Understanding potential environmental benefits of natural farming in Andra Pradesh: Ex-ante analysis

REPORT

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Understanding potential environmental benefits of natural farming in Andra Pradesh: Ex-ante analysis

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Abstract

Using Andhra Pradesh Community Managed Natural Farming (APCNF) for environmental and socio-economic impacts and generation of evidence for policy makers requires a thorough understanding of the numerous environmental and social factors. Simulations were done to assess the impacts of current practices on crop yields across fertility treatments namely, Chemical Plus, Partial and Full APCNF in West Godavari (WG) and Non-Chemical, Partial and Full APCNF in Alluri Sitharama Raju (ASR). Results show that current nitrogen (N) use efficiencies are lower than the national average which is 58 kg/kg of N (range 38– 68 kg/kg of N). For the WG site, N use efficiency of the Chemical Plus, Full and Partial APCNF treatments is 21, 34 and 58 kg/kg, respectively. This clearly shows a low response to the large amounts of chemical fertilizers being used. The low response can be attributed to depleting total soil organic carbon (SOC) as shown by the long-term (30-year) simulations which indicate a potential decline in yields with time for current crop production practices, especially under the Chemical-Plus and Non-Chemical practices. The long-term simulations, however, show a substantial increase in SOC under Full and Partial APCNF treatments in both sites. The increase in SOC is due to residue retention and manure applications practiced by the farmers. Building SOC enhances overall soil fertility, reducing the need for chemical fertilizers and promoting sustainable farming practices, which in turn provides a buffer against extreme weather conditions, such as heavy rainfall and drought, by maintaining soil moisture and temperature stability.

1 | Introduction

Agriculture has been the mainstay of India's economy for centuries, it has transitioned over the years enabling the country to reduce its dependency on food grain imports (Naresh et al., 2018; Tripathi, Nagbhushan and Shahidi, 2018). However, agriculture in its current state requires farmers to rely heavily on inorganic external chemical inputs such as fertilizers and pesticides. This imposes significant negative impacts on a range of stakeholders from the farmers to consumers and additionally on the natural ecosystems and biodiversity (Naresh et al., 2018; Tripathi, Nagbhushan and Shahidi, 2018; Smith et al., 2020). Evidently, this form of agriculture exposes smallholder farmers to high credit risk, potentially trapping them in perpetual poverty, it can also contaminate ground water, reduce soil fertility and contribute to biodiversity loss (Naresh et al., 2018). Such trends can potentially reverse traction gained in agricultural productivity and adversely affect the livelihoods of smallholder farmers that depend upon agriculture. Globally there have been a number of alternative low-input farming practices that promise to reduce input costs, enhance productivity, improve soil health and increase climate resilience

(Mangaravite et al., 2023). Amongst these is Zero Budget Natural Farming (ZBNF) now called Andhra Pradesh Community Managed Natural Farming (APCNF) that was first popularized by the Japanese scientist and philosopher, Masanobu Fukuoka. ZBNF was introduced to farmers in Andhra Pradesh through Rythu Sadhikara Samstha (RySS), a state-owned, non-profit organization (Tripathi, Nagbhushan and Shahidi, 2018). The natural farming practice is led by farmers and follows farmer to farmer extension and as a result was renamed to Andhra Pradesh Community managed Natural Farming (APCNF) to reflect the central role that farmers play. APCNF is viewed as an approach that has potential to make significant contributions towards achieving a quarter of the 169 Sustainable Development Goal targets (Naresh et al., 2018; Tripathi, Nagbhushan and Shahidi, 2018). Work done to date has shown that in Andhra Pradesh there has been a sharp decline in input costs and an increase in yields, with about 36% and 9% yield increase on groundnuts and rice, respectively (Naresh et al., 2018). However, climate change pose challenges and there is a need to understand yield stability under APCNF over time. Subsequently, this study uses the Agricultural Production Systems Simulator (APSIM) to assess rice grain yield stability across chemical and natural farming practices under current and future climate scenarios.

2 | Material and methods

2.1 Model description and configuration

The APSIM model was used to assess the long-term impacts of different management practices on the stability of rice yield production (Holzworth et al., 2014). APSIM is a modeling platform that has been used extensively in Australia, Africa and Asia mainly to add value to field experimentation and demonstration and for exploring key constraints and opportunities in direct engagement with farmers, researchers and extension agencies (Gaydon et al., 2017; Masikati et al., 2021; Wimalasiri et al., 2022; Roja, Gumma and Reddy, 2023). The model has also been used to inform policy makers, bankers and insurance institutes (Whitbread et al., 2010). It fully integrates crops, trees, soil, water, nutrients and erosion through a number of process-based modules and is flexibly configured to simulate crop productivity across diverse agroecosystems (Holzworth et al., 2015; Keating et al., 2003). The model was parameterized using on-farm data including management, however soils and climate data were obtained from ISRIC and NASA sites. The average soil and climate data used for the different sites is shown below (Fig 1a and b and Tables 1 and 2).

