CASE STUDY

#08

INDIA

Farming & landuse practices effect on soil health, incl. Minimal tillage and the natural farming movement in Ananthapur

CASE STUDY BRIEFS
Series on agriculture driven nature loss

Case Study #08: India - Farming & landuce practices effect on soil health, incl. Minimal tillage and the natural farming movement in Ananthapur.

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Content

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This is one of a series of eight case studies under the Mitigating the Agricultural Drivers of Nature Loss study implemented by the CGIAR for the World Bank that provides examples of opportunities to address the drivers and impacts of agricultural driven nature loss in different country contexts for specific case studies. Each brief is the result of an extensive review, stakeholder consultations, and a listening session with key stakeholders This case study brief specifically deals with farming and land use practices effect on soil health, including minimal tillage, and the natural farming movement in Ananthapur, India.

Ananthapur, located within the arid region of Andhra Pradesh, spanned an estimated area of **19,130 km²**

It is very dependent on agriculture, as **70%** of the district's is dedicated to agriculture.

Soil organic carbon (SOC) concentrations have dropped beneath **0.03%**, causing a stark reduction in crop productivity

Since the **1950s**, the application of nitrogen fertilizers has proliferated, bringing about the contamination of aquatic environments and a decline in soil integrity.

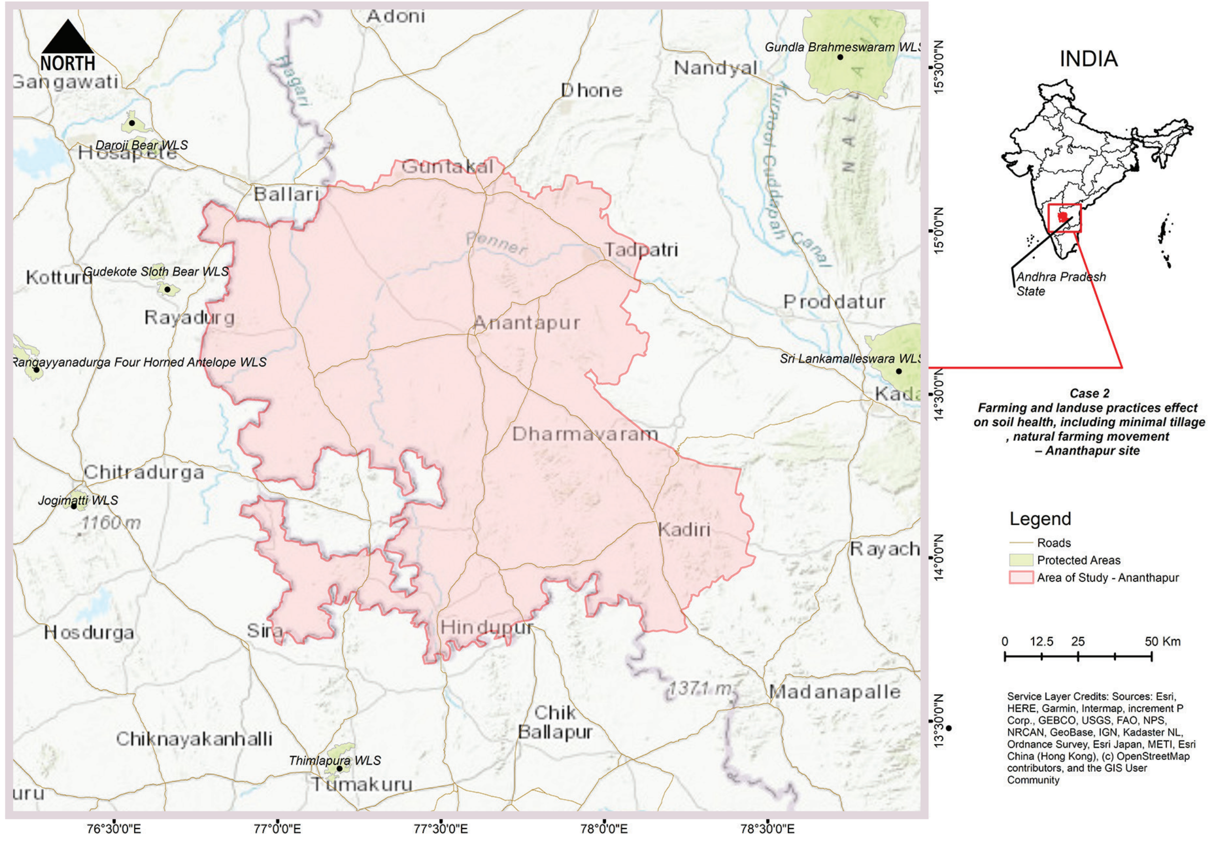


Figure 1: MAP OF THE CASE STUDY LOCATION

Overview

Prior to the bifurcation of the district, Ananthapur, located within the arid region of Andhra Pradesh, spanned an estimated area of 19,130 square kilometers. This geographical area has substantial environmental concerns attributable to its semi-arid climate, which is typified by scant annual precipitation of less than 552 mm and extreme summer temperatures that frequently surpass 38°C. It is a drought prone district but has received average or above average rainfall in most of the years in the last decade. It is very dependent on agriculture, as 70% of the district's is dedicated to agriculture. Groundnut (*Arachis hypogaea*) is the principal crop with more than 350,000 hectares.

The relentless proliferation of monocropping practices, motivated by market demand, has precipitated soil degradation, diminished biodiversity, and pronounced land degradation. Unsustainable agricultural practices, including excessive dependence on chemical fertilizers and inadequate irrigation techniques, have culminated in widespread salinization, affecting 62% of the land. The depletion of soil organic matter and the degradation of ecosystem services in Ananthapur are pivotal factors contributing to the ongoing agricultural crisis. The region's soils, predominantly Vertisols and Alfisols, have suffered from overgrazing, deforestation, and nutrient depletion. Studies reveal that soil organic carbon (SOC) concentrations have dropped beneath 0.03%, causing a stark reduction in crop productivity, particularly affecting groundnut and sorghum farming. Additionally, the reduction in microbial diversity, including essential strains like *Bacillus* and *Pseudomonas*, has harmed nutrient cycling, soil vitality, and increase in plant pathogens.

