POSITION PAPER

The agroecology of redesign

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1 Towards sustainability in agroecosystems

The concern for sustainability in agroecosystems centres on the fundamental importance of both agricultural and non-agricultural ecosystems, and their links with farmers and consumers. Agriculture is unique as an economic sector as it directly affects many of the very natural and social assets on which it relies for success (MEA, 2005; FAO, 2011, 2016a; Rockström et al., 2017; Pretty et al., 2018). These influences can be both good and bad. Industrialised and high-input agricultural systems rely for their productivity on simplifying agroecosystems, bringing in external inputs to augment or substitute for natural ecosystem functions, and externalising costs and impacts. Pests tend to be dealt with by the application of synthetic and fossil-fuel derived compounds, wastes flow out of farms into water supplies, and nutrients leach to the soil and groundwater. As a result, there has been widespread and increasing cost to natural ecosystems and human health (Pretty, 2018).

By contrast, sustainable approaches to agriculture seek to use ecosystem services without significantly trading off desired productivity. When successful, the resulting agroecosystems have a positive impact on natural, social and human capital, while unsustainable systems continue to deplete these capital assets. A wide range of different terms for more sustainable agriculture have come into use: for regenerative agriculture, a doubly green revolution, alternative agriculture, an evergreen revolution, agroecological intensification, green food systems, save and grow agriculture, and sustainable intensification (NRC, 2010; Godfray et al., 2010; FAO, 2011, 2016a; Pretty et al., 2018). Many of these draw on earlier traditions and innovations in permaculture, natural farming, the one-straw revolution, and forms of biodynamic and organic agriculture.

All sustainable agricultural systems exhibit a number of common attributes. They aim to:

1. utilise crop varieties and livestock breeds with a high ratio of productivity to make use of externally- and internally-derived inputs;
2. avoid the unnecessary use of external inputs;
3. harness agroecological processes such as nutrient cycling, biological nitrogen fixation, allelopathy, predation and parasitism;
4. minimise or eliminate the use of technologies or practices that have adverse impacts on the environment and human health;
5. make productive use of both human capital in the form of knowledge and capacity to adapt and innovate and of social capital to achieve common landscape-scale change (and thus system-wide improvements to water, pest or soil management);
6. minimise the impacts of systems on externalities such as greenhouse gas emissions, clean water, carbon sequestration, biodiversity, and dispersal of pests, pathogens and weeds.

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2 Beyond improved efficiency and substitution to redesign

The concept of sustainability should be open, emphasising values and outcomes rather than means, applying to any size of enterprise, and not predetermining technologies, production type, or particular design components. Central to the concept of all types of sustainable systems is an acceptance that there will be no perfect end point due to the multi-objective nature of sustainability. Thus, no system is expected to succeed forever, with no package of practices fitting the shifting ecological and social dynamics of every location. Hill (1985, 2014) proposed three non-linear stages in these transitions towards sustainability: i) efficiency; ii) substitution; and iii) redesign. While both efficiency and substitution are valuable stages towards system sustainability, they rarely achieve the greatest co-production of both favourable agricultural and environmental outcomes at regional and continental scales (Sandhu et al., 2015).

The first stage: 'Efficiency' focuses on making better use of on-farm and imported resources within existing system configurations. Many agricultural systems are wasteful, permitting natural capital degradation within the farm or the escape of inputs across system boundaries to cause external costs on-farm and beyond. Post-harvest losses reduce food availability: tackling them contributes directly to efficiency gains and amplifies the benefits of yield increases generated by other means. On-farm efficiency gains can arise from targeting and rationalizing inputs of fertiliser, such as through deep-fertiliser placement in Bangladesh used by one million farmers on two million hectares (Mulligan, 2016), and of pesticide and water to reduce use, and cause less damage to natural capital and human health. Such precision farming can incorporate sensors, detailed soil mapping, GPS and drone mapping, scouting for pests, weather and satellite data, information technology, robotics, improved diagnostics and delivery systems to ensure inputs are applied at the rate and time to the right place, and only when needed (Lampkin et al., 2015; Garbach et al., 2017). Automatic control and satellite navigation of agricultural vehicles and machinery can enhance energy efficiency and limit soil compaction.

