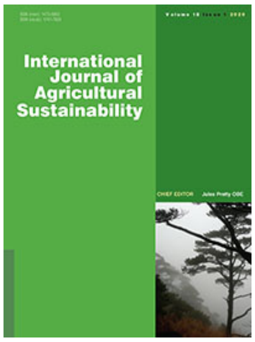

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Towards redesign at scale through zero budget natural farming in Andhra Pradesh, India*

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ABSTRACT
Zero Budget Natural Farming (ZBNF) is a form of agricultural system redesign being practiced at scale in India, particularly in the state of Andhra Pradesh. ZBNF is an emerging set of agricultural practices designed dramatically to reduce farmers direct costs (hence 'zero budget') while boosting yields and farm health through the use of non-synthetic inputs sourced locally ('natural farming'). Andhra Pradesh has set out the aim of 'rolling out' ZBNF to all 6 million of the state's farmers through a state-led programme of training and extension. We present data showing statistically significant differences between ZBNF and non-ZBNF yields and farmer incomes at multiple locations and with a variety of crops, as well as preliminary results on farmers' experiences with crop health and household transitions following the adoption of ZBNF. We conclude with reflections on the lessons derived from Andhra Pradesh's state support for ZBNF.

KEYWORDS
Agroecology; India; redesign; sustainable intensification; zero budget natural farming

1. Introduction

There is growing evidence that sustainable intensification can increase crop yields by redesigning ecosystems on and around farms (Garibaldi et al., 2019; Godfray et al., 2010; Pretty & Bharucha, 2018; Reganold & Wachter, 2016; Royal Society, 2009). In some contexts, sustainable intensification is achieving scale, reaching large numbers of farmers and hectares (Gunton, Firbank, Inman, & Winter, 2016; Pretty et al., 2018). This paper addresses the system of Zero Budget Natural Farming (ZBNF), an emerging agroecological practice that has spread in India, as a form of agricultural system redesign. The focus is on the southeastern state of Andhra Pradesh, where the state government has announced the intention to roll out ZBNF to all the state's 6 million farmers by 2024 (UNEP, 2018). This represents an infrequent contemporary example of a policy-led sustainability transition at significant scale in India, and provides a number of lessons for other state-led initiatives for sustainable agriculture.

We first introduce the concepts of sustainable intensification and agricultural system redesign. We then briefly describe some of the social-ecological challenges faced by smallholders in India's peninsular drylands and outline how alternatives are emerging to mitigate these. We go on to describe the evolution of ZBNF, beginning as a grassroots social movement (Khadse, Rosset, Morales, & Ferguson, 2017) and evolving into a major policy initiative in Andhra Pradesh. We then present some of the first available findings on the impacts of ZBNF amongst early-adopters in Andhra Pradesh, focusing on crop yields, costs of cultivation, farmer income and observed impacts on farm ecosystems and within households. We conclude the paper by discussing ZBNF as a form of agricultural

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system redesign, and reflecting on the lessons and questions it presents for wider transitions to sustainable agriculture at scale in India and in comparable contexts.

1.1. Sustainable intensification and redesign

Agricultural intensification from the mid-twentieth century centred on two linked goals: avoiding land conversion and raising yields. It was assumed this would help to meet growing demand but also spare biodiverse, non-agricultural land from being converted to low-productivity, extensive systems. Implicit in this view was the belief that agriculture would inevitably cause harm to non-cultivated landscapes (e.g. Collier, Wiradi, & Soentoro, 1973; Conway & Barbier, 1990). The resulting high throughput models of agricultural intensification have been successful at raising yields, particularly of a small number of cereal staples, and in the short term. Pellegrini and Fernández (2018) estimate that during the Green Revolution, yields grew threefold on average, helping growth in agricultural yield to outpace population increases. For each person worldwide, there is now 25% more food than was produced per capita in 1960 (Pretty & Bharucha, 2014).

Yet productivity growth has come at a significant social-ecological cost. Intensification has been enabled by a 2-fold increase in irrigated area globally, a 2-fold increase in the use of agricultural machinery, a more than 6-fold increase in the application of nitrogenous fertilizers, a four fold increase in phosphorus application, and a five fold increase in potassium (Pellegrini & Fernández, 2018; Pretty & Bharucha, 2014; Tilman, 1999). As a result, agriculture is now a key driver of breached planetary boundaries (Campbell et al., 2017; Rockström et al., 2017; Springmann et al., 2018; Tilman, Balzer, Hill, & Befort, 2011; Willett et al., 2019). Globally, it accounts for around 70% of global freshwater use, around a third of all GHG emissions and is the leading driver of land conversion (despite early confidence that intensification would protect non-cultivated ecosystems). Soil erosion in agricultural landscapes is between 10–100 times the natural background rate (IPCC, 2019). Mitigating these impacts will require radical shifts to the ways in which we produce and consume agricultural goods and services.

The potential for synergies between agriculture and ecosystem health was first hinted at in the context of smallholders in less-developed countries in the use of the term sustainable intensification (Pretty, 1997). The approach is not meant to be prescriptive, recognizing that there is no single form or initiative that can accomplish sustainable outcomes over all types of agricultural system. Instead, interventions as varied as crop varietal improvements, multi-cropping, integrated pest management, conservation agriculture, the system of crop intensification (starting as the system of rice intensification and expanding to other crops), and the intensification of small patches of land have shown the potential to achieve positive social-ecological co-benefits alongside healthy yields (Pretty & Bharucha, 2014, 2018; Pretty, Toulmin, & Williams, 2011). These outcomes have extended ambition about what is possible beyond the avoidance of harm, and towards an agenda of radical ecosystem restoration, community regeneration and social-ecological resilience.

Redesign is key to these outcomes. The term comes from a three-stage framework first developed in the mid-1980s, which proposed that transitions to sustainable agriculture occur along three distinct, non-linear phases: efficiency, substitution and redesign (Gliessman, 2016; Hill, 1985).

Efficiency is additive and incremental, though can involve step changes within existing agricultural regimes. It involves reducing waste and making the best use of resources. Examples include targeting the use of inputs, precision agriculture, mulching to reduce loss of soil moisture, drip irrigation, deficit irrigation, irrigation scheduling, monitoring soil moisture, the use of selective compounds or selective spraying, using fuel-efficient farm machinery, reducing post-harvest losses, or choosing varieties that make more efficient use of water or nutrients.

Substitution involves replacing harmful compounds, practices or techniques with alternatives that have less negative environmental or health impacts. Examples include replacing inefficient crop varieties with those that are better at converting nutrients to biomass, or ones which tolerate climate extremes; the use of biological control agents to substitute for synthetic inputs, the use of RNA-based gene slicing technologies, replacing the use of soil altogether in hydroponic systems, and no-till to replace inversion ploughing. As these examples show, efficiency and substitution are not mutually exclusive. Substitution may drive efficiency improvements, such as when wasteful or ineffective inputs or practices are replaced by better performing ones. In India, Davis et al. (2018) estimate that replacing rice with millets, maize or sorghum would reduce irrigation water demand by 33% while improving the production of protein, iron and zinc.

Both efficiency and substitution are progressive steps towards sustainability, and usually require more than new technologies. For example, the performance of infrastructure declines over time, wasting both water and energy, so regular monitoring and maintenance (and accompanying institutional architectures to enable this) is important. At the beginning of the century, the World Bank (Briscoe & Malik, 2006) estimated that Rs 17000 crore (US$250 million) would be required annually for the upkeep of Indian irrigation infrastructure, but less than 10% of this amount was actually available and even less was likely to be spent effectively (Thakkar, 2010). Where investment in efficiency-enhancing technologies is made, farmers and water managers need to be trained to manage them properly (Levidow et al., 2014; Perry, Steduto, Allen, & Burt, 2009). Finally, prevailing practices are also a function of farmers' perspectives and priorities. For example, there may be a fundamental mismatch between farmers' goals (aimed at maximizing economic returns) and water managers (aimed at minimizing water use); these mismatches need to be reconciled through knowledge exchange and communication between different stakeholders (Levidow et al., 2014). Thus, efficiency depends as much on social and human capital, collective action and well-functioning institutions as it does on new technologies or practices.

Both efficiency and substitution are necessary for responsible stewardship, but neither is sufficient for fully sustainable agroecosystems. Water saved through efficiency improvements on individual farms, for example, may not reduce overall water consumption across the landscape – and may even increase it (Grafton et al., 2018). The substitution of some harmful inputs with more benign ones may not be enough to tackle resource degradation or mitigate key negative social and ecological externalities (Altieri & Rosset, 1996).