The principal factors exacerbating this crisis encompass the excessive application of chemical fertilizers, monocropping, and inadequate irrigation management. Since the 1950s, the application of nitrogen fertilizers has proliferated, bringing about the contamination of aquatic environments and a decline in soil integrity. The expansion of groundnut monocropping systems has diminished soil biodiversity and heightened susceptibility to pests and diseases. Furthermore, deforestation and the unsustainable exploitation of natural resources have exacerbated soil erosion and nutrient depletion, intensifying land degradation. Inadequate irrigation methodologies have resulted in soil salinization, constraining crop productivity and amplifying reliance on groundwater sources.

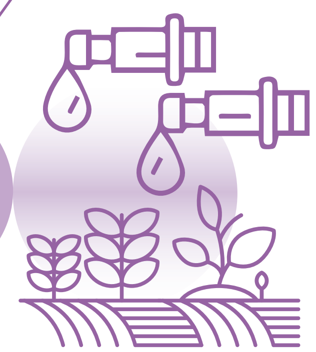
Initiatives aimed at rehabilitating soil health and fostering sustainable agricultural practices in Ananthapur have yielded varying levels of efficacy. Minimal tillage and Zero Budget Natural Farming (ZBNF) have emerged as viable interventions. By minimizing soil disturbance and advocating for the application of organic biofertilizers such as Jeevamruta and Panchagavya, these practices have enhanced microbial diversity and curtailed dependence on chemical inputs. The practice of conservation agriculture, featuring residue retention and a mosaic of crops, has played a vital role in enhancing soil structure and fertility, while the integration of phosphorus-solubilizing microorganisms has elevated nutrient accessibility and farming yield.

Because of the considerable environmental issues confronting Ananthapur, advancements in water-efficient irrigation technologies, such as drip irrigation, have resulted in significant enhancements in water-use efficacy while concurrently mitigating soil salinization. Additionally, sensor-driven irrigation systems are contributing to the refinement of water management practices, easing the burden on local water resources. Agroforestry has also demonstrated potential by improving water infiltration and curtailing soil erosion. Nevertheless, there are considerable challenges to the widespread implementation of these

Ananthapur, advancements in water-efficient irrigation technologies, such as drip irrigation

HAVE RESULTED IN:

significant enhancements in water-use efficacy while concurrently mitigating soil salinization.



sustainable practices presents. Although some governmental support exists, it is frequently inadequate, and the labor-intensive preparatory techniques required may dissuade farmers, despite a growing awareness of alternative practices.

Reformative policies and investment in sustainable land management strategies are imperative for counteracting soil degradation in Ananthapur. Initiatives such as the National Mission for Sustainable Agriculture (NMSA) and the Soil Health Card Scheme have afforded essential resources and knowledge to farmers for the adoption of regenerative agricultural practices. Additionally, the Forest (Conservation) Amendment Bill of 2023 and the Green Credit Rules of 2023 offer incentives for environmental conservation, including afforestation and sustainable agriculture initiatives.

Key drivers of the nature-agriculture conflict (fig. 2)

Overuse of Chemical Inputs

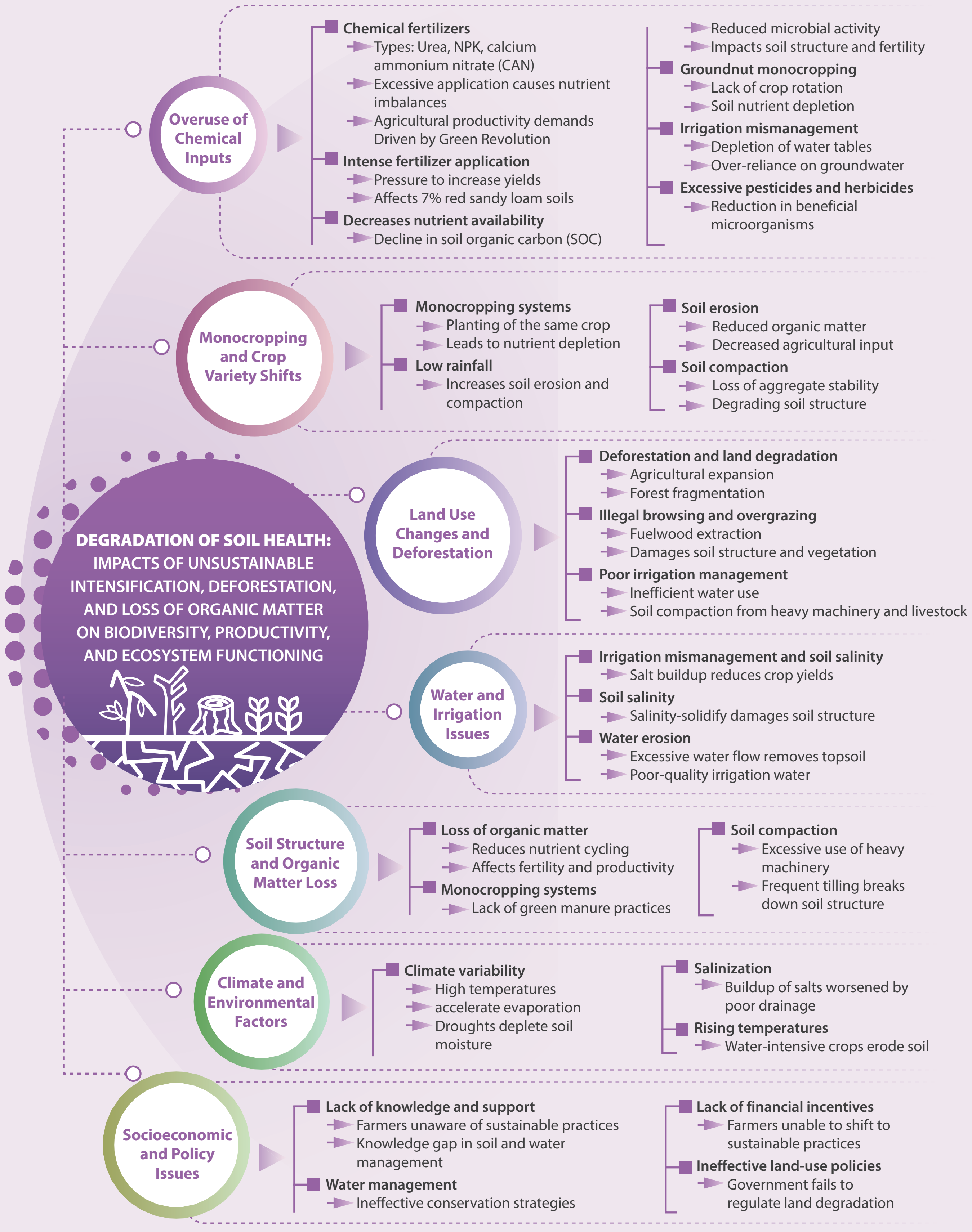
The ***overuse of chemical inputs*** in Ananthapur, India, particularly chemical fertilizers such as urea, NPK (Nitrogen-Phosphorus-Potassium), and calcium ammonium nitrate (CAN), is a significant driver of soil degradation. Since the 1950s, nitrogen fertilizer usage has escalated from a mere 0.45 kg/ha to approximately 101.2 kg/ha by 2020-21, driven by a ***demand for increased agricultural productivity***. This intense application of fertilizers, especially in red sandy loam soils, which constitute 75% of the region's soil, has led to a sharp ***decline in soil organic carbon (SOC)*** levels, dropping below 0.03% in some areas. In areas where groundwater is heavily relied upon for irrigation, the overuse of nitrogen-based fertilizers has caused ***nitrate contamination*** of water bodies, with levels exceeding the permissible limit of 45 mg/l. Additionally, the excessive use of pesticides and herbicides has ***negatively impacted soil biodiversity***, reducing populations of beneficial microorganisms like *Pseudomonas* and *Bacillus*, essential for nutrient cycling. The overuse of chemical inputs has also significantly impacted soil health by ***increasing soil bulk density***, ***reducing water absorption and holding capacity***, which ***adversely affects soil fertility and nutrient availability***. Furthermore, the loss of essential micro-nutrients due to soil erosion exacerbates the decline in soil quality.

