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Impact of Zero Budget Natural Farming on Crop Yields in Andhra Pradesh, SE India

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Abstract: It has been claimed that Zero Budget Natural Farming (ZBNF), a burgeoning practice of farming in India based on low-inputs and influenced by agro-ecological principles, has the potential to improve farm viability and food security. However, there is concern that the success of the social movement fueling the adoption of ZBNF has become out of step with the science underpinning its performance relative to other farming systems. Based on twenty field plot experiments established across six districts in Andhra Pradesh (SE India), managed by locally based farmer researchers, we present the first 'on the ground' assessment of ZBNF performance. We show that there is no short-term yield penalty when adopting ZBNF in small scale farming systems compared to conventional and organic alternatives. In terms of treatment response, we observed differences between agro-climatic zones, but in this initial evaluation we cannot recommend specific options tuned to these different contexts.

Keywords: zero budget natural farming; ZBNF; organic farming; conventional agriculture

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1. Introduction

Feeding a projected population of 9 billion by the mid-century constitutes one of the most fundamental challenges facing humanity [1,2]. Globally, agricultural production more than tripled between 1960 and 2015 [1]. This was initially facilitated, in part, by Green Revolution technologies to increase yields, and profits, compared to traditional techniques [3–5]. The resulting intensive, high-input agriculture relying on chemical fertilisers, pesticides and irrigation, has led to evidence of environmental degradation and negative health impacts associated with exposure to synthetic chemicals [6–11]. Hence, more environmentally focused solutions have arisen, such as sustainable intensification and agroecology. Such solutions have been promoted as alternative approaches to agricultural production that align more closely to the UN Sustainable Development Goals (SDGs) [12,13].

In India, 48% of the land surface was classified as degraded in 2005, driven by processes such as erosion, acidification and salinization [7]. As a result, a number of agricultural systems have been developed that are intended to be more sustainable alternatives to high-input conventional farming systems. By 2015, India had the most organic producers worldwide [14]. There are around 835,000 organic certified farms across the states of Andhra Pradesh, Gujarat, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Sikkim and Tamil Nadu, which all have state-level organic farming polices [15], with Sikkim being declared the first all-organic state in the world [16]. In principle, organic farming has the potential to address environmental concerns, through reduced use of chemical fertilisers and pesticides compared to conventional techniques. However, conversion of conventional systems to organic agriculture can result in a reduction in yield [17] and lower temporal yield stability [18]. This will have obvious implications for food security and raises the question whether organic farming can feed the world without expansion of croplands into natural ecosystems [19,20]. In addition, socio-economic impacts associated with conventional farming may not be alleviated by organic farming in India. The involvement of agribusiness companies in controlling the market for organic food, fertilisers, and seeds reduces the potential socio-economic benefits of organic farming over conventional systems [21]. Along with becoming codified in regulatory and third-party certification [16], agribusiness in farming has favoured larger farming enterprises, often leaving smallholders disadvantaged due to access or cost [4]. This has resulted in high levels of farmer debt, which have been found to contribute to increased farmer suicides in India [22].

The subsequent focus on developing sustainable and equitable approaches to agriculture underpin the Zero Budget Natural Farming (ZBNF) approach, which aims to address both environmental and socio-economic concerns within the agricultural sector. 'Zero Budget' refers to lower use of purchased inputs, and reduced involvement of agribusiness, reducing debt incurred by farmers [23]. 'Natural Farming' refers to the use of homemade amendments from readily available ingredients. These inputs are intended to promote soil health, close nutrient cycling loops, and provide greater water retention in soil, alongside integrated pest management and intercropping [15,23–25]. The particular set of practices underpinning the ZBNF approach to farming involve four 'wheels' (Table 1).

Table 1. The four wheels of ZBNF [24,25].

Wheel	Local Nomenclature	Description	Components *
1.	Bijamrita	Seed treatment, applied as a coating either to seeds before sowing, or as a root dip before transplanting	Cow dung, cow urine, CaCO3, Asafoetida, *Phyllanthus emblica* powder, ash, and water
2.	Solid Jiwamrita/Jeevamrutha (Ghanajeevamrutham)	Solid amendment, inoculum. Applied either as a top dressing or incorporated into topsoil	Cow dung, cow urine, jaggery (unrefined cane sugar), gram (legume) flour, topsoil from a native 'virgin' soil (uncontaminated soil)
	Liquid Jiwamrita/Jeevamrutha (Dhravajeevamrutham)	Liquid amendment, inoculum, applied either as a top dressing or as a foliar spray	Cow dung, cow urine, jaggery, gram flour, topsoil from a native 'virgin' soil, water
3.	Achhadana	Mulching—either as biomass/cover crops or dried crop residues	Dry crop residues applied as an amendment to the soil surface (paddy straw, groundnut husks etc.), or cover crops (often legumes)
4.	Waaphasa	Soil moisture retention—a phenomenon resulting from the first three wheels	

* may not contain all components, quantities and exact components used vary depending on resources available.