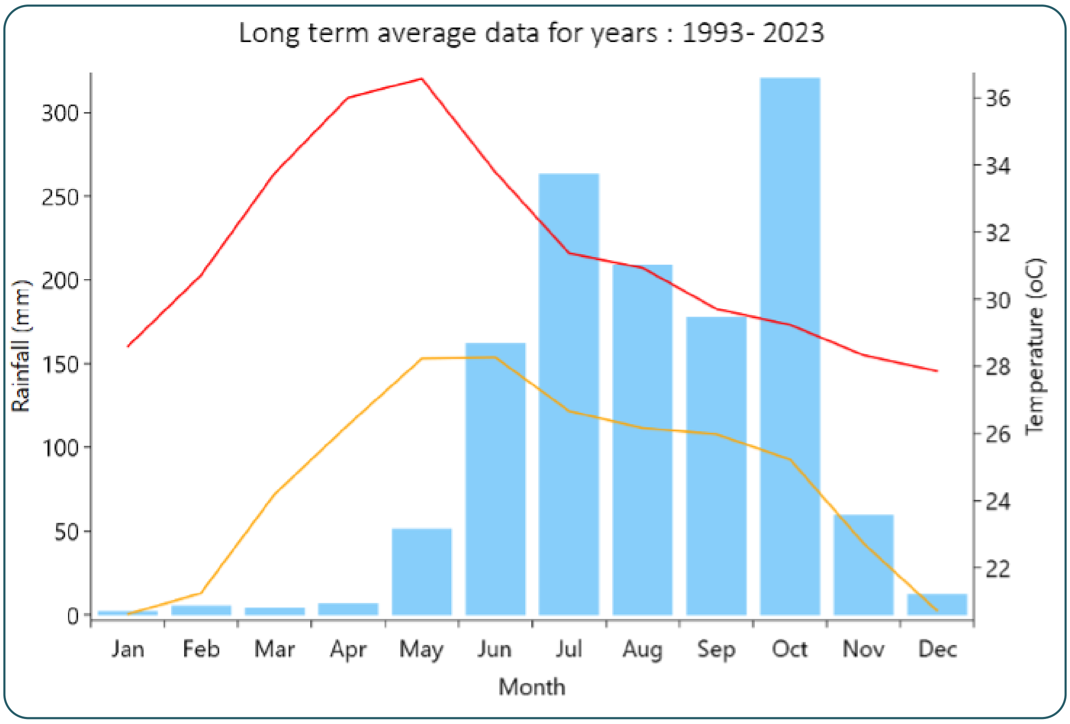


Figure 1a. Average rainfall and maximum and minimum temperatures for the WG site over a thirty-year period (1993 – 2023). The long-term average annual rainfall is 1272 mm with a standard deviation of 253 mm.

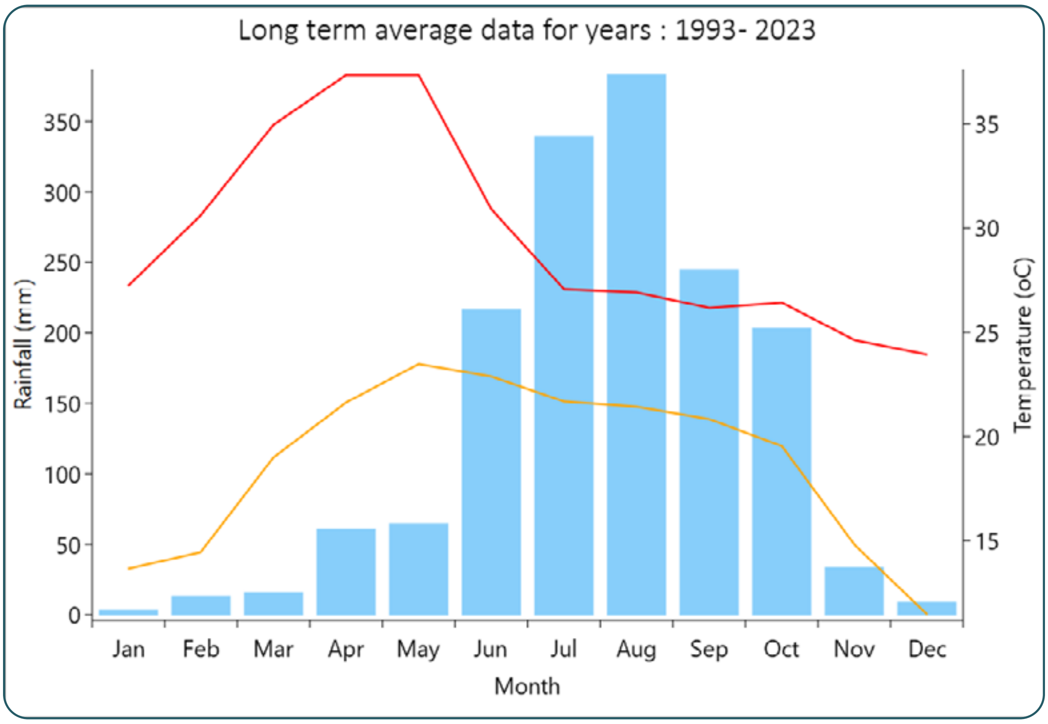


Figure 1b. Average rainfall and maximum and minimum temperatures for the ASR site over a thirty-year period (1993-2023). The long-term average annual rainfall is 1586 mm with a standard deviation of 195 mm.

Table 1. Average soil properties for the WG site used in APSIM for rice grain yield simulations.

Depth (cm)	Bulk Density (g/cc)	Air Dry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	OC (Walkley Black %)
0-5	1.33	0.09	0.17	0.33	0.38	2.72
5-15	1.37	0.17	0.17	0.33	0.38	2.14
15-30	1.37	0.17	0.17	0.33	0.37	2.16
30-60	1.4	0.20	0.20	0.34	0.37	1.91
60-100	1.42	0.19	0.19	0.34	0.37	1.59
100-200	1.42	0.19	0.19	0.35	0.38	1.42

Table 2. Average soil properties for the ASR site used in APSIM for rice grain yield simulations.

