.

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