In Andhra Pradesh, a state in southeast India, ZNBF (more recently also referred to as Andhra Pradesh Community-Managed Natural Farming, or APCNF) has been adopted enthusiastically. Around 580,000 farmers are currently engaged [26], and the government plans to scale up to 6 million by 2024 [27]. The Department of Agriculture, Andhra

Pradesh, is promoting the adoption of ZBNF through the 'not for profit' organisation Rythu Sadhikara Samstha (RySS). The RySS programme on ZBNF, in contrast to conventional state level interventions, is investing resources into farmer-led local context agroecology, supporting collective learning, women-led social organizations, and recruiting agricultural graduates [28]. Enthusiasm about the value of adopting the ZBNF approach by a range of stakeholders from government to local communities could be seen as reflecting a social movement [29], and mirrors prior legacy around agroecology [30–33].

The growing momentum of ZBNF contains some contradictions [34]. For example, a rejection of mainstream agronomic science, while accepting recent research advances in microbiology to optimise the soil microbiome. These contradictions have led to the criticism that the ZBNF movement has been driven by belief systems (e.g., Hindu promotion of indigenous cows) rather than scientific evidence [35]. There is a genuine danger that the success of the social movement fueling the adoption of ZBNF practices has become out of step with science that supports its efficacy. Furthermore, Andhra Pradesh has six different agro-climatic zones [36], ranging from temperate coastal plains to arid montane, and it is uncertain whether ZBNF performance would be consistent across contexts. Thus, there is a need to inject 'on the ground learning' of ZBNF agronomic benefits and develop processes of technology transfer to facilitate the success of future wider adoption. Fundamentally, there is a lack of evidence in the overall efficacy of the system in terms of whether the adoption of ZBNF practices improves or maintains crop yields, when compared to the alternative (conventional or organic) farming systems.

To inform the ongoing debate, here we report on the first season results from twenty co-designed field plot experiments, established across six districts of Andhra Pradesh (Figure 1a). We contrasted the effects of conventional, organic and ZBNF systems on yield of marketable crop product (Figure 1b). Along with workshops conducted with twenty stakeholders, we aim to address the following:

1. Whether there is an initial effect on yield when adopting ZBNF practises, compared to conventional or organic systems.
2. If the effects on yield are dependent on context i.e., district or crop selected.
3. The perceived benefits/mechanisms in ZBNF to inform future research.

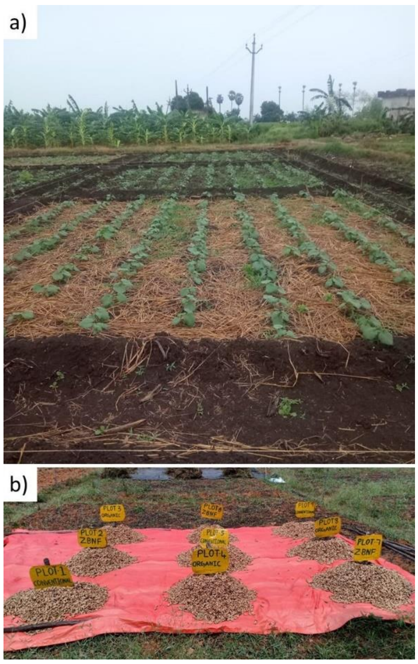

Figure 1. Example field plot experiments in Andhra Pradesh (**a**) early growth stage; (**b**) at harvest of marketable crop product.

Experiments were managed by locally based Natural Farming Fellows (NFFs) and the crops selected for each experiment reflected local practise. This is the first 'on the ground' assessment of the performance of these three farming systems at scale in Andhra Pradesh.

2. Materials and Methods

2.1. Co-Design of Experimental Approach

A series of stakeholder engagement events were designed to facilitate a co-learning process around identifying research needs to evaluate the performance of ZBNF. Twenty stakeholders were brought together in two workshops in Andhra Pradesh, and a subgroup of ten of them met on a third occasion. Their occupations ranged from researchers (national and international), government representatives (policy), agricultural extension officers (national and international), a philanthropic donor (financial support) and farmers (practical insights). The engagement processes included participatory exercises to identify research questions, presentations on ZBNF activities, brainstorming to identify research gaps, field visits, and discussions on scientific methods and protocols.