Depth (cm)	Bulk Density (g/cc)	Air Dry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	OC (Walkley Black %)
0-5	1.25	0.08	0.16	0.34	0.42	3.13
5-15	1.26	0.16	0.16	0.34	0.42	2.14
15-30	1.31	0.17	0.17	0.34	0.41	1.34
30-60	1.32	0.20	0.20	0.34	0.42	0.88
60-100	1.32	0.21	0.21	0.34	0.40	0.69
100-200	1.33	0.21	0.21	0.34	0.38	0.60

***Table 3**. Compared plot types and practices.*
*(*Jeevamrutham - a liquid mix of cow dung, cow urine, water, jaggery, pulse flour and soil; **Ghanajeevamrutham - solid and dried version of Jeevamrutham; ***Kashayams - botanical extracts).*

	Full APCNF	Partial APCNF	Non-chemical	Chemical	Chemical plus
 **All basic APCNF practices** seed treatment; *Jeevamrutham**; *Ghanajeevamrutham***	Yes	Some	No	No	Some
 **Including natural farming practices** *Kashayams****, pre-monsoon dry sowing, biocultures and biofertilizers	Yes	Yes	Some	No	Some
 **General practices** mulching and manure	Yes	Yes	Some	No	Some
 **Use of chemical inputs** fertilizer and pesticides (herbicides, insecticides)	No	No	No	Yes	Yes

3 | Results

3.1 Current crop yields

Average yields across the fertility treatments for the WG site do not vary. For the Chemical Plus, Full and Partial APCNF treatments yields of 1509, 1528 and 1452 kg/ha of rice grain were achieved, respectively, in response to the amounts of fertilizer applied (Fig 2a). The average nitrogen (N) applied per hectare is 54, 76 and 36 kg N/ha, for Chemical Plus and Partial, respectively. For the ASR[1] site, the average fertilizer application rates are lower than those of the WG site, however, the yields are within the same ranges. Rice grain yields of 1080, 1463 and 1194 kg/ha were observed under the Non-Chemical, Full and Partial APCNF practices, respectively (Fig 2b).

Average N applications for the ASR site were lower than those in the WGD site with 2, 6 and 27 kg/ha for Non-Chemical, Full and Partial APCNF practices, respectively. From these observed yields and N application rates it is evident that farmers practicing Chemical Plus are not benefiting as much as they should, this is evidenced by the N response curves. Farmers who may have started practicing natural farming are also not realizing potential yields mainly due to poor soil fertility, however as shown in the N response graph (Fig 3a and b), with improved soils, the response to N also improves.

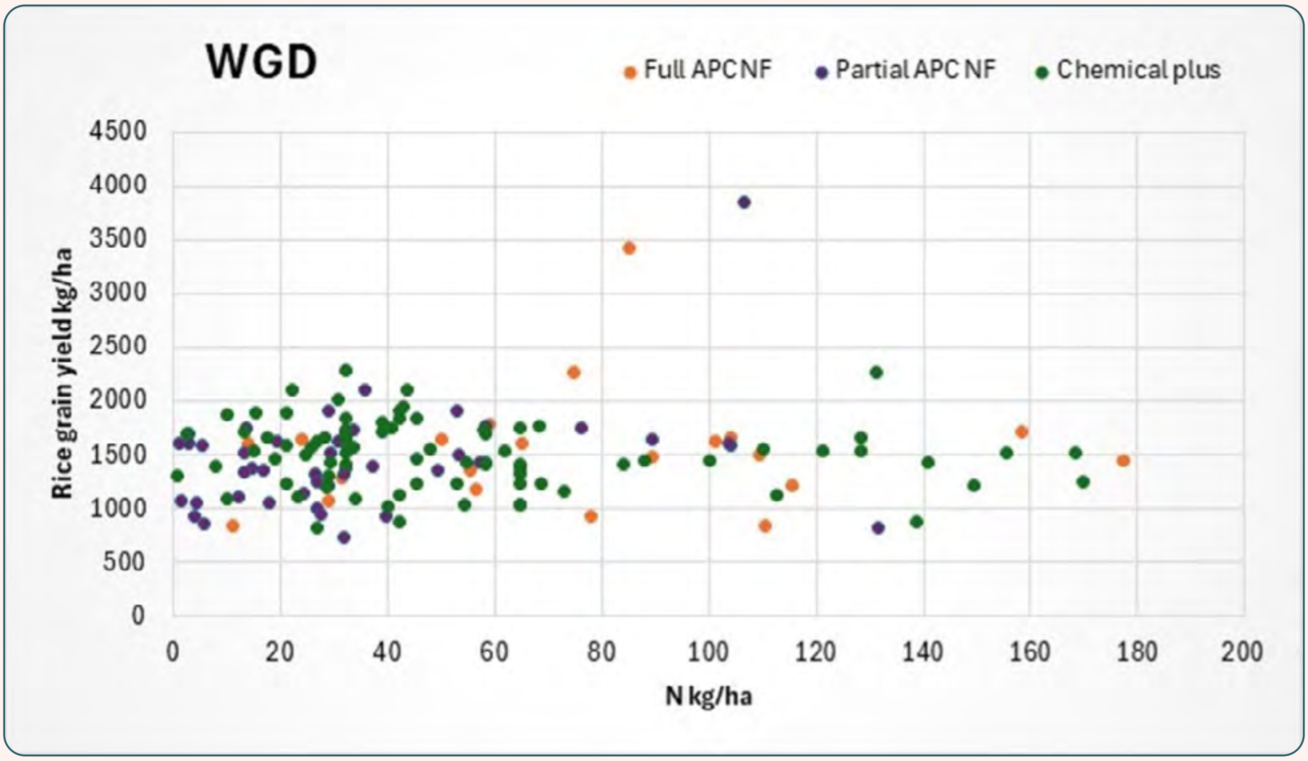


***Figure 2a**. Observed yields for the WGD site from different farms across three fertility treatments: Chemical Plus, Partial and Full APCNF.*

1. *This is the proportion of nitrogen in the amount of inputs added to each plot.*