The second stage: 'Substitution' focuses on the replacement of technologies and practices. The development of new crop varieties and livestock breeds deploys substitution to replace less efficient system components with alternatives, such as plant varieties better at converting nutrients to biomass, tolerating drought and/or increases in salinity, and with resistance to specific pests and diseases. Other forms of Substitution include the release of biological control agents to substitute for inputs; the use of gene silencing pesticides; water-based infrastructure replacing the use of soil in hydroponics; and in no-tillage systems new forms of direct seeding and weed management replacing inversion tillage (Pretty and Bharucha, 2014).

The third stage: 'Redesign' incorporates agroecological processes to achieve impact at scale (both increases in area and numbers of farmers). Redesign centres on the composition and structure of agro-ecosystems to deliver sustainability across all dimensions to facilitate food, fibre and fuel production at increased rates. Redesign harnesses predation, parasitism, allelopathy, herbivory, nitrogen fixation, pollination, trophic dependencies and other agro-ecological processes to develop components that deliver beneficial services for the production of crops and livestock (Gliessman and Rosemeyer, 2009; Gurr et al., 2016). A prime aim is to influence the impacts of agroecosystem management on externalities (negative and positive), such as greenhouse gas emissions, clean water, carbon sequestration, biodiversity, and dispersal of pests, pathogens and weeds. While 'Efficiency' and 'Substitution' tend to be additive and incremental within current production systems, 'Redesign' brings the most transformative changes across systems.

Redesign is, however, a social and institutional as well as an agricultural challenge (Gliessman and Rosemeyer, 2009). Here is a need to create and make productive use of human capital in the form of knowledge and capacity to adapt and innovate, and social capital to promote common landscape-scale change, such as for positive biodiversity, water quantity and quality, pest management, and soil health outcomes (Pretty 2003; FAO, 2019; Pretty et al., 2020).

Redesign is critical as ecological, economic, social and political conditions continue to change across whole landscapes. The changing nature of pest, disease and weed threats illustrates the continuing challenge. New pests and diseases can suddenly emerge in different ways: development of resistance to pesticides; secondary pest outbreaks due to pesticide overuse; climate change facilitating new invasions; and accidental long-distance organism transfer. Recent appearances include wheat blast (*Magnaporthe oryzae*) in Bangladesh (2016), and Fall Army Worm (*Spodoptera frugiperda*) in sub-Saharan Africa (2017) and then in China (2020). The papaya mealybug (*Paracoccus marginatus*) is native to Mexico, but spread to the Caribbean in 1994 and then to the Pacific islands by 2002. It was reported in Indonesia, India and Sri Lanka by 2008, then appeared in West Africa; the preferred host is papaya, but it has now colonised mulberry, cassava, tomato and eggplant. Each geographic spread, each shift of host, requires redesigns of local agricultural systems, and rapid responses from research and extension. Such new pests and diseases may also impact crop pollinators, as illustrated by host shifts and the accidental anthropogenic spread of bee parasites (e.g. *Varroa* mites) and pathogens (e.g. *Nosema ceranae*) (Goulson et al., 2015).

3 Social capital for redesign

For redesigned agricultural and landscape systems to have a transformative impact on whole landscapes then cooperation is required, or at least individual actions that collectively result in additive or synergistic benefits. For farmers to be able to adapt their agroecosystems in the face of stresses, they will need to have the confidence to innovate. As ecological, climatic, and economic conditions change, and as knowledge evolves, so must the capacity of farmers and communities also evolve to allow them to drive transitions through processes of collective social learning. This suggests redesigned systems have the valued property of intrinsic adaptability, whereby interventions that can be adapted by users to evolve with changing environmental, economic and social conditions are likely to be more sustainable than those requiring a rigid set of conditions to function. Every example of successful redesign at scale has involved the prior building of social capital (Ostrom, 1990; Pretty et al., 2020), in which emphasis is paid to: i) relations of trust, ii) reciprocity and exchange, iii) common rules, norms and sanctions, and iv) connectedness in groups. As social capital lowers the costs of working together, it facilitates co-operation, and people have the confidence to invest in collective activities, knowing that others will do so too. They are also less likely to engage in free-rider actions that result in resource degradation.

