Climate smartness of GIZ soil protection and rehabilitation technologies in Maharashtra, India

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Rapid Assessment Report

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and Suvarna Chandrappagari

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RESEARCH PROGRAM ON
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Farmers discussing soil fertility constraints with scientists and R4D experts from WOTR, BAIF, and CIAT

1. Introduction

Globally, agriculture is a principal contributor to climate change, directly adding 14% of anthropogenic greenhouse gas (GHG) emissions, and another 17% through land use change; the latter mostly in developing countries. The majority of future increase in agricultural emissions is expected to take place in low- to middle-income countries (Smith et al., 2007). While industrialized countries must dramatically reduce current levels of GHG emissions, developing countries face the challenge of finding alternative, low carbon or green growth development pathways (Wollenberg et al., 2016). Climate-smart agriculture (CSA) aims at transforming agricultural systems to sustain food security under climate change, and thus can contribute to addressing this challenge.

Although CSA aims at improving food security, adaptation and mitigation, it does not imply that every recommended practice should necessarily be a 'triple win'. Mitigation in developing countries should be a co-benefit, while food security and adaptation are main priorities. Low emission growth paths might have more associated costs than the conventional high emission pathways, thus monitoring and assessment can highlight opportunities for climate finance funds (Lipper et al., 2014). CSA complements sustainable intensification (SI), aiming at increasing agricultural productivity from existing agricultural land while lowering the environmental impact. SI's focus on increasing resource use efficiency which contributes to adaptation and mitigation through increased productivity and reduced GHG per unit output (Campbell et al., 2014). Both, CSA and SI underline the importance of potential tradeoffs between agricultural production and environmental degradation.

It is however, not only the (additional) challenges that climate change will bring, but also the ever existing threats that degradation of the natural resource basis poses. As far as India is concerned, "the sustainability of agriculture is the crisis India faces today" (Misra and Prakash, 2013). By 2030, India will have to annually produce 345 million tons (Mt) of food grains (ICAR, 2011), against the production of about 265 Mt in 2013-14. Meanwhile, the average farm holding size declined from 2.26 ha in 1970-71 to 1.6 ha in 2010-2011 while the number of farm holdings increased from 71 to 138 million during the same period, mainly due to progressive fragmentation of land holdings (Ganeshamurthy, 2014).

At the same time, soil erosion and loss of soil fertility are affecting crop productivity and food security (Nair, 2014). Climate change could exacerbate the issue, whereas the Indian dry areas, such as in the state of Maharashtra, are especially vulnerable. As rainfall intensities are projected to increase with progressing climate change, so is soil erosion (Mondal et al., 2014). Higher temperatures as well as reduced overall amounts of rainfall have been projected to negatively impact rice (Soora et al., 2013) and wheat (Naresh Kumar et al., 2014) productivity in India; the two major staple food crops of the country. There is little evidence that other crops will not be similarly affected.

India has come a long way, especially concerning the issue of food security and soil protection & health. To start with, the Green Revolution in the late 1960s/early 70s was propelled by the idea that boosting agricultural productivity helped to create a "springboard" out of poverty in Asia and provided the foundation for the broader economic and industrial development (World Bank 2005; Hazell, 2009; Pingali, 2012). The Green Revolution gains in agricultural productivity, food security and reduced poverty were widely associated with irrigated areas, where the benefits of improved seeds and increased use of inorganic fertilizers could be realized, while the majority of the farmers in arid and semi-arid regions could not fully reap the benefits. On the other hand, the massively increased use of chemical (only) fertilizers during the green revolution, had, and is having, negative side-effects. Among others, incentives for judicious use of inputs were, and are, largely absent, the Green Revolution incurred a range of significant hidden ecological and social costs (Shiva, 1991; Dubey and Lal, 2009; Brainerd and Menon, 2014). In response to these issues, as well as to the observed slowdown in increases of agricultural yields threatening long-term food security (Janaiah et al., 2005; Manna et al., 2005), some re-thinking took place over the past 10 to 20 years. Increasingly, the value of agricultural sustainability, as well as the fundamental importance of soil protection, uniting productivity and the integrity of the natural resource base, came into focus. Claims were made towards initiating a new, second (or 2.0) or real green revolution (Horlings and Marsden, 2011) that, among others, "embraces the concept of agroecology, i.e. the application of ecological science to the study, design, and management of sustainable agriculture" (De Schutter and Vanloqueren, 2012).