The first of two workshops took place in August 2018 with the objective of identifying key research questions. Part 1 consisted of background presentations provided by stakeholders, followed by questions from the audience. Part 2 comprised facilitated discussions in small multi-actor groups, containing a deliberate mix of expertise with the aim of ensuring each group had representation from each stakeholder community. Small multi-actor groups were asked to address the questions that had arisen from the presentations, processes that needed to be understood, and experiments that needed to be designed to test agreed hypotheses. Within the small groups, stakeholders identified the biogeochemical processes they believed were in operation due to adoption of the four wheels of ZBNF. The outputs from the groups were synthesised to develop a process diagram for the action of ZBNF practices.

The second workshop in February 2019 focused on developing and agreeing to the specific experimental design, procedures, and protocols for addressing the research questions raised in workshop 1. Twenty-two stakeholders, including representatives from research, policy, and practice, were bought together with 60% of attendees from the first workshop. Working in multisector small groups, participants were asked to develop experimental design and associated measurements to evaluate the suggested mechanisms put forward in the first workshop, namely, nutrient budget, carbon dynamics, climate resilience, water-use efficiency and soil microbiology. This workshop resulted in the methodology described below.

Finally, a subgroup of 10 workshop participants met in April 2019. Discussion points included: (i) whether the experimental design had the potential to address the research questions raised in the first workshop; (ii) any concerns regarding procedures and protocols, and how to address these concerns; and (iii) practical considerations for implementation of the proposed experimental plans.

2.2. Study Area

Andhra Pradesh abuts the South Eastern coast of India. At the last census (2017–2018), approximately 39% of the state's 163,000,000 ha land area was under agricultural production [37]. Andhra Pradesh has a diverse range of distinctive agro-climatic zones: from the cooler, higher-rainfall, montane region in the north, through the lowland valley of the Krishna River crossing the centre of the state, to the higher-temperature, arid montane region in the south-west (Figure 2). Dominant soil types of the state consist of: (i) Alfisols—red sandy/ sandy loam soils, accounting for 66% of Andhra Pradesh's cultivated area; (ii) Vertisols—black, heavier textured soil associated with poor drainage, accounting for 25% of the cultivable area; (iii) Entisols—alluvial loamy clay soils in the delta of the River Krishna, covering 5% of the total cultivable area; and (iv) Coastal sands—accounting for 3% cultivable land [36].