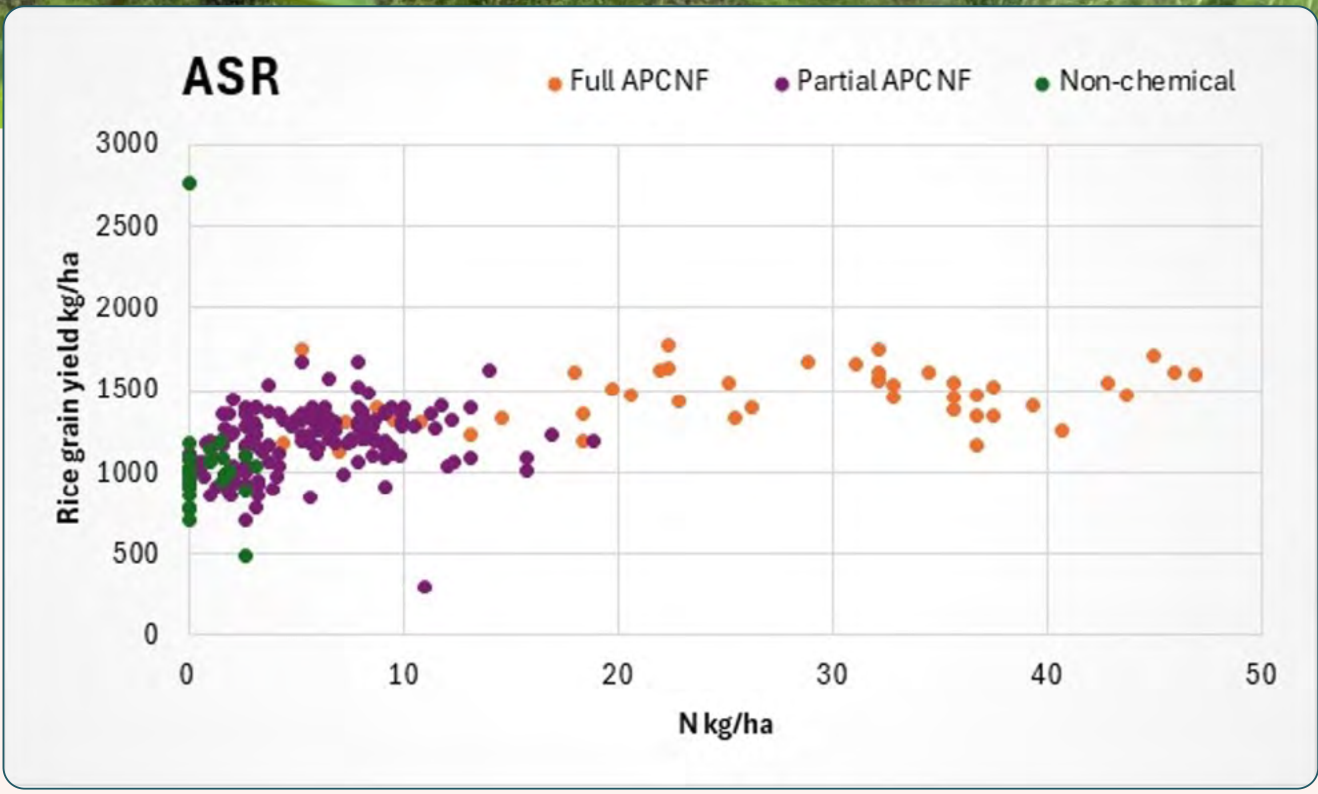


***Figure 2b**. Observed yields for the ASR site from different farms across three fertility treatments: Chemical Plus, Partial and Full APCNF.*

3.2 Nitrogen response curve

The simulated crop response to N (Fig 3a and b) shows, that under current production systems, the optimal amount to be applied to the rice variety used is about 60 kg/ha to potentially double the current observed rice grain yields. However, in Figures 3a and b the average yields (green bars) clearly show that there is some nutrient inefficiency in the current production systems in both sites, but especially in the WGD site. In the WGD site farmers under the Chemical Plus and Full APCNF are currently applying, 54 and 76 kg/ha, respectively, however their average yields are 1509 and 1528 kg/ha. These figures represent a substantial yield gap which can be reduced by improved soil management as shown by the orange bars. This indicates inefficiencies in the farming systems with returns on grain yield/kg of N falling way short of the national average. However, long-term simulations of grain yield response to N, shown by the orange bars (Fig 3a and b), clearly indicates that the N response can increase under improved crop and soil management as in the case of Partial and Full APCNF. Under the Chemical Plus treatment, 0 N/ha yields on average are below 1 t/ha while for Partial and Full APCNF are 1.6 and 2 t/ha, respectively. Higher yields at 0N are attributed to soil health built by residue retention and manure application over time. Response to N is also improved under better management.

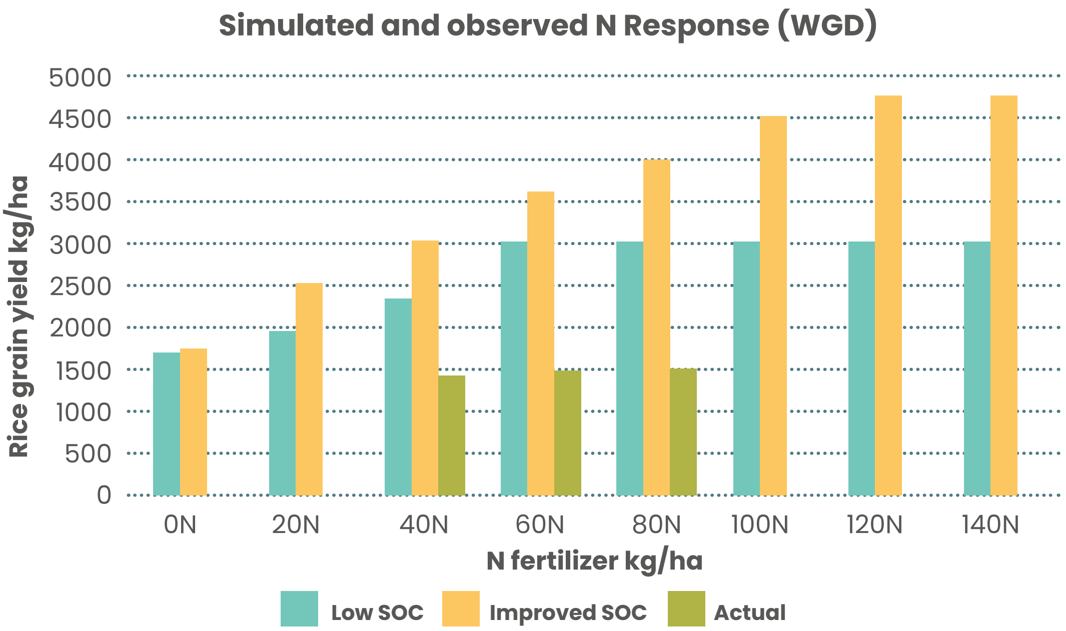


Figure 3a. *Nitrogen (N) response curve for grain yields with blue bars showing the response under current management practices, the orange bars showing the response under improved management systems and the green bars showing actual yields across fertility treatments for the WGD site. The first green bar is for Partial APCNF farmers while the second and third green bars are for Chemical-Plus and Full APCNF practices, respectively.*