What is needed once basics are mastered is redesign. Hill described redesign as an approach that 'recognises the existence of natural, ecological and psychosocial laws … and takes them into account in all of its designs and management procedures' (Hill, 1985, p. 86). In practice, this has come to mean the harnessing of agroecological processes such as predation, parasitism, nutrient cycling, biological nitrogen fixation and allelopathy to achieve healthy yields (Gliessman & Rosemeyer, 2009; Gurr et al., 2016). Farmers practicing redesign proactively manage the functional relationships that support these ecosystem services. They understand the agroecological basis of farm functioning, and focus on preventing problems before they occur (Gliessman, 2015).

Redesign requires three important shifts: in knowledge systems, farming communities and supporting institutional architectures. First, knowledge systems need to broaden away from the simplified 'technics' of high-throughput agriculture and include context-specific knowledge of whole agroecosystems, including knowledge of how effectively to steward the biodiversity and ecosystem services that influence them. Second, redesign requires farmers to work together, with collective action important across landscapes. Third, redesign requires institutional links between multiple stakeholders across scales. In essence, redesign is less about particular technologies or practices and more about the social, institutional and human dimensions of learning, communicating and monitoring dynamic agroecosystems.

Four broad principles characterize redesign initiatives.

(i). The first is a focus on transformation rather than management of an existing system. Redesigned farms are fundamentally altered by the addition of new elements, new configurations and linkages between elements. A corollary to this is an explicit emphasis on a new, essentially normative vision, and a commitment to tackle what Hill referred to as 'root causes.' For Hill and MacRae (1996), redesign is achieved 'when the causes of problems are recognized, and thereby prevented, being solved internally by site- and time-specific design and management approaches instead of by the application of external inputs' (p. 82). Hill argues for a deeper understanding of the psychosocial 'roots' of unsustainable practice (within agriculture and in society more broadly) and distinguishes between 'shallow' and 'deep' orientations to change (Hill, 2014).

(ii). Second, redesign initiatives are agroecologically-based. Farmers actively steward biodiversity to manage processes of predation, parasitism, allelopathy, herbivory, nitrogen fixation, pollination and trophic dependencies (Gliessman & Rosemeyer, 2009; Gurr et al., 2016). While efficiency and substitution are based on particular inputs, practices and technologies, redesign focuses on maintaining and managing biodiversity and whole ecosystems on and around farms. In doing so, the aim is to create 'systems capable of sponsoring their own soil fertility, crop protection and yield constancy' (Altieri & Rosset, 1996, p. 165).

(iii). Third, redesign involves new relationships and forms of organization and is essentially a social, political and cultural challenge. It depends on social capital, which comprises relations of trust; reciprocity and exchange; common rules; norms and sanctions and connectedness. Where these new relationships and forms of organization are nurtured, farmers are able to benefit from social learning, can spread new ideas, share resources and collaborate to advocate for their rights and entitlements.

(iv). Finally, redesign is knowledge-intensive and draws on a wider variety of knowledge-bases than is typical within conventional, high-throughput systems. Redesign emerges from, and is supported by double- and triple-loop learning. Double-loop learning helps us to question the assumptions behind the questions we ask, and can thus lead to reframing. Triple-loop learning reconsiders underlying values and beliefs. Double- and triple-loop learning involves reconsidered norms and transformed institutions (Armitage, Marschke, & Plummer, 2008; Hill, 2015). Both are supported by participatory and decentralized pedagogies. Farmer field schools, the use of new media, and multi-stakeholder platforms, are all examples of tools that are being used extensively alongside scaled-up redesign initiatives. Nicholls and Altieri (2018, p. 2) highlight how peer to peer knowledge exchange has led to an 'unprecedented return on agricultural technology investment'.

Agricultural systems exemplifying these principles are achieving scale worldwide. A recent global assessment of 400 projects, initiatives and programmes worldwide showed that of these, 47 exceeded the 10^4 scale (of either hectares or numbers of practicing farmers). Within this set, 17 exceeded the 10^5 scale and 14 were above 10^5. Overall, an estimated 163 M farms worldwide (covering 453 M hectares, or 9% of the global total) have redesigned their operations by implementing integrated pest management, conservation agriculture, by stewarding biodiversity on and around farms, incorporating new mixed farming elements, redesigning irrigation and crop water management and intensifying production on small patches of land or water (Pretty et al., 2018). These initiatives show promise for transformation at scale, and open up a new frontier in thinking about agricultural intensification.

2. The emergence of alternative agricultures in post-Green Revolution India

Productivity gains achieved during the Indian Green Revolution (mainly focused on high-yielding wheat and rice) have not averted a pervasive agrarian crisis India. Farmers received free electricity to pump groundwater, high yielding varieties of wheat and rice, subsidized inputs and minimum support prices. Output soared, but at a price: the northern Indian heartlands of the Green Revolution are now perhaps 'the most heavily irrigated region in the world,' with 'probably the largest rate of groundwater loss in any comparable-sized region on Earth' (Tiwari, Wahr, & Swenson, 2009, p. 1). Some 1 M ha in NW India are affected by irrigation-induced salinization and in the state of Haryana, waterlogging and salinity cause losses estimated at US$37 million annually (Datta & de Jong, 2002).

At the same time, smallholders, those without access to private tubewell irrigation, and those cultivating so-called 'resource poor' farms were largely eclipsed from the 'state subsidized windfall' experienced by more prosperous farmers (Stone, 2019; Subramanian, 2015). Up to the late 1980s, investment in irrigation and flood control was twenty-two times that dedicated to soil and water conservation in rainfed landscapes (Vaidyanath, 1994), which remained 'unrecognized in mainstream planning'. The first mention of rainfed dryland farms in the national planning process in the 1980s was accompanied by the admission that 'decades of neglect had led to dryland areas being caught in a vicious circle of high risk, low investment, poor technology and low production' (Chhotray, 2011, p. 56). Farmers in these landscapes continue to experience hunger, poverty and malnutrition and are increasingly vulnerable to a combination of climatic variability and economic development (Kumar, Shivamurthy, & Biradar, 2016; O'Brien et al., 2004; Yadav & Lal, 2018).

A number of alternatives have emerged in response to these crises, seeking to reverse rural decline through revitalized, sustainable farming systems. Encompassing a diverse array of state, private and third-sector initiatives, grassroots movements and hybrid forms, the nascent post-Green Revolution transition to agricultural sustainability in India does not constitute a homogenous nor internally consistent whole. Forms, approaches and even underlying ontologies vary markedly, but in common is a commitment to revitalizing smallholder agriculture and the ecosystems on which it depends. Many these initiatives may broadly be said to be forms of sustainable intensification, some may qualify as forms of redesign.

Emerging either in opposition to dominant agrarian political economy, as a response to longstanding marginalization, or to mitigate the social-ecological externalities of conventional cultivation, these alternatives take various organizational forms. These range from organized development initiatives, farmer collectives (e.g. for seed saving and sharing), formal certification schemes (most notably for organic production) and a new wave of what Münster (2016) terms 'neoliberal agro-entrepreneurship'. There is also a broad tradition of 'natural farming', propounded by advocates such as Narayana Reddy (in Karnataka), Shripad Dabholkar (Maharashtra), G Nammalvar (Tamil Nadu), Partap C Aggarwal (Madhya Pradesh) and Bashar Save (popularly referred to as the 'Gandhi of Natural Farming', working in Gujarat). Finally, in recent years there has also been a wave of state-led initiatives to 'convert' entire provinces to particular forms of (more) sustainable agriculture – most notably organic. The states of Sikkim, Karnataka, Mizoram, Kerala, Andhra Pradesh, Himachal Pradesh, Madhya Pradesh, Tamil Nadu, Maharashtra and Gujarat all have organic farming policies or regulations. A total of 835,000 Indian farmers are certified organic cultivators (amounting to 30% of the total number of organic farmers globally, on 1.78 M ha of land, representing an increase of some 290,000 ha since 2017) (FiBL and IFOAM, 2019). In practice, alternatives overlap and co-exist, with farmers developing and adopting components of different packages in combinations best suited to their farms.

Driving these transitions have been a combination of grassroots social movements (e.g. Khadse et al., 2017) on the influence of these dynamics on the spread of ZBNF in Karnataka, the formation of heterogeneous networks transcending conventional networks (e.g. Basu & Leeuwis, 2012, on the spread of the system of rice intensification (SRI) in Andhra Pradesh) and the engagement of conventional actors such as state agricultural universities and departments.