The overuse of chemical inputs in Ananthapur continues to degrade the soil's health and productivity, making long-term agricultural sustainability a growing concern. The reliance on chemical inputs has been linked to a decrease in beneficial microbial populations, which are crucial for maintaining soil health. Additionally, the continuous ***cultivation of crops without the application of organic fertilizers*** has contributed to the ***depletion of soil nutrients***, further compromising soil fertility.

Monocropping and Crop Variety Shifts

The agricultural shift in Ananthapur from traditional cropping systems to ***monocropping*** has significantly impacted soil health, particularly through the dominance of groundnuts (*Arachis hypogaea* L.) as the primary crop. Groundnut cultivation has expanded across 1.38 million hectares of land, with yields declining

Figure 2:
CASUAL PATHWAY OF INTERRELATED DRIVERS



from 1.23 tons to 0.8 tons per hectare due to the combined effects of ***soil degradation*** and low rainfall. Traditionally, spreading-type groundnut varieties, which provide better soil cover, have been replaced by ***bunch-type varieties*** such as GG-2 and GG-5 that leave the soil more exposed, ***increasing the risk of soil erosion*** . Monocropping, particularly of groundnut in Ananthapur, has also been linked to ***low nutrient use efficiency*** and ***increased vulnerability to pests and diseases***, contributing to further soil degradation.

In Ananthapur, farmers are heavily reliant on monocropping systems, particularly for millet, sorghum, and groundnut, which ***do not replenish organic material in the soil***. The ***absence of crop rotation and green manure practices*** has led to a 25-30% reduction in soil organic carbon (SOC) in some areas over the past decade. SOC is essential for soil structure and fertility, but continuous cropping with minimal organic input depletes this critical component. Studies have shown that groundnut farms in the region are particularly affected, with up to 35% less SOC compared to diversified cropping systems. This shift towards monocropping has resulted in ***reduced soil biodiversity***, with microbial communities like Rhizobium and Pseudomonas fluorescens being particularly affected. These microbes, essential for nitrogen fixation and disease resistance, have declined due to the lack of crop diversity and the ***reduced input of organic matter.*** The predominance of monocropping, combined with ***erratic rainfall*** and ***drought conditions***, exacerbates soil fertility issues, as the region's soils are primarily red sandy loam with low organic matter.

Monocropping on Alfisols in Ananthapur has exacerbated soil degradation. The continuous cultivation of groundnuts without crop rotation has led to the ***depletion of soil organic carbon (SOC)***, critical for maintaining soil fertility and structure. The SOC in monocropped fields has dropped by over 52%, and groundnut yields have fallen by 13 kg per hectare annually. Furthermore, monocropping has ***increased the demand for chemical fertilizers*** like urea and diammonium phosphate (DAP), as organic residue return to the soil is minimal. As a result, ***soil compaction*** and the ***loss of aggregate stability*** are widespread, further ***degrading soil structure and water retention capacity***. However, the overall reliance on monocropping continues to challenge sustainable soil management, underscoring the need for a transition towards more diverse cropping systems to restore soil vitality and productivity. Despite these challenges, the shift towards intercropping systems, such as peanut and pigeonpea, has emerged as a strategy to mitigate risks and enhance soil health by improving biodiversity and nutrient cycling. Without diversified cropping systems, soil health in Ananthapur remains under threat, and farmers are forced to expand into new lands, perpetuating cycles of land degradation.

Deforestation and Land Degradation

Deforestation and land degradation in Ananthapur are driven primarily by ***agricultural expansion*** and overexploitation of natural resources. ***Forest fragmentation***, as forests are cleared to make way for agriculture, leading to a ***decline in biodiversity and ecosystem services***. The forest cover in Ananthapur has decreased to as low as 10%, with actual forest cover being fragmented and estimated at only 2.6% based on remote sensing data. Crops such as ***groundnuts and cotton***, which require significant land area, contribute to the deforestation problem. The expansion of these crops, driven by ***market demand*** and the push for higher yields, accelerates ***soil erosion*** and ***loss of organic matter***. Additionally, poor soil and ***water conservation practices*** have worsened ***soil erosion*** and significantly ***reduced soil fertility***, affecting approximately 32% of the land, with severe degradation impacting 17% of the region.

Illegal fuelwood harvesting further degrade forest ecosystems, leading to a loss of wildlife habitat and increased human-animal conflict, particularly with species such as wild hyenas.