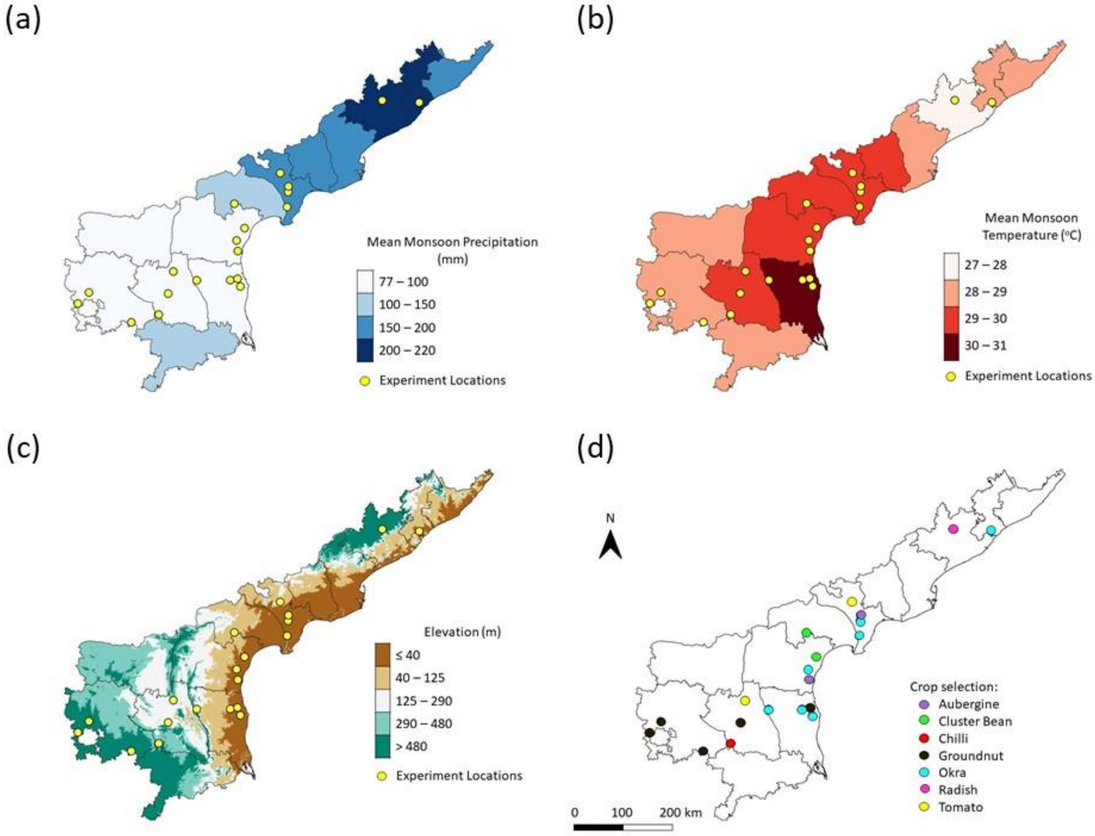

Figure 2. Maps of Andhra Pradesh and Experiment Locations (**a**) Mean monsoon rainfall (2018) of each district; (**b**) Mean monsoon temperatures (2018) of each district; (**c**) Elevation; (**d**) Experiment crop selection.

Twenty field experiments were established in Andhra Pradesh during the Kharif (monsoon) season (July-November) in 2019. To adequately represent all the major agro-climatic regions, experiments were spread over 6 districts: (i) Anantapur; (ii) Kadapa; (iii) Krishna; (iv) Nellore; (v) Prakasam; and (vi) Visakhapatnam, with rainfall ranging from c. 77–220 mm, and temperatures ranging from c. 27–31 °C in the Kharif (monsoon) season (2018 figures). Details of the twenty farms can be found in the Supplementary Information (Table S1).

2.3. Experimental Design

The experiment on each farm consisted of three treatments (ZNBF, organic, conventional) applied to 6 × 6 m plots, replicated three times. A total of nine plots per farm were arranged in a Latin square design. There are twelve possible combinations for a 3 × 3 Latin square, and these were randomly assigned to each experiment. It was not possible to give a unique arrangement to all the twenty experiments, so we ensured that no two experiments in the same district had the same Latin square arrangement.

In general, treatments consisted of: (i) Chemical seed treatment and fertilizers such as urea, diammonium phosphate (DAP) and potash in the *conventional* treatment; (ii) Trichoderma seed treatment and farmyard manure, vermicompost and biofertilizer application in the *organic* treatment; and (iii) Bijamrita seed treatment, jiwamrita (solid and liquid) and locally sourced organic dead mulch application in the *ZBNF* treatment. The mulch material applied in the ZBNF treatment was selected based on what was locally available, generally paddy straw or groundnut husk. Dosages and exact amendments used in each system depended on the crop selected. Full details of the growing protocols used for each crop can be found in the Supplementary Information (Tables S2–S9). These protocols were developed with agriculture extension staff of the region (for organic and conventional), and RySS (for ZBNF), and were based on national advice given to farmers for the different crops under the three treatments.

2.4. Crop Selection

Crops selected were Aubergine (*Solanum melongina*), Chilli (*Capsicum annum* L.), Cluster bean (*Cyamopsis tetragonoloba*), Groundnut (*Arachis hypogaea*), Okra (*Abelmoschus esulentus*), Radish (*Raphanus sativus*) and Tomato (*Solanum lycopersicum*). Crop selection for each experiment was based on suitability for the district and local trends (what neighbouring farms were growing), to be representative of local practice. As a result, crop selection was often confounded within districts (Figure 2d). Crops were hand sown/transplanted according to the spacing outlined in the growing protocol (Supplementary Information Tables S2–S9) and grown as a monocrop. The timing of the growing season varied depending on the crop selected (Supplementary Information, Table S1).

2.5. Pest/Pathogen Management

All treatments were subjected to some form of seed treatment: fungicide in the *conventional* treatment (e.g., thiram); commercial inoculant in the *organic* treatment (e.g., *Trichoderma*); and bijamrita in the *ZBNF* treatment (Table 1). Exact seed treatment and dosage depended on the crop selected (Supplementary Information Tables S1–S7). If a pest/pathogen incident was encountered during the growing season, each treatment had additional management procedures applied. These are summarised in the Supplementary Information (Table S8) and procedures depended on the pest/pathogen in question. Briefly, the *conventional* treatment consisted of chemical pesticides such as dimethoate (insecticide) and copper oxychloride (fungicide). The *organic* treatment used purchased neem oil and/or insect traps (grease coated bottles, yellow sticky plates, etc.) in place of chemical insecticides; and microbial inoculants (e.g., *Trichoderma* or *Pseudomonas* sp.) in place of fungicides. The *ZBNF* treatment also used insect traps, not chemical insecticides, but also used homemade 'Neemasthram' and 'Agnasthram' in place of purchased neem oil. Neemasthram was prepared from cow dung, cow urine, neem seeds and leaves as well as other bitter tasting leaves available locally (e.g., castor). Agnasthram consists of cow urine, neem leaves, tobacco leaves, chillies, and garlic [35].