Many alternatives actively position themselves in terms broadly consonant with 'redesign', inasmuch as they aim towards vibrant rural lifeways and seek to fundamentally re-vision farmers' relationship with the land and with the market. Münster characterizes these initiatives as a form of 'protective double-movement', 'aiming to regenerate rural society from the consequences of the commodification of land (nonhuman nature) and labour (human nature)', or as ways to repair or rework the metabolic rift brought about by capitalist agriculture (Münster, 2016, p. 222). Most promote 'low external input' forms, advocating 'ecologically integrated techniques and the development of local food markets to reduce farmers' dependency on market inputs that are external to the local farm system … theoretically reducing expenses while lowering the ecological burden of agriculture' (Brown, 2018, p. 3).

3. Zero budget natural farming and its spread in Andhra Pradesh

ZBNF is a system developed in the 1980s by Indian farmer, agricultural scientist and extension agent Subhash Palekar who established ZBNF after a period of self-study of the *Vedas* (the oldest of the Hindu scriptures), organic farming and conventional agricultural science, testing methods on his own farm. The phrase 'Zero Budget' refers to the aim of achieving dramatic cuts in production costs by ending dependence on external synthetic inputs and agricultural credit. It is not meant to signify 'zero costs'. Instead, as practicing farmers clarify, it is meant to signify that 'the need for external *financing* is zero, and that any costs incurred can be offset by a diversified source of income' (ABZNF 2018 quoted in Khadse & Rosset, 2019, p. 9, emphasis added). The phrase 'Natural Farming' invokes the agroecological basis on which these cuts are to be achieved. The practice consists of four principles, referred to by ZBNF practitioners as the four 'wheels' of ZBNF (Table 1). In addition to these, ZBNF farmers also reduce or avoid the application of synthetic pesticides, relying instead on homemade preparations for controlling fungus and insect pests, sourced from locally available trees and plants such as neem, chili, garlic and tobacco. Finally, farmers are encouraged to plant live fences, use trenches for water harvesting and design fields using a 'five layer' multi-cropping model, integrating trees with crop plants in a 'canopy' formation wherein each plant is able to access the right amount

Table 1. The four wheels of ZBNF and their intended impacts (adapted from La Via Campesina, 2016).

Wheel and practices	Intended Impact
Bijamrita (Seed treatment)	Protection from seed and soil-borne disease
The application of a homemade seed treatment consisting of cowdung and urine to seeds and seedlings.	Increase soil carbon Activate nutrients
Jivamrita (Liquid and solid inoculants)	Improve soil condition
The application of an in-situ culture of water, cow manure and urine (from the indigenous variety, *Bos indicus*), unrefined cane sugar, legume flour and uncontaminated/ virgin soil (to introduce local soil microbiota).	Increase activity of soil biota including microbes and earthworms Increase soil organic matter Prevent harmful fungal and bacterial growth
Acchadana (Mulching)	Improving soil condition, particularly topsoil
Soil mulching (avoiding tillage), straw mulching (the application of straw to the soil) and live mulching (intercropping with, e.g. nitrogen-fixing crops).	Adding organic matter and fertility Increased activity of soil biota (including microbes activated by *Jivamrita*) and soil insects.
Whapasa (Soil aeration)	Reduced overreliance on irrigation and improved
Building up of soil humus	aeration and soil moisture profile

of sunlight (Khadse & Rosset, 2019; La Via Campesina, 2016; Palekar, 2019). While ZBNF remains the most widely used term to describe these practices, there has been recent discussion amongst policy-makers and leading practitioners of a potential change in terminology to 'Chemical Free' Natural Farming or even 'Community Managed' Natural Farming to better reflect farmer practices and avoid misunderstanding regarding input costs. In this paper, we retain use of the term 'Zero Budget' in order to reflect existing usage, and in the absence of any formal or widely accepted change in terminology.

ZBNF has so far been adopted most prominently in the states of Karnataka and Andhra Pradesh. Adoption in Karnataka has been achieved through a grassroots social movement, initially spearheaded in 2002 by the Karnataka *Rajya Raitha Sangha* (an organizational member of La Via Campesina) (Khadse et al., 2017). Palekar's teachings initially received a mixed response from farmers, until early adopters began showcasing success to peers (Khadse & Rosset, 2019). Training workshops grew in number and size, with an estimated 200 workshops having been organized over the last 15 years in the state (Khadse & Rosset, 2019). The state governments of Himachal Pradesh (Government of Himachal Pradesh, 2018) and Karnataka have since allocated funds to support the spread of ZBNF and the state governments of Rajasthan, Meghalaya, and Gujarat have all expressed an interest in setting up programmes for ZBNF.

Precise figures for numbers of farmers adopting ZBNF across the country are unavailable, partly because learning, teaching and practice are not centrally organized by any single agency, and partly because farmers tend to adapt the package, adopting one or two elements (Khadse et al., 2017). What is clear is that farmers are enthused by the method. In Karnataka for example, an estimated 60,000–100,000 farmers have attended 60 training camps organized over the last decade (ZBNF leader cited in Khadse et al., 2017).

In contrast to the 'bottom up', grassroots organization of ZBNF elsewhere, Andhra Pradesh has made ZBNF the central pillar through which to execute state agricultural and rural development policy. The formal roll out of ZBNF-focused extension in Andhra Pradesh was foreshadowed by a number of initiatives designed to help farmers (particularly smallholders) transition to more sustainable and viable agricultural livelihoods. Before turning to the specifics of the ZBNF programme, we briefly describe these initiatives, which contained within them a number of institutional innovations now supporting the spread of ZBNF.

Andhra Pradesh is located in southeastern India, and has been known as India's 'Rice Bowl' on account of its tracts of irrigated paddy cultivation within the basins of the Godavari, Krishna and Penna rivers. Further inland, rainfed dryland farming predominates, with farmers relying to varying extents on protective irrigation from mainly private sources. Across the state, some 62% of the population is employed in agriculture and allied activities, cultivating around 8 M ha of cropped area and generating just over a quarter of the state's GDP. In addition to rice, the state is also a major producer of fruit, eggs, and aquaculture products. The adoption of Green Revolution innovations contributed to significant yield growth for important food staples – rice, groundnut and lentils. However, from the 1990s, yields began to decline. Conventional high-throughput systems began to be recognized as costly and increasingly ineffective. By the early 2000s, small farmers (those cultivating <2 ha) were spending 35% of their cultivation expenditure on synthetic pesticides and fertilizers (against a national average of 30%) (Government of India, 2005).

The significance of this is two-fold. First, high expenditure on synthetic inputs is a key driver of indebtedness. In the early 2000s, small farmers in Andhra Pradesh earned just $154 annually from agriculture and related sources (with an average annual income of $440 and average expenditure on cultivation of $268) (Thallam et al., 2009). As a result, some 82% of farm households in the state were indebted, with an average outstanding loan amount of $660 per farmer (more than twice the national average of $280) (Centre for Economic and Social Studies, 2007). Second, this model of farming came with a high ecological footprint, with the state recording amongst the highest rates of consumption of synthetic pesticides in India, with application rates of 0.87 kg a.i./ha (against a national average of 0.3 kg/ha).

Responding to these challenges, a number of grassroots and civil society initiatives emerged in the early 2000s, attempting (in the first instance) to effect a transition away from synthetic inputs. NGOs such as the Centre for World Solidarity helped spread awareness of alternative, ecologically benign methods of pest control. At the same time, farmers began experimenting with alternative methods independently, helping to create wider acceptance for more participatory forms of knowledge creation and innovation (Thallam et al., 2009).

A step-change was brought about when the Society for Elimination of Rural Poverty (SERP) (a non-profit set up by the Government of Andhra Pradesh) integrated 'Community Managed Sustainable Agriculture' (CMSA) into its poverty reduction programme. This was managed by community institutions – in the main, a pioneer initiative was the creation of federated structures of women's self-help groups (WSHGs) encompassing some 10 M women, organized into just over 850,000 groups and representing around 90% of all poor households in the state. This institutional architecture helped drive a 'complete paradigm shift [away] from conventional agriculture' (Thallam et al., 2009, p. 11, parentheses added), as well as significant cost-savings for farmers (Rao, 2012) in three (non-linear, loosely overlapping) stages (Figure 1).