Land degradation is exacerbated by ***overgrazing***, particularly in pastures where grazing indices are 7.5 times higher than optimal levels. This overgrazing strips the land of its vegetative cover, leaving the soil exposed to erosion. Erosion rates in the district range between 11 to 17 t/ha/yr, well above the natural soil formation rate of 2 to 11 t/ha/yr, leading to severe soil fertility loss. The prevalent monocropping system, particularly groundnut cultivation, has also contributed to low soil fertility, exacerbated by frequent dry spells and the lack of integrated nutrient supply systems. Inefficient use of fertilizers has further deteriorated soil health. ***Intensive farming practices*** in marginal lands have worsened ***soil compaction*** and ***nutrient depletion***. As a result, land that was once fertile is becoming increasingly unproductive, forcing farmers to clear more forested land to maintain crop yields, creating a vicious cycle of degradation.

Farming practices

In Ananthapur, ***irrigation mismanagement*** is a key driver of ***soil salinity***, with significant implications for ***soil health***. A major subdriver is the ***over-extraction of groundwater*** to meet the ***water demands of expanding agriculture***, particularly for ***water-intensive crops*** like paddy and sugarcane. The over-reliance on groundwater, combined with poor irrigation techniques such as ***flood irrigation***, has resulted in a rise in soil salinity. The predominant groundnut monocropping system in the region also faces challenges due to low soil fertility and erratic rainfall patterns, exacerbating the impact of poor irrigation management. Reports suggest that 62% of Ananthapur's land is affected by salinity, particularly in areas where ***improper drainage systems*** exacerbate salt buildup in the soil. This accumulation of salts reduces the soil's ***ability to retain water***, further ***limiting crop productivity*** and ***harming plant health***. In villages such as Kalyandurg and Setturu in Ananthapur, ***water erosion*** and salinity-sodicity processes dominate the landscape, making agricultural sustainability increasingly difficult.

In addition, ***poor-quality irrigation water*** exacerbates soil salinization. Studies reveal that TDS levels in well water often exceed 1500 mg/L, rendering the water unsuitable for agriculture. This leads to severe impacts on crops like

groundnuts and rice, where yield declines of up to 40% have been reported in salinity-affected regions. The use of marginal quality groundwater for irrigation has also led to increased ***sodicity,*** as sodium salts accumulate in the soil, further degrading crop productivity and soil health. Over-extraction of groundwater has resulted in levels dropping by 4-5 meters annually, which in turn draws salts from deeper soil layers, worsening the salinity. More than 64% of farmers are now reliant on these saline water sources, further degrading the soil. The ***lack of adequate drainage systems*** has also resulted in the formation of ***hard clay pans***, which ***hinder root growth and nutrient uptake***.

Frequent tillage operations ***compact the soil, reducing its porosity***, and ***hindering the infiltration of water and air***. Frequent tilling and the ***removal of crop residues*** have also contributed to a 15-20% ***decrease in soil organic matter*** over the past decade. Research shows that compacted soils have ***higher bulk density***, reaching values of 1.6 Mg m^3 in sandy soils, significantly ***affecting root growth*** and ***microbial activity***.

Climate Variability and Environmental Crises

Climate variability has had a significant impact on soil health and agricultural productivity. The region, known for its semi-arid climate, experiences highly variable rainfall, with an annual mean of only 552 mm, which is below the state average. This ***low and highly variable rainfall*** leads to significant ***soil moisture stress*** and ***fertility crises*** due to inadequate nutrient diffusion in plants. This inconsistent rainfall pattern is compounded by ***temperature extremes*** that range from 15°C to 45°C, further stressing the agricultural systems. The region faces frequent ***droughts***, occurring approximately once every two and a half years, which exacerbate the fragility of the local ecosystem. The erratic monsoon seasons lead to periods of intense rainfall followed by prolonged dry spells, significantly reducing the availability of soil moisture. This moisture deficiency not only ***hampers crop growth*** but also ***diminishes soil fertility*** as nutrient availability depends on adequate moisture. Inadequate rainfall, coupled with the loss of fertile topsoil due to erosion, creates a cycle of degradation that is difficult to reverse.

Over time, the region's Alfisols and Vertisols have become particularly vulnerable to ***erosion*** and **salinity-sodicity** processes due to ***increased evapotranspiration*** driven by rising temperatures. The region's ***reliance on rain-fed agriculture*** exacerbates these issues, as fluctuating monsoons and drought conditions have resulted in the ***loss of soil structure*** from monoculture practices and chemical use, contributing to ***nutrient imbalances***. These climate change-induced shifts have not only ***worsened soil moisture retention*** but also ***reduced crop productivity***. Climate change-induced temperature increases have led to greater evapotranspiration, ***reducing soil moisture retention.*** Additionally, climate change has intensified ***soil degradation*** and increased erosion, collectively threatening agricultural sustainability in this semi-arid region. The region's ***greenhouse gas emissions***, notably from agricultural practices, have intensified, creating a feedback loop that accelerates soil degradation while contributing to global climate change.

Lack of Knowledge and Government Support

Farmers in the region, many of whom ***lack access to proper education and training*** in sustainable agricultural practices, continue to ***rely on outdated or harmful methods*** of farming. Studies have shown that there is a knowledge gap among farmers, especially in the proper use of fertilizers and seed treatment, with nearly 100% of respondents in a study failing to apply recommended seed rates, and 59.2% unaware of appropriate row spacing for crops. In Ananthapur, this lack of knowledge regarding soil health management significantly contributes to ***declining soil fertility and productivity***. The ***absence of extension services*** further exacerbates this issue, leaving many smallholder farmers without the resources or technical support needed to adopt sustainable practices. This gap in understanding is also worsened by ***insufficient government support for educational initiatives***, such as soil health awareness campaigns and the effective use of Soil Health Cards, which are crucial for informing farmers about soil conditions and nutrient management practices. Government initiatives that promote sustainable land management are either inadequate or under-enforced, which contributes to the ongoing ***misuse of the land***, particularly with regards to water management and soil fertility restoration efforts.

The lack of financial incentives also hampers progress. Government ***subsidies for chemical fertilizers***, such as urea, continue to promote ***unsustainable farming practices***, despite the fact that the region soils are becoming increasingly degraded. The ***deficiency of policies*** that encourage organic farming or the use of biofertilizers is evident, as farmers still largely ***depend on synthetic inputs*** that ***degrade soil health*** over time. ***Nonexistent markets*** that provide premiums for sustainably cultivated crops (organic, natural farming etc.) is one of the reasons for ***low adoption rate of such sustainable practices***. ***Cultural barriers*** further hinder the integration of sustainable agricultural practices, ***limiting the participation of marginalized g***roups, including women, in government-supported programs. This challenge is compounded by ***ineffective land-use policies***, which ***fail to incentivize farmers*** to adopt agroforestry or other soil-conserving practices. The need for improved coordination between stakeholders and enhanced capacity-building efforts is essential to address these challenges and promote better soil health management in the region. As a result, ***soil organic carbon levels continue to decline***, and Alfisols and Vertisols remain highly susceptible to further degradation.