2.6. Experimental Implementation

Experiments were implemented and managed by RySS personnel, including *Research Coordinators (RCs)* forming a six-member technical staff with master's degrees in agricultural, environmental science, microbiology, or related discipline, and *Natural Farming Fellows (NFFs)*, 20 graduates with bachelor degrees in an agricultural related subject, usually from agricultural college. One NFF was responsible for management and collection of data from an individual experiment. One RC was stationed in each district to act as project manager to the NFFs in their district.

Clear, detailed, instruction booklets, co-created with the RySS Research coordinators (Supplementary Information, Figure S1) on how to lay out the experiments, were provided to each NFF. Face-to-face training, by practising soil scientists, was also conducted both in English and in translation in the native language of each district. Training videos were created, reiterating the face-to-face training, that could be referred to at any time. A well-established communications network was put in place so that NFFs also had the opportunity to ask questions at any time.

ZBNF was formed as a result of critique and contestation of pre-existing mainstream agricultural science and practise [34]. Therefore, having representatives from an organisation charged with promoting the movement away from the 'present paradigm of high-cost chemical inputs-based agriculture' [26] raised the question of whether the conventional treatment in this experiment would be managed in a way that fairly represented conventional farming practices in Andhra Pradesh. It is also important to note that, for ZBNF promoters, the practice of organic farming resembles chemical farming in socio-economic terms because of the involvement of agribusiness companies [21]; therefore, it is not in line with the 'Zero-budget' element of ZBNF. In order to reassure stakeholders, detailed growing protocols were provided to NFFs and these documents were freely available to any visitor wishing to discuss the experiment. The importance of impartiality was a key component of the NFF training, along with good record keeping. Stakeholders, including critics of the ZBNF approach, were also given the opportunity to be present during the application of soil amendments and other activities on site. On balance, we have concluded that the considerable benefits offered by the involvement of RySS and the NFF network in the co-creation and implementation of this experiment outweigh the potential risks of impartiality.

2.7. Yield

Yield was considered as the mass of produce obtained from each plot, as it would be taken to market, rather than whole plant biomass. In the case of fresh vegetables, this was fresh biomass of vegetables after they were picked; and in the case of groundnut, this was the dry mass of kernels (see Figure S1 for more details). This decision was made with the stakeholders in mind, as the amount of marketable product is a simple message to communicate to policy makers and farmers.

2.8. Statistical Analysis

The aim of this study was to compare the three treatments (conventional, organic and ZBNF) across a large scale. It was not our intension to examine differences in yield as a function of farm, particularly given that the different farms selected different crops, with a large range in resultant yield masses. Therefore, the application of z score transformations to the yield of the crops on each of the 9 plots, on each experiment, was used to normalise the data, as follows:

$$z = \frac{x_i - \overline{x}}{S} \quad (1)$$

Equation 1. z score transformation, where z is normalised yield for a single plot, x_i is the plot yield for the single plot, $\overline{x}$ is the mean yield of all 9 plots of the given farm experiment, and S is the standard deviation of the yield of all 9 plots on the given farm experiment. Therefore, if a plot yield is equal to the mean yield of all 9 plots on a given experiment, then $z = 0$. If the plot yield is below the mean yield of all 9 plots, then $z < 0$. Finally, if the plot yield is above the mean yield of all 9 plots, then $z > 0$.

A mixed effects model was conducted on z transformed yield data using Minitab Version 20, with both random and fixed effects. The mixed effects model was applied using restricted maximum likelihood (REML) estimations according to the software protocols [38]. District, treatment, and crop selected were classified as fixed factors, and farm as a random factor, nested within district. Interactions were also included in the mixed-effects model to examine whether there were significant interactions between treatment and the district in which the experiment took place, or the crop that was selected. Tukeys post-hoc testing was also conducted to examine significant differences between particular treatments (conventional, organic and ZBNF).

As a result of z transformation, the mean for each district and crop was zero; thus, there was no effect size as a result of district or crop selected in this model. This compromise was deemed acceptable because district and crop selected are often confounded and the aim of our research was to examine the treatment effect of farming practices (conventional, organic and ZBNF). Our interest in the district and crop selected was to investigate whether there were significant interactions between them and treatment (i.e., do ZBNF practices increase the yield of one type of crop, but decrease the yield of another type, compared to conventional or organic farming practices?). Examination of these interactions is of interest to policy makers in agricultural guidance documents, particularly since codes of practice are often tailored to individual crops.