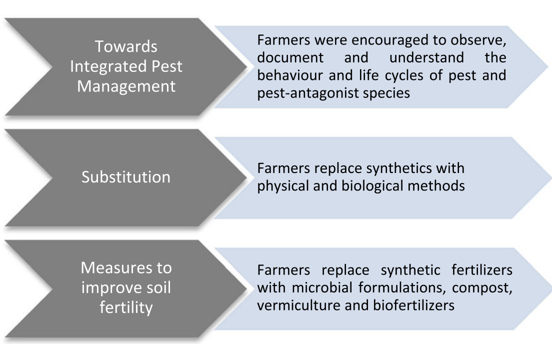

Figure 1. Three-stage transition towards sustainable production in Community Managed Sustainable Agriculture in Andhra Pradesh (adapted from Thallam et al., 2009).

As part of these efforts towards sustainable agriculture, Subhash Palekar was invited to conduct a number of ZBNF training workshops in the state. At around the same time, the Andhra Pradesh department of agriculture set up a dedicated non-profit organization, the *Rythu Sadhikara Samstha* (RySS, 'Farmers Empowerment Organisation') in 2014. The RySS now acts as the single institutional mechanism coordinating 'all programmes, schemes and activities intended for farmer's empowerment, encompassing welfare, development, capacity enhancement, credit flow, financial support and allied empowerment activities' (Government of Andhra Pradesh, 2019). The spread of ZBNF is tightly woven into this mandate, with the RySS designated by a formal Government Order in 2016 as the Implementing Organisation responsible for the roll out of ZBNF. The overall goal is to reach 6 million farmers and convert 8 million hectares (90% of the cultivated area) into ZBNF fields by the end of the next decade, paying special attention to conserving both farmer livelihoods and ecosystems. The RySS estimates that around 580,000 farmers have begun practicing ZBNF in the state by 2019, up from 163,000 in 2017–2018 (V Thallam 2019, *pers. Comm.*, email dated 28th September, 2019).

4. Building social and human capital

Key to the scaling of ZBNF in Andhra Pradesh has been the work done from the early 2000s to build a dense, multi-layered community-based extension ecosystem. This ecosystem is organized across 3 scales: a 'zone', (consisting of approximately 80 households); a *Gram Panchayat* (roughly analogous to a village-level administration) and finally, a 'cluster' of five Gram Panchayats (Figure 2).

Peer to peer learning is key: 'Community resource persons' (CRPs) are farmers who have been designated as community-level extension agents. The CRPs' main role is to communicate ZBNF principles

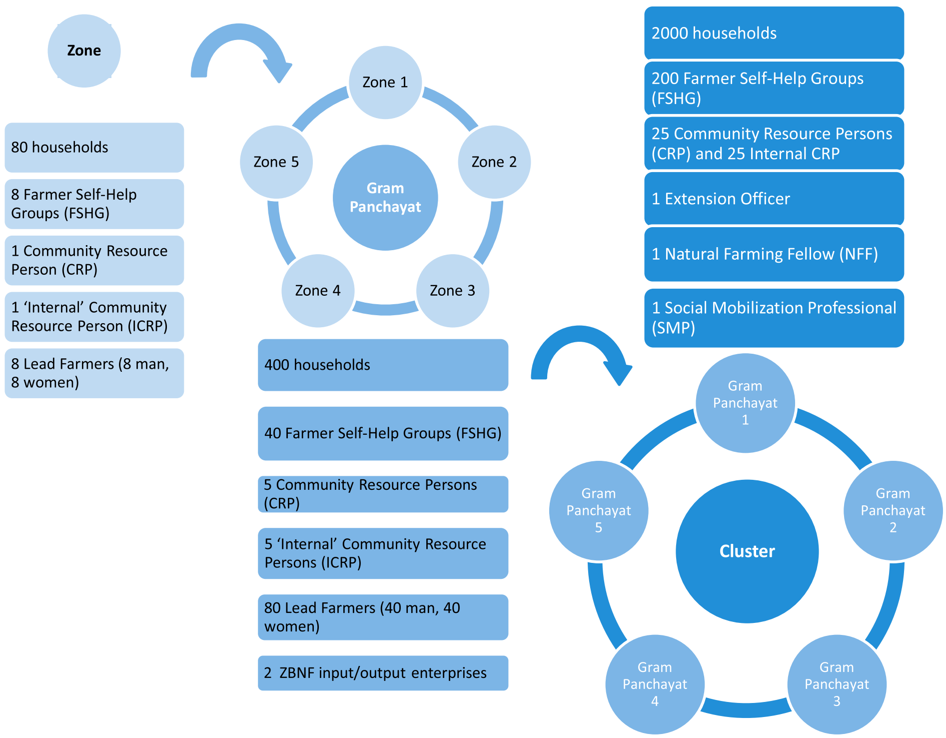

Figure 2. Institutional-levels supporting ZBNF roll-out in each zone, gram panchayat and cluster (adapted from RySS, 2018a).

among potential adopters, fulfilling a detailed brief requiring extensive engagement with farmers. Khadse and Rosset (2019) highlight how

> they [CRPs] have a full schedule of mandatory daily activities to ensure that they cover all of the SHGs [self-help groups] assigned to them. In the mornings, they organise a study circle in a specific village. In the afternoon they visit farmers' fields for troubleshooting. In the evenings, they project videos related to the days learnings so that farmers can engage in discussions. (p. 15, parenthesis added)

Farmer field schools are held weekly, facilitated by trained conveners, and include male and female farmers engaged in ZBNF 'best practice'.

Farmers transitioning to ZBNF in Andhra Pradesh are thus embedded within a supportive network of peers, practitioners and formally trained agronomists, together forming a dense learning ecosystem designed to support a knowledge-intensive transition towards more integrated, complex agricultural systems. Farmers are encouraged to experiment with ZBNF, progressively deepening their practice. This means that for some farmers, early adoption may be restricted to simple input substitution – using ZBNF formulations in place of synthetic externally derived inputs. Success with these then encourages further experimentation, and farmers may move closer to adopting the whole ZBNF package. RySS interim targets and scaling plans estimate that a typical farmer begins by experimenting with ZBNF on approximately one quarter of land available, supported by a 'farm action plan' designed with the local self-help group or village organization, transitioning to full-scale adoption across the entire farm in approximately 3 years (RySS, undated).

Five *Gram Panchayats* together make a 'cluster', each of which is additionally supported by a designated multipurpose extension officer, a Natural Farming Fellow, and Community Resource Persons (CRPs), including one dedicated to 'social mobilization'. Natural Farming Fellows are graduates who undertake a 2-year Fellowship during which they are resident in a village, practicing ZBNF as a 'role model farmer' (Figure 2), assisting in the spread of ZBNF within the villages that form a cluster (Figure 2), and working on a selected thematic area (RySS, 2019a, 2019b). CRPs are local residents who may be regarded as 'exemplar' ZBNF farmers, implementing all aspects of ZBNF, who play a leading role in promoting farmer-to-farmer learning and acting as advocates for ZBNF (a function termed 'social mobilization' within the RySS) (RySS, 2019b).

The planned roll out aims to replicate this architecture across each of Andhra Pradesh's 12,924 Gram Panchayats, at an estimated cost of Rs. 10,000,000 (US$ 140,100) per Panchayat (translating to around Rs. 25,000 (US$ 350) per household). ZBNF 'sub-committees' are formed at every level of village and local government administration up to district level, holding monthly meetings. Community-based monitoring is carried out by women's self-group members, who inspect fields (with budgets provided for these inspections). Finally, village shops and hiring centres are set up to act as knowledge centres and supply points for ZBNF inputs, and equipment. Local hiring centres contain low-HP machines such as pulverisers, power weeders and sprayers.

Since the inception of the programme in 2016, there have also been four further 'mega-training' programmes in Andhra Pradesh organized with Subhash Palekar, each hosting thousands of farmers, local extension officers and RySS staff. Community Resource Persons continually acquire new skills through human-mediated digital extension videos on ZBNF practices followed by farmer group discussions after video sessions. In order to facilitate this, they are trained in using smart phones (as well as ICT to monitor farmers' progress).