Core impacts of the nature-agriculture conflict

The agricultural expansion in Ananthapur has had profound effects on biodiversity, particularly impacting soil microorganisms essential for soil health and fertility. Key species like *Azospirillum* and *Rhizobium*, which play crucial roles in nitrogen fixation, have seen dramatic population declines due to the overuse of chemical inputs. Studies have shown that microbial populations, including *Pseudomonas* and *Bacillus*, have decreased by over 30% in areas of monoculture farming, while invertebrates such as earthworms and nematodes, vital for nutrient cycling, have experienced up to 40% declines. These shifts contribute to increased soil compaction and reduced soil fertility, as the loss of biological diversity weakens the ecosystem's natural ability to regenerate. Furthermore, the expansion of groundnut monoculture and crops such as cotton has displaced larger fauna like ants and beetles, further degrading the ecosystem.

Soil degradation in Ananthapur is closely linked to unsustainable agricultural practices, including the excessive use of chemical fertilizers and monocropping. The overuse of nitrogen-based fertilizers, combined with poor water management, has led to severe salinization issues, with more than 61% of the land affected by salinity. Poor-quality irrigation water and over-extraction of groundwater have compounded these challenges, depleting essential nutrients and reducing the soil's ability to retain moisture. Moreover, erratic rainfall patterns and frequent droughts have intensified soil degradation, leading to a 15% reduction in the soil's water retention capacity. The lack of crop diversity, along with the limited use of organic manures, has further reduced the soil's organic carbon content, resulting in lower productivity and long-term unsustainability.

The environmental crisis in Ananthapur is exacerbated by inadequate government support and a significant knowledge gap among farmers. Many smallholder farmers lack access to education and training on sustainable land management, leaving them reliant on outdated practices. Government subsidies for chemical fertilizers, such as urea, continue to promote these unsustainable methods, despite the evident degradation of soil health. Additionally, insufficient government initiatives aimed at promoting organic farming or the use of biofertilizers further undermine efforts to restore soil quality. Cultural barriers also limit the participation of marginalized groups, including women, in sustainable agricultural programs. This lack of coordinated action and capacity-building efforts hinders the region's ability to address the core drivers of the nature-agriculture conflict, perpetuating cycles of soil degradation and environmental decline.

Effective management approaches and solutions available (fig. 3)

No-Till Farming

In Ananthapur, India, ***no-till farming*** has been successfully implemented to combat soil degradation, with a focus on ***preserving soil structure*** and ***promoting microbial biodiversity***.

Farmers have primarily used groundnut (*Arachis hypogaea*) and millet (*Pennisetum glaucum*), crops well-suited to dryland conditions, in these systems. Groundnut, with its nitrogen-fixing properties, ***improves soil fertility***, while millet thrives with minimal soil disturbance. A study in Ananthapur revealed that no-till farming ***reduced soil erosion*** by 30% and ***enhanced moisture retention***, allowing farmers to ***reduce irrigation*** needs by 20%, particularly crucial during frequent droughts. Additionally, the microbial biodiversity in the soil increased by 15%, ***improving nutrient recycling*** and overall soil health. No-till farming practices in Ananthapur also significantly contribute to maintaining soil health by enhancing soil fertility and reducing erosion. This method, combined with ***crop residue retention***, has ***improved soil organic carbon levels*** and overall soil quality, which is crucial in rainfed ecosystems where soil degradation is prevalent due to intensive tillage practices.

Conservation Agriculture

Conservation Agriculture (CA) has proven highly effective in enhancing soil health through multiple practices, including ***residue retention***, ***crop diversification***, and ***reduced tillage***, which help ***preserve soil structure*** and improve long-term sustainability. Farmers in the region ***leave crop residues***, such as groundnut and millet stubble, on their fields, which has ***increased soil organic matter*** by 20%. This practice ***enhances moisture retention*** and ***reduces erosion***, addressing the area's susceptibility to soil degradation due to its semi-arid climate. Additionally, CA emphasizes minimal tillage, which helps ***preserve soil structure and organic matter***, further improving soil fertility and moisture retention. The retained residues ***promote microbial biodiversity***, with an observed increase of 15-20% in microbial activity, which is essential for ***nutrient cycling*** and ***improving soil structure***.

Other key practices include ***cover cropping*** with cowpea (*Vigna unguiculata*) pigeon pea (*Cajanus cajan*), which help fix nitrogen in the soil, ***reducing the need for chemical fertilizers*** by 30%. The integration of ***organic amendments***, such as farmyard manure and groundnut shells, has significantly ***increased soil organic carbon (SOC)*** levels, which is vital for soil health and crop productivity. These leguminous cover crops also play a role in ***weed suppression*** and ***improving soil aeration***, while contributing to increased soil fertility. Integrating ***green and brown***

mulching with cover crops like cowpea (*Vigna unguiculata*) and sesbania (*Sesbania bispinosa*) increased the ***soil's organic carbon content*** by 20%. Specific practices, such as recycling farm waste and applying organic manures alongside reduced tillage, have proven effective, leading to ***increased soil pH*** towards neutrality and higher organic carbon stocks. Coupled with ***drip irrigation***, these practices led to a 25% ***increase in crop productivity*** for groundnut and millet.

Rotation systems in Ananthapur typically involve alternating between millet, pigeon pea, and groundnut, ***breaking pest and disease cycles*** and ***reducing pest-related losses*** by 25%. Furthermore, mulching combined with reduced tillage limits soil disturbance, reducing erosion by 30%, while also preserving soil moisture, which is critical in the water-scarce conditions of the region. The adoption of CA-based technologies has gained momentum, indicating a shift towards more sustainable farming practices that prioritize soil health in the region. These combined conservation agriculture practices have significantly improved long-term soil sustainability and productivity, ensuring resilience in the face of climatic challenges.