3. Results and Discussion

An initial yield reduction is commonly observed when converting from conventional agriculture to organic farming [17,19,20]. The 'chemical free' parallels in organic farming and ZBNF have called into question whether replacing intensive conventional farming with ZBNF will provide enough food to meet the growing requirements of the large and growing Indian population [23,24]. Initial findings from our research, however, suggest that there will not be a short-term yield penalty when converting land from conventional agricultural practices to ZBNF methods in small scale systems, regardless of crop selected. Standardized (z-score transformed) yield across the 20 farms in the study was found to be significantly influenced by treatment (Table 2) but there was no significant difference in yield on the conventional plots compared to organic or ZBNF (Figure 3). Furthermore, the significant difference in yield in the ZBNF and organic treatments (Figure 3) suggests that different mechanisms are at play in these two systems, and that criticisms of organic farming in terms of production may not apply to ZBNF.

Table 2. Summary of yield REML mixed-effects model of z transformed yield. With treatment, district and crop variety as factors. Significant treatment effects are highlighted in bold (<0.05) See Supplementary Information for residual plots (Figure S2).

Factor	Type	Levels	Degrees of Freedom	*F*-Value	*p*-Value
Farm	Random (nested in district)	20			
District	Fixed	6			
Crop	Fixed	7			
Treatment	Fixed	3	2	7.86	**<0.01**
District x Treatment	Interaction		10	2.18	**0.022**
Treatment x Crop	Interaction		12	1.15	0.326

The data presented in this article were collected during the first season that experimental treatments were established, the majority of which were situated on land with a long history of conventional agriculture (Supplementary Information, Table S9). These initial findings, therefore, would be of particular interest to short-term lease tenant farmers, who may be unable to lease the same land every year. Andhra Pradesh has the highest percentage of tenant holding farmers of all the states of India (42.3% compared to the national average of 13.7% [39]), so farming methods that show results on yield in the short term are of great importance. However, it is uncertain whether a lower yield in the organic treatment will continue to be observed in subsequent seasons, or whether yields in the organic plots will improve with time, as soil organisms proliferate and provide the ecological processes required to support crops.

There were significant interactions between treatment and district, suggesting that context may play a role in the efficacy of ZBNF (Figure 4). The southern (drier) districts of Andhra Pradesh (Anantapur, Kadapa, Nellore, Prakasam) had the highest yield in the ZBNF > conventional > organic treatment. There was no significant difference between the treatments in Krishna, and the effects of treatments were reversed in the northernmost district of Visakhapatnam (highest yield in conventional > organic > ZBNF). This observation suggests that improved water holding capacity could be an important yield-promoting mechanism responsible for improved performance of ZBNF systems in more arid regions. ZBNF is the only system featured in this research that uses mulching, which can regulate soil temperature and moisture to improve crop yield [40–42]. This moisture and temperature regulation may account for the higher yields in the ZBNF system, and would also account for ZBNF not being significantly higher in the wetter regions where moisture is not a limiting factor. This will need to be further explored in the drier, winter rabi season.