Many forms of social capital have emerged in support of transitions towards greater sustainability and equity. These include transnational farmer movements, such as La Vía Campesina with 200 million families represented worldwide (Martínez-Torres and Rosset, 2014), national land rights and anti-land grab movements, such as MST (Movimento dos Trabalhadores Rurais Sen Terra: Veltmeyer, 2019), national rural unions (Welch and Sauer, 2015) and agroecology and social movements (Veltmeyer, 2019). At the same time, organisation around food has advanced in the form of food sovereignty and justice movements (McMichael, 2013) and alternative food networks (AFNs) and alternative food movements (AFMs), particularly from urban food production landscapes and many involving consumers as well as growers/farmers (Desmarais and Wittman, 2014; Saulters et al., 2018).

The concept of system redesign implies the establishment of new knowledge economies for agriculture and land (MacMillan and Benton, 2014). It is clear that the technologies and practices increasingly exist to provide both positive food and ecosystem outcomes: new knowledge needs to be co-created and deployed in an interconnected fashion, with an emphasis on ecological and technological innovation (Willyard et al., 2018). There have been many adaptations in terminology for these systems of co-learning: farmer field school, learning lab, science and technology backyard platform, science field shops, junior life schools, innovation platform, farmer-led council, agro-ecosystem network, farmer cluster network, joint liability group, land care group and epistemic community. What is common to these social innovations has been an understanding that individual farmers, scientists, advisors and extensionists also undertake a transformative journey. Their worldviews are challenged and change, resulting in the formation of broader epistemic communities of common interest (Norgaard, 2004), that utilise, synthesise and apply knowledge and skills from many sources. For sustainable outcomes, cognitive social capital in the form of beliefs and worldviews also changes.

A recent study assessed the formation of social groups within specific geographical territories in eight categories of agricultural and land management intervention (*Figure 1*; Pretty et al., 2020). Across the eight categories and 122 distinct initiatives, it was shown that 8.54 million intentionally-formed social groups had been formed worldwide (Pretty et al., 2020). These comprised groups collectively managing 300 million hectar of agricultural and non-agricultural land. This represents a growth in these types of groups from 0.005 million at the end of the 1980s (primarily in participatory irrigation management) to 0.48 million in 2001 (Pretty and Ward, 2001), and now to 8.54 million by 2020 (exponential fit: R=0.982). *Figure 1* shows the marginal increase between 2000 to 2020 in groups in each of the eight categories.

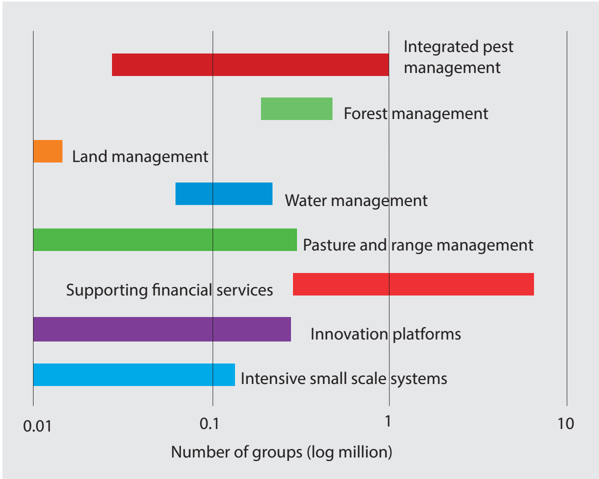

FIGURE 1
Increase in numbers of groups in eight categories of sustainable agriculture and land management (2000–2020) (Source: Pretty et al., 2020).

4 Impacts of redesign

It has become clear that social capital established in the form of groups can lead to optimal outcomes for members of these groups. But by definition, those people outside may be excluded from the benefits of membership. This phenomenon of "the dark-side of social capital" (Coleman, 1990) has seen both elite capture (the already wealthy or more powerful individuals using groups to strengthen personal benefit at the expense of others), exclusion (group membership restricted to only some members of a population or location), and negative selection (where individuals are actively excluded). Nonetheless, the majority of the literature points to the benefits of social capital to i) individuals, groups/communities, ii) agricultural systems, and iii) wider landscapes and ecosystem services.