Introduction of Phosphorus-Solubilizing Microorganisms

In Ananthapur, India, the introduction of specific ***phosphorus-solubilizing microorganisms (PSMs)*** such as *Pseudomonas fluorescens* and *Bacillus megaterium* has been instrumental in ***improving phosphorus availability in the soil***. These microorganisms, when combined with P-fertilization techniques and other PSMs like arbuscular mycorrhizal fungi (AMF), have significantly boosted phosphorus uptake and crop yields. These microorganisms were introduced through biofertilizer applications at a rate of 1–2 kg/ha, typically dissolved in a solution containing 200 mg/L of the inoculum. For instance, treatments using combinations such as P50+PSB+AMF have demonstrated higher phosphorus content in both grains and stover of maize and wheat, ***enhancing overall soil nutrient dynamics***. This method has proven to increase the solubilization of insoluble phosphate by 40%, significantly enhancing phosphorus uptake by crops such as groundnut and millet. A case study in Ananthapur revealed that the application of Pseudomonas fluorescens led to a 25% increase in phosphorus availability within 60 days of application, resulting in better root development and overall plant health.

The introduction of these PSMs also contributed to a 15% ***rise in microbial biodiversity*** by promoting more ***efficient nutrient cycling*** and ***reducing the need for chemical phosphorus*** fertilizers by 30%. The microorganisms are typically introduced via seed treatment or soil application, and the results show that phosphorus uptake efficiency can increase by 25-30% in crops like millet and groundnut, ***improving yields*** by the same percentage. These integrated approaches not only enhance nutrient availability but also promote sustainable agricultural practices in the region. This biofertilizer application is conducted twice during the crop season to ensure continuous availability of phosphorus throughout the critical growth stages.

Use of Traditional Farming Practices

The integration of traditional Indian farming practices, such as ***Navadhanya*** and ***Zero Budget Natural Farming (ZBNF)***, has shown significant potential in maintaining soil health. Navadhanya, a traditional multi-crop cultivation method, involves sowing nine different crops in the same field to ***enhance biodiversity***, ***promote soil health***, and ***increase resilience against pests and diseases***. ZBNF emphasizes chemical-free farming, aligning with agroecological principles that ***enhance soil organic carbon (SOC) levels*** and improve soil quality. Practices such as ***Jeevamruta*** and ***Panchagavya*** has been vital in promoting soil health and enhancing agricultural sustainability. These practices rely on natural

Figure 3:
CASUAL PATHWAY OF INTERRELATED SOLUTIONS

ingredients like cow dung, cow urine, jaggery, and plant extracts to create biofertilizers and biopesticides that ***enrich the soil with essential nutrients*** and ***beneficial microorganisms***.

Jeevamruta, when applied at a rate of 200 liters per hectare, has been shown to increase microbial diversity in the soil by 25%, significantly ***enhancing nutrient cycling*** and ***improving soil structure***. The use of ***organic amendments*** like farmyard manure and groundnut shells has further ***increased SOC sequestration***, ***enhancing soil fertility and crop yield***. This biofertilizer, prepared by fermenting cow dung, urine, jaggery, and legume flour for 3-5 days, reduces the need for synthetic fertilizers by 30-40%, promoting a more sustainable and eco-friendly approach to farming. These practices also enhance ***soil organic matter content***, which ***improves water retention*** and ***reduces erosion***, critical for regions like Ananthapur, which face frequent droughts and soil degradation. Similarly, Panchagavya, a **bio-pesticide** and growth promoter made from cow milk, ghee, urine, and plant extracts, has ***boosted crop yields*** by 15-20% in groundnut and millet systems when applied as a foliar spray or soil treatment. This mixture is fermented for 7-10 days and used at a 3-5% dilution, reducing the need for chemical pesticides by 25% while ***improving plant resilience to pests and diseases***.

Community-managed approaches have also facilitated the adoption of these practices, promoting awareness and training among farmers, which is crucial for the long-term sustainability of soil health. ***Complementary traditional biofertilizers*** such as Amrutpani, a one-day fermented solution of cow dung, urine, and jaggery, and Bijamrita, a seed treatment solution, further enhance soil fertility and protect crops. These traditional methods not only reduce dependency on chemical inputs but also contribute to the resilience of agricultural ecosystems, supporting food security and environmental sustainability. These methods have proven highly effective in ***improving long-term soil health*** and ***reducing farming costs***, demonstrating their importance in sustainable agricultural practices in the region.

Water-Saving Irrigation Technologies

The implementation of water-saving irrigation technologies such as ***drip irrigation*** and ***sprinkler systems*** has proven critical in ***addressing water scarcity*** while ***maintaining soil health***. In Ananthapur, where erratic rainfall and soil moisture stress are prevalent, these technologies play a crucial role in ensuring soil health and ***crop productivity***. One key initiative under the Andhra Pradesh Community Natural Farming (APCNF) program is to keep the soil under green cover year-round through ***Pre-Monsoon Dry Sowing (PMDS)***. This innovative method involves sowing crops in non-farming seasons to maintain continuous. PMDS allows for sowing, tilling, and tending the land in periods without crop cover, such as before the monsoon, during summer, after Kharif, and before the start of Rabi season.

Drip irrigation has been widely adopted, allowing for precise water delivery directly to plant roots, ***reducing water wastage*** through evaporation and runoff. Studies have shown that the use of drip irrigation systems in crops like groundnut and millet has ***improved water-use efficiency*** by 30-40%. Effective practices, such as the use of ***conservation furrows*** for in-situ moisture conservation, also help ***retain water in the soil***, ***enhancing crop productivity*** under semi-arid conditions. In addition, this method has contributed to a 20% increase in soil moisture retention, which is crucial for sustaining crops during the frequent droughts in the region. These technologies also help ***prevent further soil salinization*** by minimizing excess water application, ensuring that salts do not accumulate in the soil profile.

Moreover, the adoption of ***sensor-based irrigation systems***, which monitor soil moisture levels in real-time, has enabled farmers to ***optimize water use***, reducing irrigation by 25% without compromising crop yields. Ridge and furrow sowing has been identified as a superior method for crops like pigeon pea, allowing for better water management and ***soil moisture retention***. The ***combination of drip irrigation with mulching techniques*** has further enhanced water retention, leading to a 15-20% ***increase in crop productivity*** for key crops such as millet and pigeon pea. Additionally, these technologies have been integrated with ***rainwater harvesting systems***, allowing farmers to collect and store rainwater for use during dry spells, ***reducing dependence on unreliable rainfall*** by 30%. By integrating these water-saving techniques, farmers can ***improve soil structure and fertility*** while addressing the challenges posed by monoculture and chemical use that degrade soil quality. This comprehensive approach to water management has not only improved agricultural sustainability but also ***increased the resilience of farming systems*** in water-scarce regions like Ananthapur.