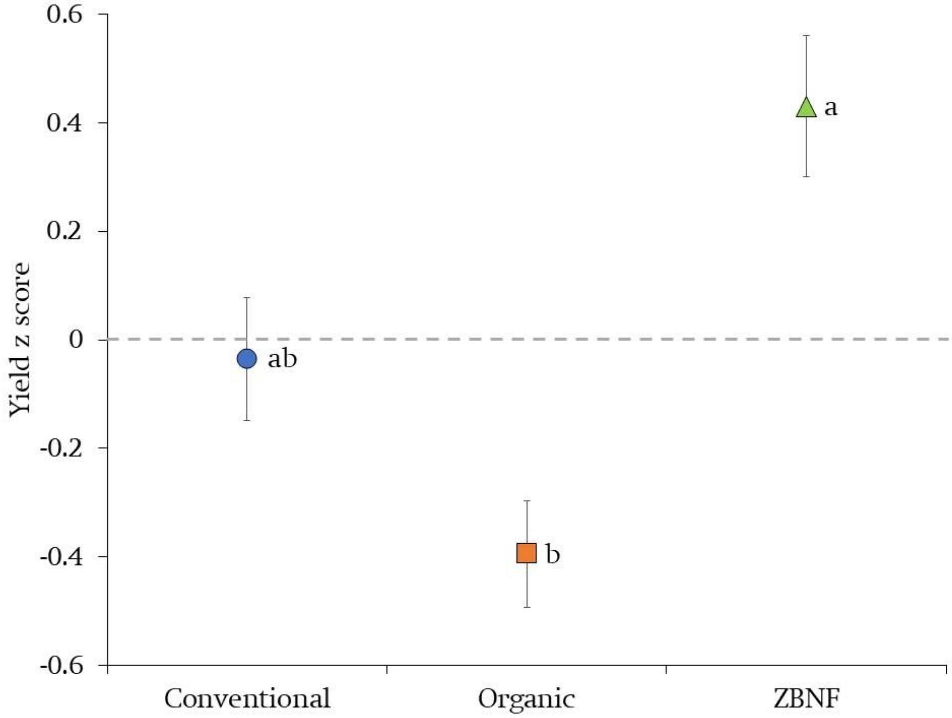

Figure 3. Yield of farming systems in Andhra Pradesh (z transformed). Mean of each treatment across all 20 experiments (n = 60). Error bars are standard errors of the mean. Treatments that are labelled with the same lower-case letter (**a**,**b**) are not significantly different according to REML mixed-effect model with Tukeys post-hoc testing (p > 0.05).

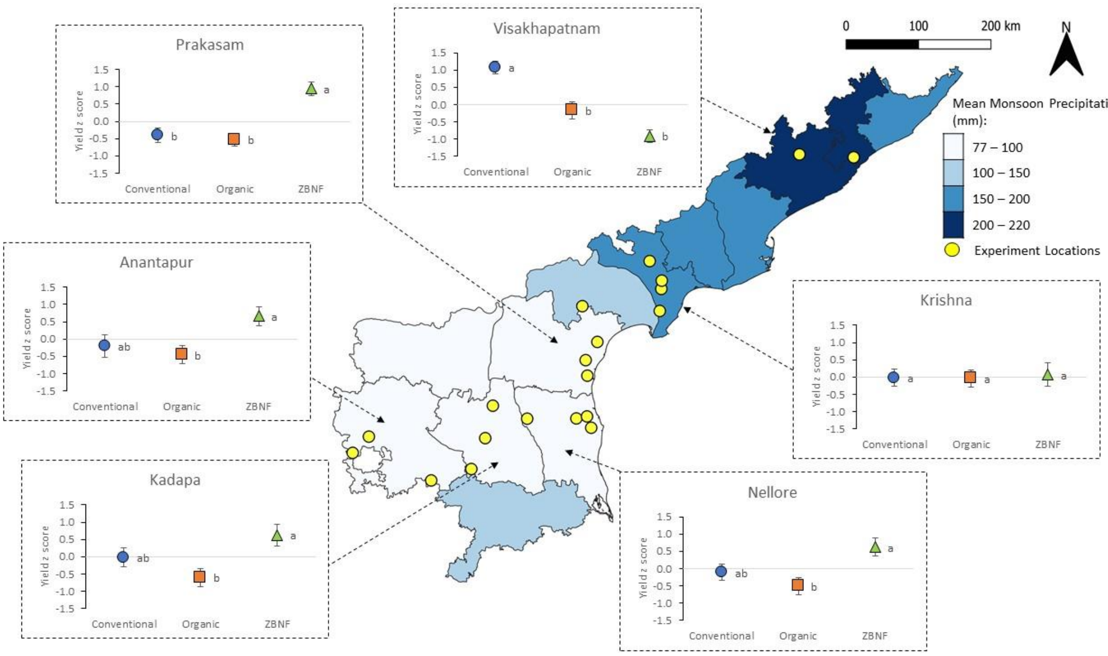

Figure 4. Yield of farming systems (z transformed) according to district and 2018 mean monsoon rainfall. Mean of each treatment across all experiments in that district (Anantapur n = 9; Kadapa n = 9; Krishna n = 12; Nellore n = 12; Prakasam n = 12; Visakhapatnam n = 6). Error bars are standard errors of the mean.

There was no significant interaction between the crop selected and the treatment applied (Table 2). Furthermore, when the model was repeated but crop selected was categorized as legume or a non-legume crop, the interaction between treatment and 'legume/non-legume' as a factor was also not statistically significant (F-value 1.44 p = 0.240, data not shown).

The four wheels of ZBNF have been suggested to increase yield through a number of biochemical interactions, highlighted during workshop discussions with stakeholders (Figure 5). Perception of the ZBNF system is that the amendments applied strongly increase soil biodiversity and, as a result, this diverse belowground biological community provides multiple ecosystem services, including the supply of nutrients, carbon sequestration, and resilience to external stresses. Further research is needed to evidence the claimed mechanisms involved in maintenance of crop yield in the ZBNF system. However, there is a body of research into the benefits of systems that use seed treatments of *Ferula* spp. (e.g., 'asafoetida') [43–45] and *P. emblica* [46]; inoculum and biostimulants [47–49]; and organic matter applications [50–52] from which the stakeholders, and we, could draw parallels to ZBNF.