5. ZBNF outcomes for crops, incomes and farm ecosystems

The literature on the impacts of ZBNF impacts, and draws mainly on data collected outside Andhra Pradesh. Khadse et al. (2017) surveyed 97 farmers in Karnataka in 2012, asking farmers to rank changes to general crop yields, income and production costs on a three-point scale (increase, decrease or no change). 78.7% of their respondents stated that yields had increased, 85.7% reported improvements to income, and 90.9% reported that production costs had decreased. In Andhra Pradesh, internal surveys carried out by RySS of crop yields show higher yields under ZBNF conditions and notable increases in farmer income (mainly through reduced production costs). Crop-cutting experiments conducted in 2017 showed that 88% of farmers surveyed ($n = 1614$) had benefited from an increase in yields and decrease in costs, with yields increasing across crop types and in some cases, outpacing average state yields for Andhra Pradesh (RySS, 2018b).

We analyzed data from crop-cutting experiments conducted by RySS amongst farmers who took up ZBNF in 2016. Crop-cutting was conducted during the 2017 *kharif* (monsoon) season, on 1531 ZBNF and 1531 non-ZBNF plots. Data were sent to the UK-based team as an Excel dataset. This was cleaned, checking for errors or data gaps, and then saved to a database on IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA) in advance of analysis. These data cover food crops (rainfed and irrigated cereals, legumes and horticultural crops) and cash crops (irrigated and rainfed cotton) across all 13 districts in Andhra Pradesh. To facilitate paired comparisons between ZBNF and non-ZBNF conditions, crop cuttings were taken from two 5×5 m samples (10×10 m for cotton), one from crops grown using ZBNF practices, and the other using conventional practices. This control sample was taken either from a section of a ZBNF farmers' field where conventional practices were being used (most farmers stagger the adoption of ZBNF), or from an adjacent field where the same crop was being cultivated using conventional practices (subject to matching for soil type, seed variety and irrigation regime). The majority of the sample were smallholders cultivating <1 ha each of land.

Across the sample, a Mann–Whitney U Test (as the data were non-parametric) showed a statistically significant difference between ZBNF and non-ZBNF crop yield: (ZBNF (Md = 13.21), non-ZBNF (Md = 12), $U = 956250.5$, $z = -8.82$, $p < 0.001$). ZBNF yields were higher than non-ZBNF yields across all districts except one (the district of West Godavari, where yields were 7% lower, likely due to anaerobic soil due to water logging, which is a normal phenomenon in the delta region). All crops except irrigated maize and irrigated cotton show higher yields under ZBNF relative to a non-ZBNF control (see Figure 3 for yield differences that attained statistical significance with the Mann–Whitney test). Costs of cultivation under ZBNF conditions were lower, and net incomes higher, than non-ZBNF for all crops (Figures 4 and 5). Irrigated crops achieved slightly larger reductions in costs of cultivation relative to rainfed crops (−28% against −24%, determined by calculating total reductions across all irrigated crops versus all rainfed crops).

Previous models of agricultural intensification in India have relied either on the heavy abstraction of groundwater or intensive water use of surface water. India is the world's largest consumer of groundwater, with some 10 million wells supporting up to 70% of

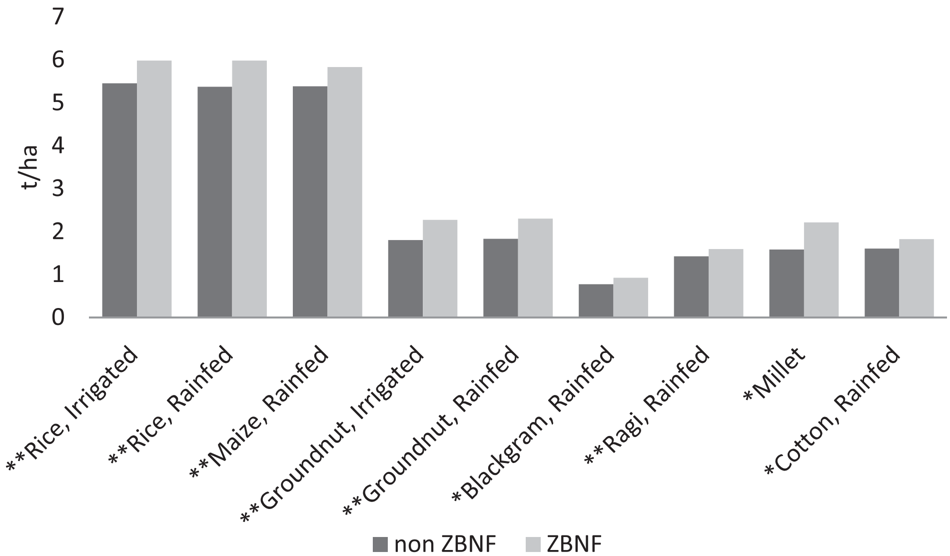

Figure 3. Yields (t/ha) under ZBNF and non-ZBNF for key *kharif* season crops, 2017 (* significant at $p < 0.05$ and ** significant at $p < 0.001$).

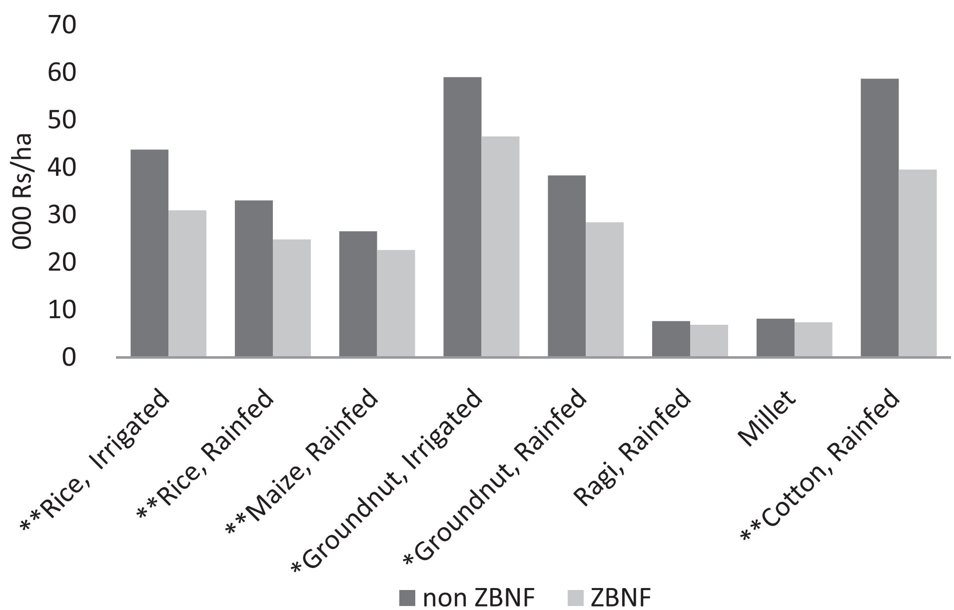

Figure 4. Cost of cultivation under ZBNF and non-ZBNF crops (000 Rs/ha), *kharif* season 2017 (* significant $p < 0.05$, ** significant at $p < 0.001$).

Table 2. Mann-Whitney U Tests for difference in yields, cost of cultivation and income between ZBNF and non-ZBNF across a sample of rainfed crops ($n = 678$ pairs).

	ZBNF compared with non-ZBNF	ZBNF Actual	Non-ZBNF	Significance
Yields (t/ha)	+16.5%	4.80	4.12	$P < 0.001$
Cost of cultivation (000 Rs)	−23.7%	22.9	30.0	$P < 0.0005$
Gross income (000 Rs)	+14.2%	80.6	70.6	$P < 0.001$
Net income (000 Rs)	+50.0%	54.0	36.0	$P < 001$

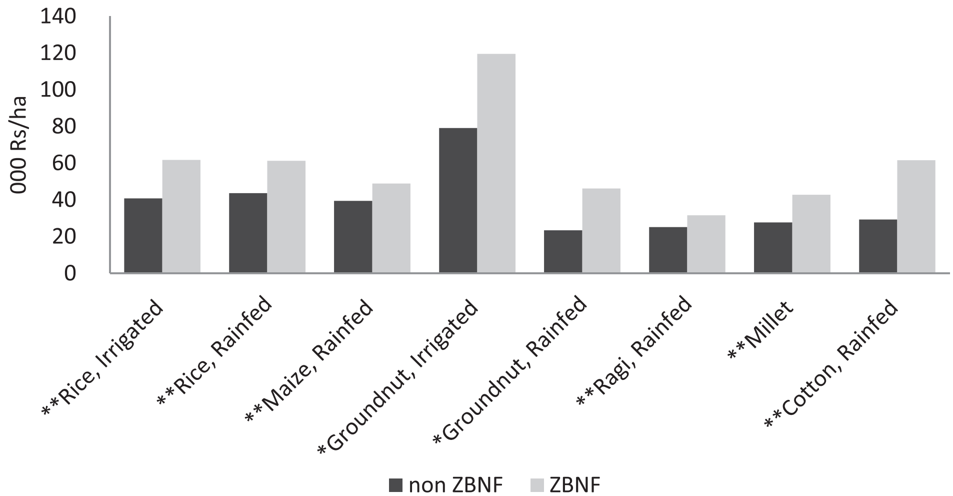

Figure 5. Net incomes under ZBNF and non-ZBNF crops (000 Rs/ha), *kharif* season 2017 (* significant at $p < 0.05$ and ** significant at $p < 0.001$).

the country's agricultural production (Fishman, 2018; Shah, 2008). New models of intensification are thus required; methods that do not work for rainfed crops without requiring irrigation intensification are unlikely to be sustainable over time. In light of this it is encouraging to note that rainfed crops within the sample ($n = 678$ pairs; representing farmers of rainfed paddy, maize, groundnut, finger millet and cotton) fare better under ZBNF methods than non-ZBNF controls (Table 2).