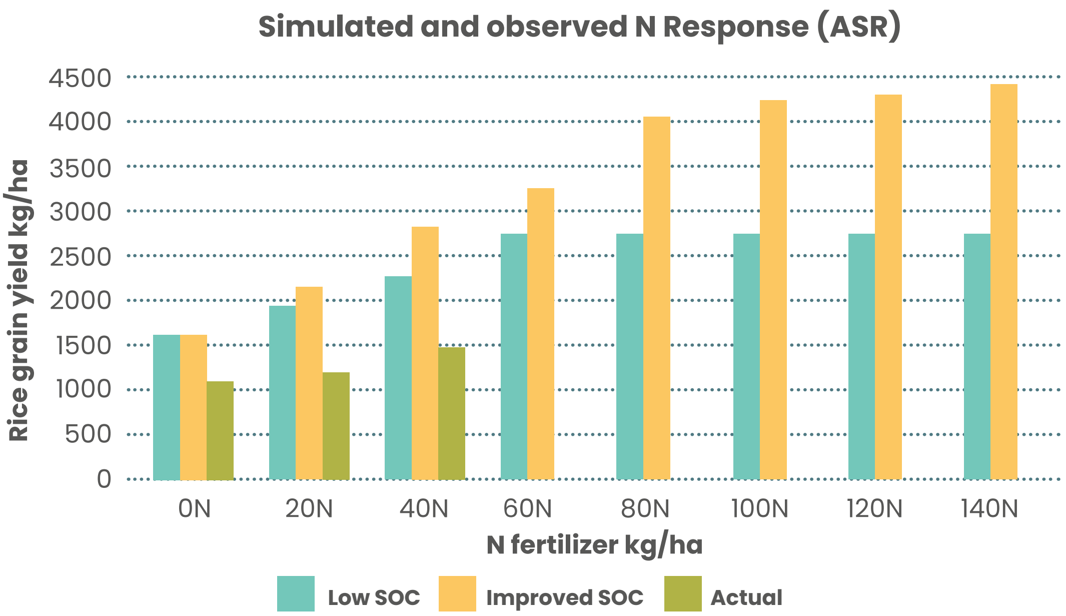


Figure 3b. *Nitrogen (N) response curve for grain yields with blue bars showing response under current management practices, orange bars showing response under improved management systems, and the green bars showing actual yields across the fertility treatments for the ASR site. The first green bar is for Non-Chemical farmers while the second and third green bars are for Partial and Full APCNF practices, respectively.*

3.3 Yield stability

The simulations covered a period of 30 years (1993 – 2023) for the two sites (WGD and ASR). The three fertility treatments show variability in crop yields in response to rainfall variation. Figure 4a shows near zero yields for WGD for the year 2002 under all treatments because India experienced a severe drought that year with a 51% reduction in rainfall (KALSI, Jenamani and HATWAR, 2021). However, this was not observed for the ASR site, this could be attributed to the lower annual rainfall standard deviation than that of the WGD site (Fig 1a and b). No crop yield limitations were imposed in the model, hence the results on attainable yields using current inputs. The importance of residue retention and manure application is evident under the Full and Partial APCNF treatments, where yields increased over time due to improved soil fertility. The Chemical Plus treatment and Non-Chemical practices show a yield decline over time in response to depleted soil nutrients. In the long-term, farmers under Full and Partial APCNF can potentially achieve greater yields than is currently the case (Fig 4a and b). The use of proper varieties coupled with sustainable practices, such as residue retention and manure application, can potentially lead to stable rice grain yields over time.

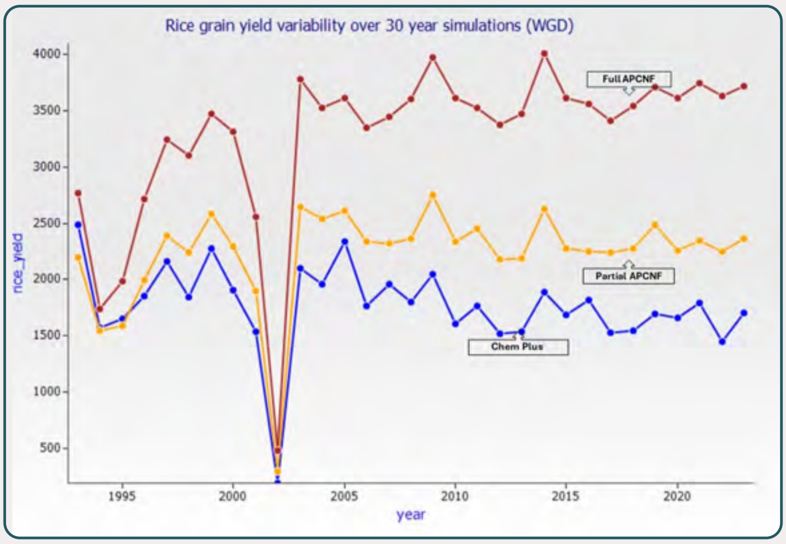


***Figure 4a**. Long-term (30-year) simulations on rice grain yield stability for the WGD site with no resets of soil organic carbon, nitrogen and water across the three fertility treatments.*