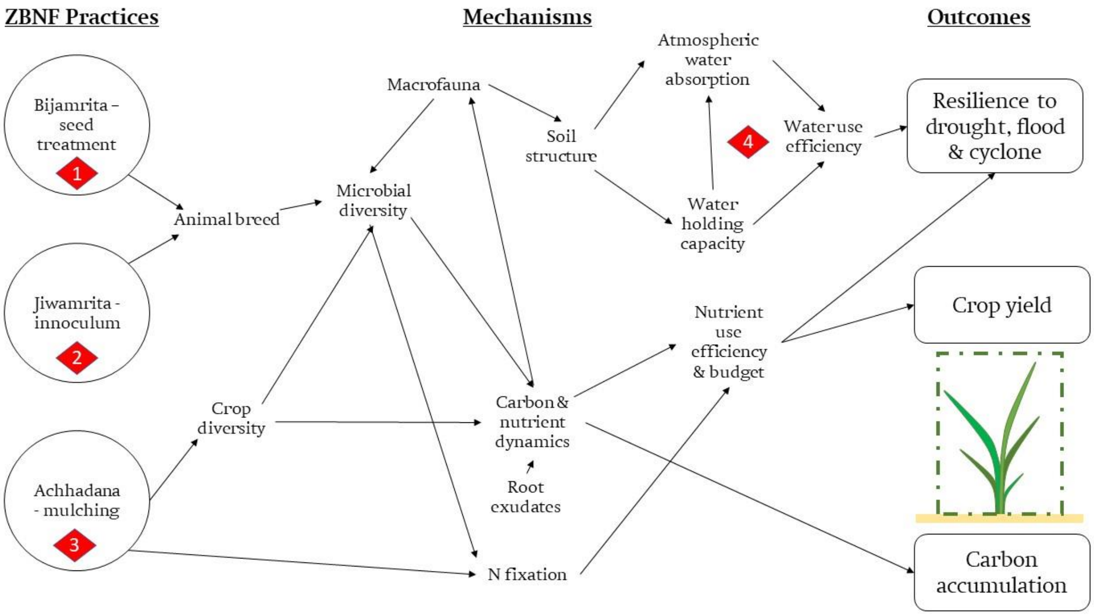

Figure 5. Conceptual model linking operations of ZBNF with biogeochemical processes. Based on the four wheels of ZBNF (numbered in red diamonds, see Table 1 for more details of the wheels). Output created during workshop discussions.

Yield is an important aspect for consideration in the assessment of agricultural sustainability [53]; the monitoring of yield allows us to assess the efficacy of ZBNF to contribute to SDG 2 (Zero Hunger). However, we acknowledge that yield is not always the most important factor when considering ecosystem services, human and soil health, or socio-historical subjectivity of ZBNF farmers [54], which drives adoption of farming practise. Next steps in the assessment of the efficacy of ZBNF need to build on the foundation of our simple metric of productivity in terms of yield, to encompass environmental and socially progressive outcomes [13] of ZBNF to reflect contributions to other SDGs.

There is increasing recognition that context and local knowledge in agricultural approaches, which value community involvement and empowerment, are key [33,55,56]. Dissemination of information on ZBNF practises in Andhra Pradesh is largely conducted face-to-face through community ambassadors (e.g., NFFs) and self-help groups. Therefore, an experiment that is being conducted within these communities, where locally based farmers and stakeholders can visit and discuss in person has real value. Our platform provides a base from which knowledge exchange can occur between local members of the farming community and researchers. The network of NFFs involved in this research allowed us to establish 'on the ground' experiments at scale and across several agro-climatic zones in Andhra Pradesh. Establishing a network of this nature from scratch, with trained local graduates across the state, would not have been possible with the time and resources available.

4. Conclusions

There has been growing concern that the social movement promoting ZBNF has become out of step with the science underpinning it. In the first on-the-ground assessment of the effects of ZBNF on yield, our results suggest that there will not be an initial yield penalty when converting to ZBNF, when compared to organic or conventional systems. These findings could be of particular interest to short-term lease tenant farmers. Initial assessment suggests, however, that performance of ZBNF may be agro-climatic context specific. Further work is needed to evaluate the long-term effects of ZBNF adoption, encompassing effects on yield and other environmental and social outcomes, in line with SDGs.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su14031689/s1: Table S1, Farm crop selection, ZBNF mulch selection and management history; Table S2, Growing protocol for aubergine; Table S3, Growing protocol for chilli; Table S4, Growing protocol for growing cluster bean, Table S5. Growing protocol for groundnut, Table S6. Growing protocol for okra; Table S7, Growing protocol for radish; Table S8, Growing protocol for tomato; Table S9, Pest and disease management strategies in conventional, organic and ZBNF; Figure S1, Example instruction booklet for implementation of experimental design; Figure S2, Residual plots of REML mixed-effects model on z transformed yield.

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