While the RySS continues to collect data from crop-cutting experiments annually (thus allowing future longitudinal assessments), independent evaluations of changes to crop yields are also forthcoming (most notably from multi-site trials being conducted by the Indian Council of Agricultural Research).

6. Farmer testimonies on outcomes for farm ecosystems and household transitions

Field observation, farmer testimonies and reports from extension workers, are so far the primary source of information on broad changes on and off farm in Andhra Pradesh. Natural Farming Fellows, Community Resource Persons and other RySS staff have been collecting farmer testimonies since the first adoption of ZBNF. In 2018, some of these were transferred to the UK-based co-authors, anonymised, and saved as a collection of short, qualitative testimonies on the themes of biodiversity, resilience to climate shocks, and crop health. It should be noted that these do not necessarily represent a systematically collected body of generalizable evidence, but have been purposively collected and presented to show that under favourable circumstances, farmers have experienced positive outcomes across a range of farm health indicators beyond increases to crop yields and incomes.

(i). Crop health and resilience to climate shocks: both farmers and extension workers report better plant health and vigour in ZBNF fields (Boxes 1 and 2) amongst a range of horticultural and arable crops, including after flooding (Figure 6) and dry spells. RySS workers attribute this to deeper and larger root systems and more robust plant structures in plants raised under ZBNF conditions. RySS workers and ZBNF farmers in the districts of Ananthapur, Kurnool and Vishakapatnam, for example, reported greater resilience to cyclone damage (Figure 6) as well as dry spells (with yields maintained under ZBNF conditions during the 2016 drought as well as dry-spells in 2017). The generalizability of these outcomes should be established through further studies that use stratified random sampling across the landscape and assess the performance of ZBNF fields following a range of different types and severities of climate shock.

(ii). Biodiversity: no systematic biodiversity assessments have been conducted following the adoption of ZBNF, but farmers and extension workers have been using text messaging and WhatsApp to share photos of insects and other fauna noted on ZBNF fields. One systematic comparison

Figure 6. ZBNF paddy field (left) and non-ZBNF paddy (right) after cyclone damage, Vishakapatnam district, (2017) (Source: RySS Natural Farming Fellows 2017).

between ZBNF and non-ZBNF fields occurred in 2018, finding a difference in earthworm numbers and castings between ZBNF and non-ZBNF fields across 480 samples taken from all 13 districts in Andhra Pradesh. ZBNF fields hosted an average of 232 earthworms per square metre, compared with just 32 on non-ZBNF fields (RySS, 2018c *unpublished data*). ZBNF farmers also report a number of earthworms on ZBNF plots (Figure 7), as well as beneficial insects (pollinators and pest antagonists), including honeybees, lacewing bugs (an antagonist to aphids, leafhoppers, whiteflies and mealybugs) and ladybugs in various crop types and agro-climatic zones.

Box 1. Farmer testimony on the impact of ZBNF practices on crop quality (*name changed).

Kamal*, a farmer from Anantpur district has been practicing agriculture for 15 years. He has just over 2 hectares of land, on which he has mainly been cultivating Papaya for the last 5 years. He was inspired by his interaction with a Community Resource Person in 2017, and began practicing ZBNF. He has been learning about the method through regular attendance of his local farmer self-help group, which has also given him access to credit with three loans.

At first, he began by preparing *Ghanajeevamrutham* and *Dravajeevamrutham* on his own. He avoided the use of any synthetic fertilizer and used drip irrigation. Over the first 7 months', the entire papaya plantation has changed dramatically. He has observed a number of changes to the papaya trees, including dense leaf-growth, budding within 2 months and a greater number of fruit per tree. In the first cutting, he has been able to fetch a higher than average price at market due to the quality of the fruit. Kamal's papaya field attracts farmers from surrounding villages and his success has inspired a number of other farmers to take up ZBNF.

Box 2. Farmer testimony on improved farm health after the adoption of ZBNF, improved yields and higher income (*name changed).

Mr. Kumar* had initially leased out his land on lease. The tenant farmer indiscriminately used synthetic pesticides and fertilizers. Kumar was dismayed by the condition of the soil and cancelled the lease agreement. He decided to practice natural farming on his field after he learned about its benefit and underwent a training programme over one week. After undertaking natural farming practices he observed the following changes in his field:

(i) Soil: Improved porosity and increased numbers of earthworms

(ii) Income: Intercropping of sugarcane with chilli, eggplant, tomato and coriander provides

(iii) A year-round income.

(iv) Insects & pest control: He is maintaining 12 hens and 5 turkeys, to help control insects and pests in the field.

(v) Mulching: He uses residue of previous crops

(vi) Value addition: Sugarcane to jiggery, paddy to rice

(vii) Marketing: Consumers come directly to his fields to buy his produce

(viii) Cattle: He has his own cattle shed through which he uses cow dung and cow urine in his own fields along with selling the surplus to the villages to create awareness about natural farming.

In addition to new crop types and rotations, farmers have added new elements to fields to help control insect pests. The addition of bird perches, yellow plates, pheromone trap crops and the use of 'friendly' insects, all introduced during earlier efforts

Figure 7. Earthworms on ZBNF plot (Source: RySS Natural Farming Fellows 2018).

for community managed sustainable agriculture, continue to be used by ZBNF farmers. Farmers have also begun experimenting with adding elements independently, keeping small free-ranging poultry, like hens and turkeys, and allowing them to forage through fields as a means of pest control. Crop diversity has also clearly increased, with farmers specifically encouraged to take up polycropping. Further work will need systematically to assess biodiversity improvements on and around ZBNF farms, and the pathways through which change occurs.

(iii). Household transitions: in order to capture farm-system and household-level change we asked a small number of ZBNF farmers to describe household and landscape level change over the last three years (from adoption of ZBNF in 2016 to the present) (Figure 8(a and b)). This data was collected remotely by RySS-based Natural Farming Fellows following a template for participatory rural appraisal (PRA) provided by the UK-based co-authors. Ethical approval was obtained from the Departmental ethics review panel at the Global Sustainability Institute at Anglia Ruskin University prior to data collection. Ethical review covered the methods used to collect, store and analyse these participatory data. Before conducting the PRA, the UK-based research team prepared a simple random sampling list of farmers covering all crops and districts, after which a subset of 34 individuals were purposively selected based on their availability and willingness to participate.

In July 2018, a two-day exercise was conducted with the selected farmers, who were asked to follow a single instruction: to graphically illustrate significant changes to their farms, households or wider communities since the uptake of ZBNF. We did not predetermine what aspects of change farmers should illustrate, leaving it to them to represent what they felt was most important. Descriptions were captured through drawings on one A5-sized sheet per farmer, with the support and facilitation of local Natural Farming Fellows. The drawings thus obtained consist of resource maps of local villages and fields; social maps illustrating new webs of relationships supporting crop cultivation, harvesting, storage and sale; food plates illustrating new dietary regimes; income and expenditure cycles and value chains. Figure 8(a and b) provide a figurative example. Drawings were scanned and sent electronically to the UK-based team, who were debriefed on each drawing during a conversation conducted over Skype. Key themes are summarized in Table 3. Further work is necessary to assess how these various outcomes play out over time and across a stratified sample of ZBNF farms.