For individuals, groups/communities, there is evidence of changes to personal capabilities and growth, to worldviews, and locally-generated resource availability, through emergence of new leaders of groups, especially by women (Agarwal, 2018), and changes in the relationships between women and men (Westerman et al., 2005); the positive role of women leaders is seen in group effectiveness and conflict resolution over common resources (Coleman and Mwangi, 2013); and changes in the worldviews of farmers (Campbell et al., 2017; van den Berg et al., 2020), as well as of scientists and extensionists working with farmers in novel innovation platforms (Zhang et al., 2016).

For agricultural systems, there is evidence of increased system outputs and reduced input needs, through increases in crop productivity, such as by farmer field schools on all crops (FAO, 2019), and in grazing and pasture productivity (NRC, 2010); increases in tree and agroforestry cover on farms (Garrity et al., 2010; Bunch, 2018); reductions in the use of pesticides in integrated pest management (Yang et al., 2014); and adoption of organic and zero-budget systems (Reganold and Wachter, 2016; Bharucha et al., 2020).

To natural capital and key ecosystem services, there is evidence of increased productivity and reductions in use of harmful or potentially-harmful compounds and releases through increases in irrigation water availability and efficiency of use (Zhou et al., 2017); improvements in forest productivity of wood, forage and secondary products (FAO, 2016b); increases in carbon sequestration in soils by conservation agriculture (Lal, 2014); and reductions in surface water flows and soil erosion (Reij and Smaling, 2008).

5 Policy challenges for sustainability transitions

Despite this progress on the ground towards sustainable systems relying on agroecological principles and building both natural and social capital, state policies for transitions toward sustainability remain poorly developed or counter-productive. In the EU, farm subsidies have increasingly been shifting towards targeted environmental outcomes rather than payments for production, but this has not as yet guaranteed synergistic benefits across whole landscapes (Maréchal et al., 2018). Several countries have offered explicit public policy support to social group formation, such as for Landcare (Australia), watershed management (India), joint forest management (India, Nepal, DR Congo), irrigation user groups (Mexico) and farmer field schools (Indonesia, Burkina Faso).

In India's state of Andhra Pradesh, the state government has made explicit its support to community-based natural farming (formerly zero-budget natural farming: ZBNF), aiming to reach six million farmers by 2027 (Bharucha et al., 2020; Smith et al., 2020). In Bhutan and the Indian states of Kerala and Sikkim, policy commitments have been made to convert all land to organic agriculture (Meek and Anderson, 2020); the greening of the Sahel through agroforestry began when national tree ownership regulations were changed to favour local people (Waldron et al., 2017). In China, new national policy frameworks emphasise innovation, coordination, greening and sharing as key parts of a new strategy for the greening of agricultural systems (Xinhua, 2016). And across the world, consumers are increasingly playing a role in connecting directly with farmers, such as through group purchasing schemes, farmers' markets and certification schemes, which may in turn change consumption choices (Allen et al., 2017).

The key question thus centres on what could happen next. Sustainable agriculture approaches have been shown to increase productivity, raise system diversity, reduce farmer costs, reduce negative externalities, and improve ecosystem services. There is thus a range of potential motivations for farmers to adopt agroecological approaches on farm, and for policy support to be provided by national government, third sector and international organisations. But sustainable transitions still require investments to build natural, social and human capital: redesign is not costless. A recent global assessment of sustainable intensification (SI) showed that projects-initiatives in some 100 countries containing 163 million farms have crossed an important substitution-redesign threshold, and are using SI methods, on an area approaching 453 million hectar of agricultural land (Pretty et al., 2018). This comprises 29 % of all farms worldwide; and 9 % of agricultural land (total worldwide crop and pasture land is 4.9 x 10^9 hectares). In every case, social capital formation leading to knowledge co-creation has been a critical pre-requisite. In every case, too, farmer benefit (e.g. food output, income, health) was demonstrated and understood.

There are important arguments that suggest the world would not need to increase agricultural production if less food were wasted, and less energetically-inefficient meat was consumed by the affluent. These changes would help, but there is no magic wand of redistribution. Most, if not all, farmers need to raise yields while improving environmental services. The evidence shows that redesign of agro-ecosystems around agroecological approaches to sustainability can achieve yield increases. The evidence from farms of redesign and transformations offers scope for optimism. The concept and practice embodied in the application of agroecology will be a process of adaptation and redesign, driven by a wide range of actors cooperating in new agricultural knowledge economies.

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