Multicropping Systems.

Multicropping systems in Ananthapur, India, have proven highly effective in ***improving soil health*** and ***enhancing agricultural resilience***, particularly in water-scarce environments**.** By integrating crops such as groundnut (*Arachis hypogaea*), millet (*Pennisetum glaucum*), and pigeon pea (*Cajanus cajan*) into a single farming system, farmers have ***increased microbial diversity*** in the soil by 20%, which supports better ***nutrient cycling*** and ***reduces the risk of soil degradation***. The groundnut/pigeon pea intercrop has ***minimized crop failures*** by improving productivity under drought conditions, as pigeon pea matures earlier, escaping terminal drought stress that often affects monocropped groundnuts. Studies in the region demonstrated that multicropping ***reduces the likelihood of pest outbreaks*** by 30% due to the diverse plant root exudates that ***suppress harmful pathogens*** and ***promote beneficial soil organisms***. Additionally, this system ***enhances nutrient uptake*** by alternating deep-rooted and shallow-rooted crops, ensuring that different soil layers are accessed for nutrients, thus preventing depletion.The multicropping systems used in Ananthapur have also ***increased water-use efficiency*** by 25%, as different crops have varied water requirements, allowing more effective management of limited water resources. For example, pigeon pea, which requires less water, is intercropped with water-demanding crops like groundnut, optimizing water distribution in rainfed conditions.

Research further suggests that ***integrating organic practices***, such as using farmyard manure (FYM) alongside chemical fertilizers, helps sustain soil health by maintaining essential physical, chemical, and biological properties of the soil. This approach has also resulted in a 20-30% increase in crop productivity compared to monocropping, with higher yields in groundnut and millet due to the complementary **nutrient uptake** and **pest control** provided by the mixed cropping environment. These systems also ***reduce the need for chemical fertilizers*** by 30% as the leguminous crops (like pigeonpea) fix atmospheric nitrogen, contributing to soil fertility. Additionally, the Navadhanya method, which involves sowing nine different crops together, enhances biodiversity and promotes soil resilience by increasing resistance to pests and diseases. Additionally, diverse cropping systems help reduce soil erosion, contributing to improved soil fertility and resilience against environmental stresses.

Policies and investment reforms (fig. 4)

India has implemented several national and local policies to promote sustainable agriculture and soil conservation. Key programs include the ***Drought Prone Areas Programme (DPAP)***, launched in 1973-74, which focuses on improving the productivity of drought-affected regions through soil and water conservation measures, aiming to combat land degradation in arid and semi-arid areas. The ***National Mission for Sustainable Agriculture (NMSA)***, launched in 2010 as part of India's ***National Action Plan on Climate Change (NAPCC)***, focuses on improving agricultural productivity by conserving natural resources.

Additionally, the ***Soil Health Card Scheme (SHC)***, launched in 2015, helps farmers manage soil health by providing recommendations for balanced fertilizer use, reducing the overuse of chemical inputs, and enhancing soil fertility and productivity, as outlined by the Ministry of Agriculture & Farmers Welfare in 2023.

Other critical programs like the ***Integrated Watershed Management Programme (IWMP)***, launched in 2009, and the ***National Policy for Management of Crop Residues (NPMCR)***, launched in 2014, address soil and water conservation and promote sustainable practices across the country. The ***National Rural Employment Guarantee Act (NREGA)***, implemented to provide employment while improving infrastructure, also plays a role in soil and water conservation projects. The ***Draft National Soil Policy***, developed through consultations in 2021 and 2022, aims to provide a framework for the protection, restoration, and sustainable management of soils in India. Its goal is to reduce soil loss by one-third by 2030, with a baseline of 146.82 million hectares from 2004.

Local governance through **Panchayats**, established by the **73rd Constitutional Amendment**, plays a key role in implementing these programs. Panchayat members work closely with state governments and agricultural extension officers to spread awareness and ensure the adoption of sustainable land management practices, assisting farmers in adopting new technologies and policies aimed at protecting soil health.

In addition, the ***Forest (Conservation) Amendment Bill***, 2023, focuses on enhancing forest carbon stocks and promoting afforestation through compensatory afforestation, balancing forest conservation with infrastructure needs. The ***Green Credit Rules***, 2023, incentivize environmental conservation through green credits, promoting sustainable agriculture and reforestation practices. The ***National Green Tribunal Act (NGT)***, 2010, further enforces environmental laws, addressing grievances related to soil and water conservation. Besides, India is committed to the ***Paris Agreement*** of 2015, which seeks to limit global warming to below 2°C and emphasizes the importance of soil conservation for climate change mitigation. Soil conservation plays a crucial role in carbon sequestration, as healthy soils can absorb significant amounts of carbon dioxide, reducing atmospheric greenhouse gases.

Highlights and key messages (fig. 5)

Soil health in Ananthapur, India, is experiencing significant degradation, prompted by a multitude of unsustainable agricultural practices that have been entrenched over numerous decades. The overreliance on chemical fertilizers, particularly nitrogenous compounds such as urea, in conjunction with monocropping methodologies centered around crops such as groundnut and millet, has critically compromised soil quality. Furthermore, inadequate irrigation amplifies these issues, resulting in challenges like soil salinization and nutrient drainage, which further threatens the region's already vulnerable ecosystem. The semi-arid climate, characterized by erratic precipitation and recurrent droughts, intensifies these challenges, hastening soil degradation in landscapes that are inherently susceptible due to their complex topographical features.

The deterioration of ecosystem services within this region is increasingly becoming evident. The soil's capacity to retain moisture has significantly diminished, resulting in a decrease in water availability for crops during essential growth phases. Nutrient cycling, a fundamental process for sustaining soil fertility and plant vitality, has also been disrupted due to the decline in microbial biodiversity. The regulatory services for pests, which historically mitigated the proliferation of deleterious species without the need for chemical treatments, are similarly diminishing. These influences have together driven the increase in soil salinization, the erosion of soil organic carbon, and the loss of helpful microbial groups, like *Pseudomonas* and *Bacillus*, that are vital for ensuring nutrient availability. This degradation poses a grave threat to the long-term viability of agriculture in Ananthapur. As the land's productivity declines, farmers are compelled to depend increasingly on chemical inputs, perpetuating a detrimental cycle.