7. ZBNF transitions as a form of redesign

Agricultural system redesign constitutes a fundamentally social, cultural and institutional challenge rather

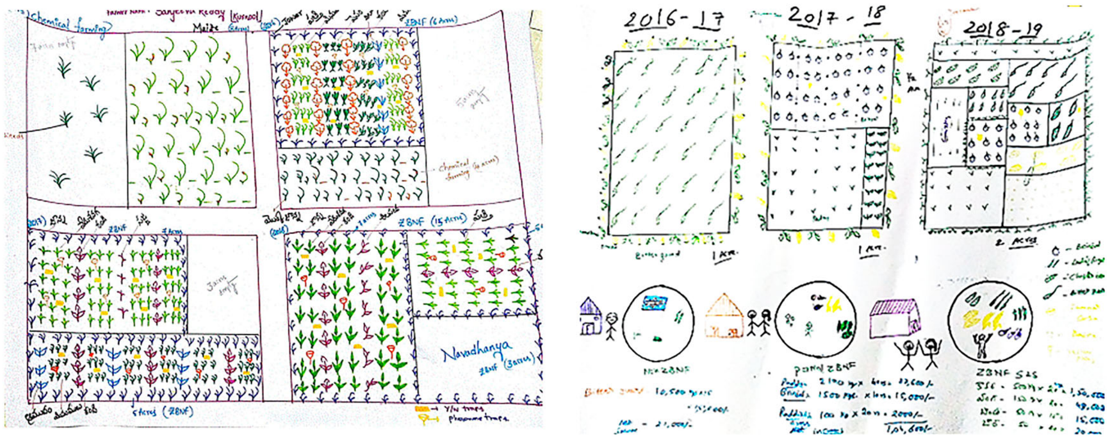

Figure 8. (a and b) Resource (field) map representations on the evolution of cropping systems on a rainfed farm in Kurnool district, between 2015 and July 2018.

than either a set of technologies or practices (Hill, 1985). Within this section, we reflect on the ways in which ZBNF is consonant with the concept of redesign. An important qualification is the lack of any uniformity in ZBNF 'practice' either in general or within the structured uptake of the package designed by RySS by Andhra Pradesh's farmers. Farmers adopting the method following attendance of Palekar's training camps have adapted the method to suit the practicalities of their individual farms, and may adopt a suite of methods – agroecological or otherwise – alongside Palekar's prescribed inputs and farm designs (Khadse et al., 2017). Methods may also change year by year, depending on external drivers (weather and prices) or imperatives at farm and household level. The resulting complex of results and impacts across the state is likely to be extraordinarily complex, and complicates efforts to discuss 'general' ZBNF practice and outcomes. Farmers adopting ZBNF in Andhra Pradesh through structured support from RySS, though arguably part of a more formalized programme, nevertheless also adopt the method progressively (Khadse & Rosset, 2019), leading to a broad range of farm regimes across the landscape. Nevertheless, our aim at this stage is to discuss underlying principles, rather than evaluating ZBNF practice against a set of fixed criteria.

First, ZBNF – both as advocated by Palekar and as practiced specifically in Andhra Pradesh – is radical, going beyond incremental change within existing agricultural systems. Proponents aim to fundamentally transform farm systems, and with them, rural livelihoods. Palekar specifically discusses changed norms and subjectivities: 'the internal and external change

Table 3. Key themes from farmers' testimonies on ZBNF outcomes for farms and households.

Theme	
Crop health and resilience	Farmers reported greater crop resilience to dry spells and other climate shocks. Annotations with income figures showed that losses of some high value crops due to pest attacks or climate shocks were adequately offset by stable yields in other crop types, an outcome enabled by the RySS model of encouraging more complex crop mixes. Incomes were held stable despite crop losses, due to significantly lower production costs.
Greater crop diversity and more complex cropping patterns	Farmers illustrated transitions from monocropping to polycropping, with the progressive addition, year on year, of new crops and crop mixes, the design of new rotations and more complex cropping patterns. One farmer illustrated a transition from 1 crop type in 2016–10 in 2018, representing a significant increase in productivity but also human and natural capital.
Food plates	Farmers illustrating food plates drew a greater number of food types as well as greater quantities of food.
Health	Farmers illustrated a transition from periods of ill health to better health, smiling faces illustrated positive affect.
Incomes	Farmers illustrated improvements to housing, with transitions from *katcha* (rough, thatched) housing to *pukka* (permanent, concrete or mortar) housing.

simultaneously' (Palekar, 2010). ZBNF farmers are seen to be enacting new moral imperatives (Khadse et al., 2017) and are encouraged by Palekar to undergo no less than a 'change of personality and of the culture of farming', with a new ecological rationality: 'a new mindset … which involves a curiosity about ecosystems, renewed pride about being a farmer and a focus on a good life' (Münster, 2014, p. 25). Münster (2018, p. 755) describes how Palekar's training camps act as revival meetings in which farmers are 'repeatedly invited to stand up, raise their right arm and solemnly vow to transform themselves from being a "demon destroyer of nature" to a "saint protector of nature"'.

Proponents and practitioners (particularly self-identified ZBNF 'purists') also explicitly position ZBNF in stark opposition to mainstream agronomy and the dominant system of knowledge politics that advances it. Palekar calls on farmers to 'boycott all the techniques of Agricultural Universities' (Münster, 2018, p. 757) and he is also opposed to alternatives that, in his view, make insignificant or incremental adjustments. Organic agriculture, for example, is criticized by Palekar for not being radical enough, on the basis that farmers simply replace synthetic inputs with permissible alternatives (Münster, 2016) without actually re-visioning their relationship to the land. For Palekar, ZBNF is meant to drive a more fundamental cultural challenge to mainstream agronomy and replaces the common focus on accumulation or productivity with a focus on 'autonomy, health and self-sufficiency' (Münster, 2016, p. 223). It is beyond the scope of this paper to disaggregate these vibrant and continuing debates or to assess the relative merits of various positions; here we seek to point out that both ZBNF proponents and practitioners seek to implement radical change that goes beyond incremental improvements to farm efficiency or input substitution.

Both 'zero budget' and 'natural farming' are meant to signify substantial shifts in relations with markets and nature. The first, 'zero budget', signifies no less than a drive for complete independence from external inputs (and thus from input suppliers and, ostensibly, the entire constellation of capital, credit and indebtedness so central to farmers' contemporary livelihoods). In this sense, Palekar and ZBNF proponents seek to engage with key structural drivers of farmer poverty and agrarian distress, actively engaging with the 'root causes' mentioned by Hill (1985). 'Natural farming' is about more than permissible inputs. Instead, ZBNF farmers are encouraged to (re) conceptualize their farms as vibrant and intrinsically abundant ecosystems, which simply need to be stewarded respectfully. For example, Palekar compares the sustainable farm to the 'self-sufficient forest', which needs no external inputs in order to thrive.

For many farmers, Palekar's trainings are the first time they come to explicitly understand the agroecological basis of sustainable cultivation (Khadse & Rosset, 2019). In doing so they report undergoing a 'paradigm shift', realizing that soils are not an empty medium requiring external fertilization, but inherently fertile and abundant, only needing to be stewarded appropriately. Farmers also report a new sense of perspective as to their capacities and the need for a 'more than human' approach: '*From Palekar he* (the farmer) *claims to have learned that there are many things humans cannot do*' (cited in Münster, 2018, p. 756). Alongside this comes new 'affective relationships' between farmers and their cattle, wherein indigenous variety cows are 'treated … like a pet; cuddled, stroked, caressed, and admired for [their] beauty' (Münster, 2017, p. 25).

Finally, in Andhra Pradesh, RySS (2018d, p. 14) positions itself as an organization that seeks to drive transformative benefits for the economy, environment and equity through sustainable agriculture. It explicitly aims at:

> Converting the agriculture sector of Andhra Pradesh to 100% regenerative agriculture, zero budget natural farming through 6 million smallholders will deliver transformative benefits for the economy, environment and equity. It will present a first-of-its-kind blueprint for sustainable commodities production that reverses biodiversity losses and preserves ecosystem services, providing an opportunity for reclaiming planetary boundaries.

In all these ways, ZBNF discourses and material practices – diverse, variable and evolving as they are – reflect a key feature of Hill's concept of redesign: working outward from a core normative vision, a focus on addressing 'root causes' and going beyond technics to transform systems in their entirety and from within (including, quite explicitly, the active involvement of the farmers' inner life, a reconsideration of fundamental relationships between the farmer, his land, and the rest of nature, and a reworking of the knowledge politics which mediates this relationship).