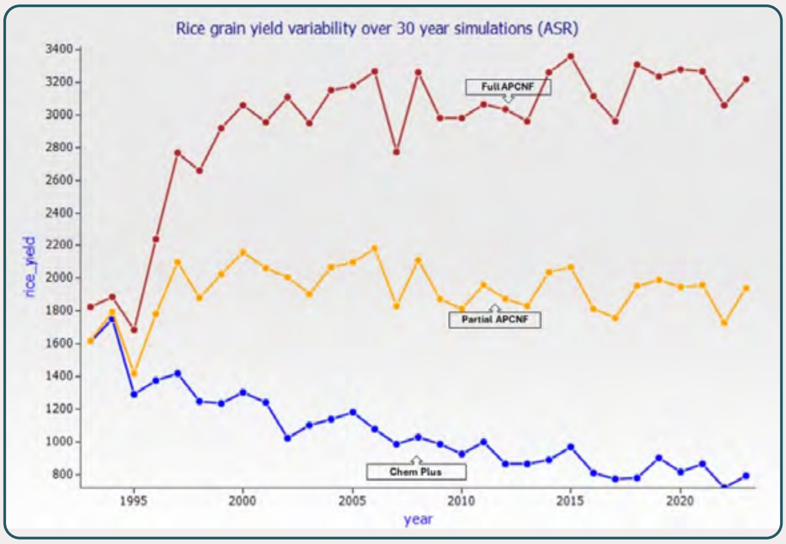


***Figure 4b**. Long-term (30-year) simulations on rice grain yield stability for the ASR site with no resets of soil organic carbon, nitrogen and water across the three fertility treatments.*

3.4 Long-term soil organic carbon dynamics

The impacts of different management practices on soil organic carbon (SOC) across the two sites (Fig 5a and b) were assessed. Results show that with time SOC decreases under the Chemical Plus and Non-Chemical treatments. To the contrary, the Partial and Full APCNF treatments show increases in SOC with time, with greater increases experienced under Full APCNF. Increases in SOC are important for buffering the impacts of climate change on future crop production.

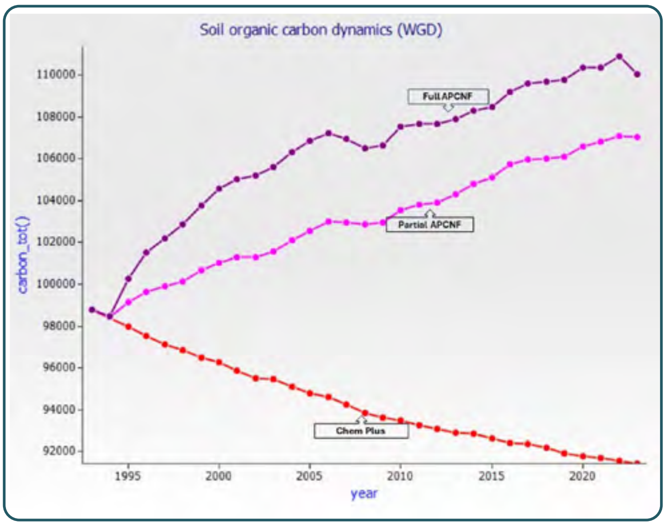


Figure 5a. *Long-term (30-year) simulations on soil organic carbon dynamics for the WGD site across the three fertility treatments.*

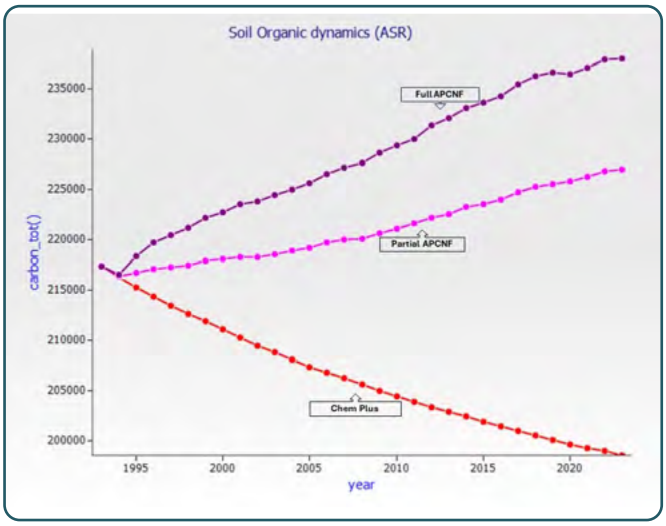


Figure 5b*. Long-term (30-year) simulations on soil organic carbon dynamics for the ASR site across the three fertility treatments.*

3.5 Impacts of rainfall variation on rice grain yield

Both increased and decreased rainfall can significantly affect rice production in various ways, depending on its timing, intensity, and duration. While rice is a semi-aquatic crop that requires substantial water, excessive rainfall can lead to adverse growth conditions. The impacts of rainfall gradients (-30 to +30%) on grain yield were assessed. For WGD the simulations show varying responses to rainfall gradients under the Chemical Plus treatment (Fig 6a). Increased rainfall shows reduced grain yields while reduced rainfall shows greater yields than the control. At 50% probability of exceedance, yields are around 2500, 3500 and 2000 kg/ha for Chemical Plus, Partial and Full APCNF, respectively. For the ASR site (Fig 6b) similar trends were observed, however yields under the Non-Chemical treatments were the lowest with average yields of around 1000 kg/ha at 50% probability of exceedance.