Regenerative agricultural practices present a potential avenue for ameliorating these issues. Dynamic methods such as no-till farming,

Figure 4:
TIMELINE OF MAIN POLICIES AND REFORMS

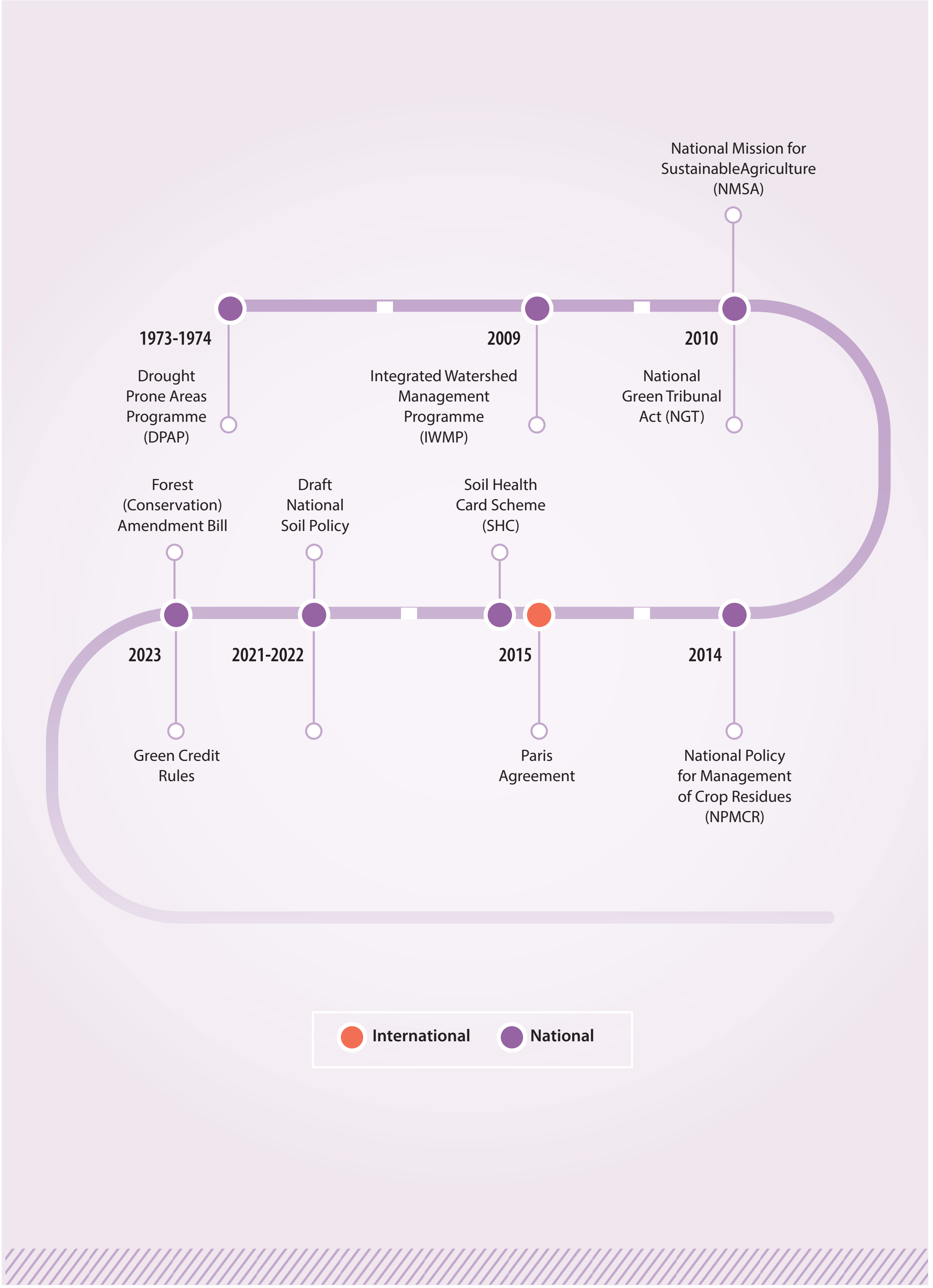


Figure 5:

MATCHES BETWEEN DRIVERS AND SOLUTIONS

mulching, and crop diversification have illustrated hopeful advancements in boosting soil health. For instance, no-till farming aids in maintaining soil structure, mitigating erosion, and fostering microbial diversity. Conversely, mulching contributes to moisture retention and curtails soil erosion, an aspect that is particularly vital in the semi-arid context of Ananthapur. Furthermore, the integration of phosphorus-solubilizing microorganisms has demonstrated significant potential in improving phosphorus availability, supporting nutrient uptake, and elevating harvest outputs. Collectively, these methodologies diminish the reliance on chemical fertilizers while fostering soil resilience, enabling farmers to sustain productivity amidst challenging environmental conditions.

To amplify these sustainable agricultural practices, policy reforms and strategic investments are imperative. Initiatives such as the Soil Health Card Scheme, launched in 2015, equip farmers with the requisite knowledge and tools to monitor and enhance soil health through customized recommendations for fertilizer application. The Forest Conservation Amendment Bill of 2023 further advances this agenda by reconciling infrastructural requirements with the imperative for afforestation, a critical strategy for sustaining carbon stocks and bolstering soil health. Moreover, the establishment of green financing mechanisms, including carbon credits under the Green Credit Rules of 2023, generates economic incentives for farmers to embrace sustainable practices. These policies signify a pivotal step toward reversing the prevailing trends of soil degradation and aligning agricultural practices with broader environmental objectives, including India's commitments under the Paris Agreement.

Local governance plays a pivotal role in the successful realization of such initiatives. Panchayati raj institutions, through a framework of decentralized governance, bear the obligation of ensuring the proficient implementation of both state and national policies at the community level. They engage in collaborative efforts with agricultural extension officers to disseminate knowledge regarding sustainable agricultural practices and to foster the integration of technologies aimed at the restoration of soil health. By partnering with local agriculturalists and extending technical support, these institutions ensure that regenerative practices are comprehended and actively executed throughout the region. This holistic methodology, which combine policy reinforcement, innovative agronomic techniques, and community participation, presents a viable trajectory for alleviating the soil health crisis in Ananthapur while simultaneously enhancing long-term environmental sustainability and agricultural resilience.

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INDIA

Farming & landuse practices effect on soil health, incl. Minimal tillage and the natural farming movement in Ananthapur

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