A second key pillar of Hill's concept of redesign is its explicitly agroecological focus. Palekar's vision and ZBNF practice are clearly agroecological in scope and biodiversity-focused (Khadse et al., 2017). Palekar exhorts farmers to steward biodiversity on and around farms and most notably within soil. Within Andhra Pradesh, more complex cropping patterns, including rotations, multi and polycropping are building on-farm biodiversity, though more work is needed in order to systematically assess the influence of ZBNF on non-cultivated biodiversity both on and around farms.

Finally, redesign is a predominantly social and institutional challenge. It involves new relationships within and between actors, all working collectively across scales. ZBNF has clearly involved the building of both social and human capital. Its spread has been enabled through collaborative action across landscapes, peer-to-peer learning as well as collaborations between experts and 'expert practitioners'. Khadse et al. (2017) describe how ZBNF in Karnataka has successfully adopted a social movement dynamic that has facilitated its spread. Within Andhra Pradesh, the state roll out of ZBNF has of course proceeded through the functioning of a formal public sector institution – the RySS, working in partnership with farmers via a dense extension and farmer support networks. There is thus a clear difference between the narrow technocentrism that characterizes the formal extension systems of which Palekar is so critical, and the more participatory, farmer-led and farmer-focused forms which have driven the spread of ZBNF – both within grassroots social movements and within the more formal roll out in Andhra Pradesh. This hybrid model has helped farmers to go beyond simple yield increases, to additive and multiplicative improvements across the farm (Box 2).

8. Lessons for wider transitions to sustainable agriculture

The spread of ZBNF presents a relatively infrequent example of a policy-led transition to sustainable agriculture being implemented at scale in India. In this final section, we discuss a few important lessons presented by the Andhra Pradesh experience and outline a number of emerging questions requiring further research.

The first lesson centres on the role of clear policy directives, accompanied by adequate financing and institutional support. Policy support is vital for scaling sustainable agriculture (Garibaldi et al., 2019; Mier y Terán Giménez Cacho et al., 2018; Pretty & Bharucha, 2014), and a number of notable redesign initiatives that have achieved scale have done so as a result of explicit policy shifts. The regreening of the Sahel, for example, has been achieved by changing national tree ownership regulations that allowed the spread of agroforestry at scale (Godfray et al., 2010). Public policy support has also been vital to the development of social capital supporting sustainable agriculture (e.g. Australian Landcare, community forest management in India, Nepal and Vietnam, Mexican irrigation user groups, and farmer field schools in across Asia and Africa) (Pretty et al., 2018).

Key to the sustained scaling of ZBNF in Andhra Pradesh has been the layering of initiatives, allowing for momentum and experience to build. Previous programmes on community supported sustainable agriculture have put in place an institutional architecture on which the ZBNF programme is able to capitalize. The RySS has been nominated as the single agency responsible for all aspects of the roll-out of ZBNF and its work is supported by funding from the central and state government, as well as funding of around Rs. 100 crore (just over US$14 million) from private philanthropy (the Aziz Premji Foundation) for technical support.

The second key lesson has been the emphasis on farmer-focused, participatory extension, building human capital (farmer learning) and two types of social capital – links between farmers (bonding capital) and between farmers and 'experts' in the agricultural research and innovation ecosystem (linking capital). Here too, previous work has been vital. The community-supported sustainable agriculture programme initiated by SERP has been capitalized on, and the RySS now coordinates a dense network of farmer-led and farmer-focused groups extending to the level of individual households. Farmers are able to gain information, peer-support and 'troubleshooting' from a range of facilitators (some of them fellow farmers). This level of engagement sets ZBNF 'extension' apart from conventional state-led extension models in India and, we suggest, is likely to be a key driver of sustained spread over time. It also provides a key lesson for farmer-focused development initiatives elsewhere in India, where the widespread neglect of dryland smallholders in formal skills provision, public agricultural extension and state livelihood support (Gajjar, Singh, & Deshpande, 2019) has been a key driver of continued vulnerability.

At present, public modes of knowledge delivery match neither the scale nor the complexity of the social-ecological challenges facing smallholders, particularly in dryland systems. Extension services remain fixed in a 'transfer of technology' model, are not well matched to local social-ecological contexts, and do not necessarily target socially or economically marginalized farmers. They are also understaffed, with an estimated 100,000 extension agents in post (of the 1.3–1.5 million required) (Glendening, Babu, & Asenso-Okyere, 2010). Where extension services are available, farmers lack the opportunity for follow-up, and information may be provided to farmers who are either from privileged groups or those who are easiest to reach (Cole & Fernando, 2012). Partly as a result, just 5.7% of Indian farmers report receiving information from a public extension agent (Glendening et al., 2010).

Yet, there is also a more cautionary lesson. Ambitious policy initiatives at state level need to proactively engage with gaps in knowledge provision and exchange. In Sikkim, farmers who transitioned away from synthetic inputs were not provided with enough guidance on how to deal with crop pests, and struggled to cope with decreased yields across a variety of crops (Pandey & Sengupta, 2018). These farmers call for more and better formal support and training, and also restructured regulation and markets that allow for profitable sales (Taneja, 2017). Andhra Pradesh's initial success with ZBNF has enthused policy makers in other states as well as at national level. Going forward, it is important that farmer-focussed ZBNF programmes are informed by the institutional and organizational innovations implemented by the RySS, which enables farmers to work within a rich learning ecosystem, supported by peers and more conventional experts.

This brings us to the third key lesson: the importance of farmer-led and farmer-focussed knowledge-exchange. While RySS staff 'teach' a formalized version of ZBNF to farmers, it is clear that RySS aims to give farmers scope to experiment with the methods, adapt them and adopt ZBNF progressively (the explicit provision for a three-year transition, built into interim RySS targets, is one example). One emerging tension is the need to communicate key elements of ZBNF *technique* versus engaging farmers with the more advanced or abstract *principles* animating ZBNF practice (Khadse & Rosset, 2019). On the one hand, RySS has created a participatory learning ecosystem to facilitate collective learning through face-to-face interaction with peers and other experts, through exposure to video and other media, and through direct engagement with Palekar's training camps. On the other hand, interviewees 'reveal that it is not possible to start with high complexity concepts at the first go' (Khadse & Rosset, 2019, p. 15). Instead, farmers begin by using ZBNF as a form of input substitution before moving on to more advanced practices and engaging with the underlying principles.

A key set of questions for further research centres on the need to design evaluations that take into account diverging levels of engagement and types of adoption across different farms. Evaluations of agroecological 'packages' involving multiple components is difficult, as these are often adapted to suit the particular needs of farmers and communities (Milder, Garbach, DeClerck, Driscoll, & Montenegro, 2012). Outcomes from standardized or simplified practices in field trials may not therefore correspond with outcomes from the methods used by farmers. In the context of sustainable intensification, evaluations must also go beyond impacts on yields. Improvements to environmental variables are even more challenging to assess, as outcomes are highly sensitive to initial conditions, as well as the parameters timescales and any weightings used (Elliot, Firbank, Drake, Cao, & Gooday, 2013). These considerations should inform on-going evaluations of ZBNF, underway across India via the Indian Council of Agricultural Research (ICAR), with a view to informing further policy making at national level (Tiwari, 2019). Beyond trials on research stations, assessing outcomes for practicing farmers is complicated by the fact that ZBNF – like other initiatives – is 'layered' on top of an existing array of practices and technologies. In Andhra Pradesh for example, farmers may have previously experimented with organic production, or may be using some elements of the system of crop intensification such as wide spacing and a revised irrigation schedule. These may have had impacts on soil health or biodiversity prior to the implementation of ZBNF, and this will be difficult to 'separate out' in evaluations.

A final set of questions around centres on the need for longitudinal assessments. Redesign initiatives are not static, as contexts continually change. Multidisciplinary longitudinal assessments are needed to explore how practice and outcomes change over time, either progressing towards greater sustainability or reverting to older forms of management. Unintended consequences may also unfold, particularly over time, and especially if underlying norms and values remain unchanged (e.g. see Bharucha, Smith, & Pretty, 2014 on the long-term outcomes of decentralized watershed management). Redesign innovations specifically seek to re-vision the underlying status quo, but beyond a certain scale, all innovations must engage with existing power relations and incumbent actors who can thwart, dilute or co-opt them (Brown, 2018). Alongside longitudinal assessments of ZBNF outcomes for farmers and landscapes, there will thus be a need to track how the underlying principles of ZBNF are being implemented as the package is formally adopted by state-led institutions and is adopted by existing programmes.

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