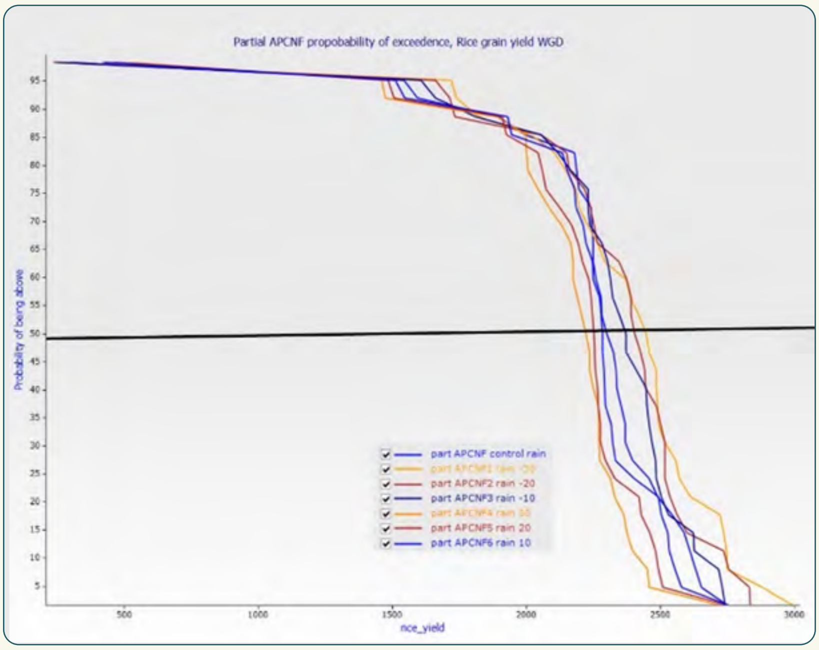
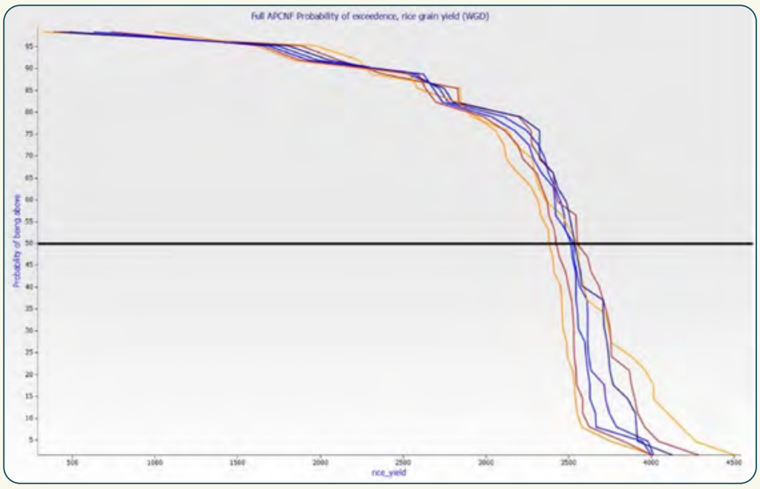


Figure 6a.1*. Impacts of different rainfall regimes (-30, -20, -10, 0, +10, +20, +30%) on rice grain yields for the WGD site across the three fertility treatments: Chemical Plus, Partial and Full APCNF.*



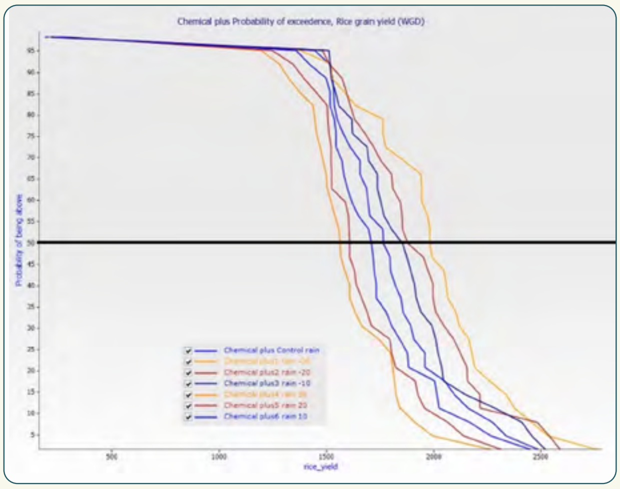
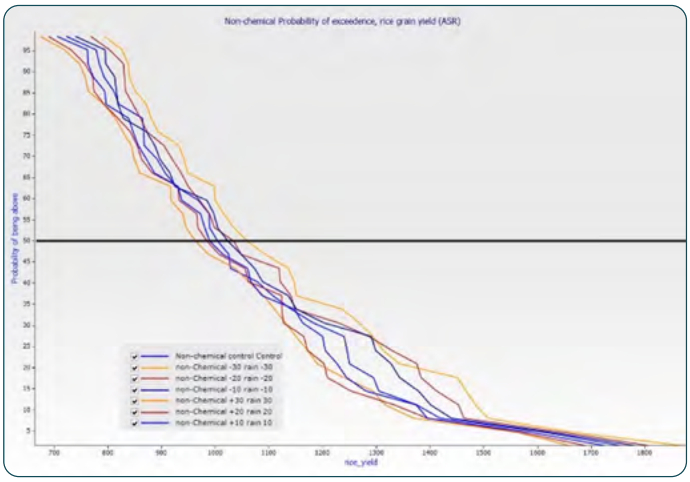


***Figure 6a.2-3**. Impacts of different rainfall regimes (-30, -20, -10, 0, +10, +20, +30%) on rice grain yields for the WGD site across the three fertility treatments: Chemical Plus, Partial and Full APCNF.*



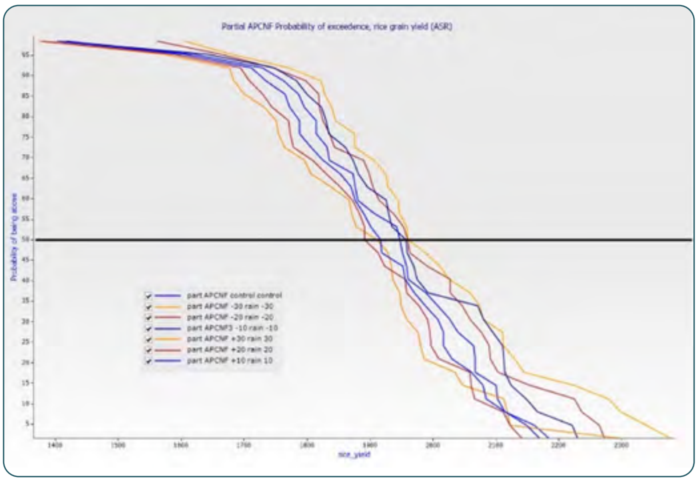


***Figure 6b.1-3**. Impacts of different rainfall regimes (-30, -20, -10, 0, +10, +20, +30%) on rice grain yields for the ASR site across the three fertility treatments: Chemical Plus, Partial and Full APCNF.*

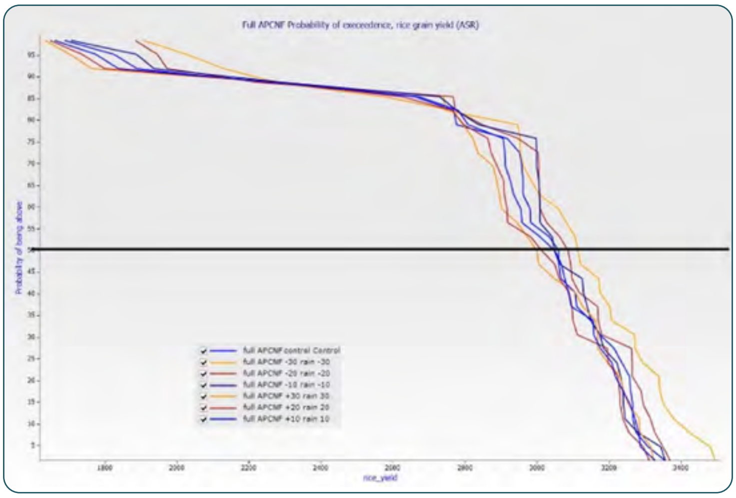


Figure 6b.1-3. *Impacts of different rainfall regimes (-30, -20, -10, 0, +10, +20, +30%) on rice grain yields for the ASR site across the three fertility treatments: Chemical Plus, Partial and Full APCNF.*

3.6 Impacts of temperature change on rice grain yield

Daily minimum (Tmin) and maximum (Tmax) temperatures have significant impacts on rice production. Rice, being a thermosensitive crop, requires specific temperature ranges for optimal growth and development. For rice seeds to germinate effectively, the Tmin needs to be within the range of 10°C to 15°C. Temperatures below this can delay germination or result in poor seedling vigor, uneven or delayed emergence, reducing the overall plant stand and affecting yield potential.

The maximum temperature (Tmax) has profound impacts on rice production. As a crop that thrives within a specific temperature range, rice can suffer significantly from a high Tmax, particularly during critical growth stages, The optimal temperature range for rice seed germination is around 20°C to 35°C. A Tmax beyond this range at different crop growth stages can have detrimental effects resulting in reduced yields.

4 | Summary

Increased SOC benefits rice production as it is a critical component of soil health and fertility. Increased SOC enhances overall soil fertility, reducing the need for chemical fertilizers and promoting sustainable farming practices as shown under long-term N response curves (Fig 3). Soils rich in organic carbon can better buffer against extreme weather conditions, such as heavy rainfall and drought, by maintaining soil moisture and temperature stability, as is evident in Figure 6a and b. Increasing SOC helps in sequestering carbon dioxide from the atmosphere, contributing to climate change mitigation and improving long-term sustainability of rice production. By adding manure and retaining and incorporating crop residues instead of burning them SOC levels can improve. By adopting sustainable practices, rice farmers can increase SOC levels, leading to improved soil health, higher yields, and greater resilience against environmental stresses.

5 | References

Gaydon, D.S. et al. (2017) 'Evaluation of the APSIM model in cropping systems of Asia', *Field Crops Research*, 204, pp. 52–75. Available at: https://doi.org/10.1016/j.fcr.2016.12.015.

Holzworth, D.P. et al. (2014) 'APSIM – Evolution towards a new generation of agricultural systems simulation', *Environmental Modelling & Software*, 62, pp. 327–350. Available at: https://doi.org/10.1016/j.envsoft.2014.07.009.

KALSI, S., Jenamani, R. and HATWAR, H. (2021) 'Meteorological features associated with Indian drought in 2002', *MAUSAM*, 57, pp. 459–474. Available at: https://doi.org/10.54302/mausam.v57i3.491.

Mangaravite, J.C.S. et al. (2023) 'Decomposition and release of nutrients from species of tropical green manure', 70(3).

Masikati, P. et al. (2021) 'Agriculture extensification and associated socio-ecological trade-offs in smallholder farming systems of Zambia', *International Journal of Agricultural Sustainability* [Preprint]. Available at: https://www.tandfonline.com/doi/abs/10.1080/14735903.2021.1907108 (Accessed: 17 June 2024).

Naresh, R. et al. (2018) 'Zero budget natural farming viable for small farmers to empower food and nutritional security and improve soil health: A review'.

Roja, M., Gumma, M.K. and Reddy, M.D. (2023) 'Crop modelling in agricultural crops', *CURRENT SCIENCE*, 124(8).

Smith, J. et al. (2020) 'Potential yield challenges to scale-up of zero budget natural farming', *Nature Sustainability*, 3, pp. 1–6. Available at: https://doi.org/10.1038/s41893-019-0469-x.

Tripathi, S., Nagbhushan, S. and Shahidi, T. (2018) 'Zero Budget Natural Farming for the Sustainable Development Goals'.

Wimalasiri, E.M. et al. (2022) 'Impact of climate change adaptation on paddy yield in dry zone Sri Lanka: A case study using agricultural production systems simulator (APSIM) model', IOP Conference Series: *Earth and Environmental Science*, 1016(1), p. 012036. Available at: https://doi.org/10.1088/1755-1315/1016/1/012036.