In line with this trend, organic agriculture, though still somewhat underappreciated in India, is gaining incredible momentum. In 2013, according to Willer and Lernoud (2016), 99.2 million hectares of cereals were produced organically, making India the number 1 organic producer of cereals as far as acreage is concerned.

Recently, the importance of social inclusion and participation has been added, and authors like Srivastava et al. (2016) "propose a «commercial ecological agriculture» which should be an amalgamation of sustainable agricultural practices and supported by a progressive coordination among all the stakeholders."

Within this context, the BMZ-GIZ Soil program on 'Soil Protection and Rehabilitation for Food Security' as part of Germany's Special Initiative "One World – No Hunger" (SEWOH) invests in sustainable approaches to promoting soil protection and rehabilitation of degraded soil in Kenya, Ethiopia, Benin, Burkina Faso and India. It furthermore supports policy development with regard to soil rehabilitation, soil information and extension systems.

The CIAT-led project 'Climate-smart soil protection and rehabilitation in Benin, Burkina Faso, Ethiopia, India and Kenya', supports the BMZ-GIZ Soil program, and intends to widen the scope of soil protection and rehabilitation for food security by aligning with the goals of CSA. The project builds on CIAT's expertise in both soil science and CSA. It assesses the climate smartness of selected, GIZ-endorsed soil protection and rehabilitation measures in the five countries because, soil rehabilitation is often evaluated for productivity and food security benefits, with little attention to 'climate smartness'. Likewise, CSA initiatives have not given due attention to soil protection and rehabilitation, despite their strong potential to contribute to all three pillars of CSA. There is a need to align soil protection and climate-smart agriculture, in implementation of agricultural innovation practices that address soil degradation issues and climate change mitigation and adaptation.

Thus the goal of the project is to produce detailed information on the climate smartness of ongoing soil protection and rehabilitation measures in these countries, identify suitable indicators for future monitoring and evaluation, as well as potential to increase the climate smartness of these measures.

This report focuses on the GIZ-supported soil protection and rehabilitation work ongoing in India, and summarizes the result of a first, rapid assessment of the climate smartness of suggested, best-bet technologies to protect or rehabilitate soils.

Results presented are based on insights gained during a stakeholder workshop held on 5-6 April 2016 at WOTR Darewadi training centre in Maharashtra. During this workshop, the diversity of farming systems in the project area were assessed, major farm systems derived and then evaluated in terms of the potential impact of selected soil protection and rehabilitation measures on the performance of these major farm types. Subsequently, farmer surveys were carried out to gather further relevant details. Data were then analysed towards the climate smartness by farm types addressing the three CSA pillars of food security, adaptation and mitigation using the four indicators: food calorie production, nitrogen balance, soil erosion and greenhouse gas emissions.

Research clusters

The GIZ supported Soil Protection and Rehabilitation for Food Security program in India takes place in the two States of Maharashtra and Madhya Pradesh. In these states, seven research regions have been identified (Figure 1). Within each region, implementation work is being carried out in selected clusters by three NGOs: the Watershed Organisation Trust (WOTR), the BAIF Development Research Foundation (formerly registered as the Bharatiya Agro Industries Foundation, BAIF), and the Foundation for Ecological Security (FES). This study focuses on the research regions in the state of Maharashtra.

The research regions are:

WOTR - Maharashtra

- Ahmednagar
- Jalna
- Dhule

BAIF - Maharashtra

- Amaravati
- Yavatmal

FES - Madhya Pradesh

- Mandla
- Balaghat

Reference maps on soil and climate characteristics highlighting differences across research regions in the state of Maharashtra can be found in the Appendix.

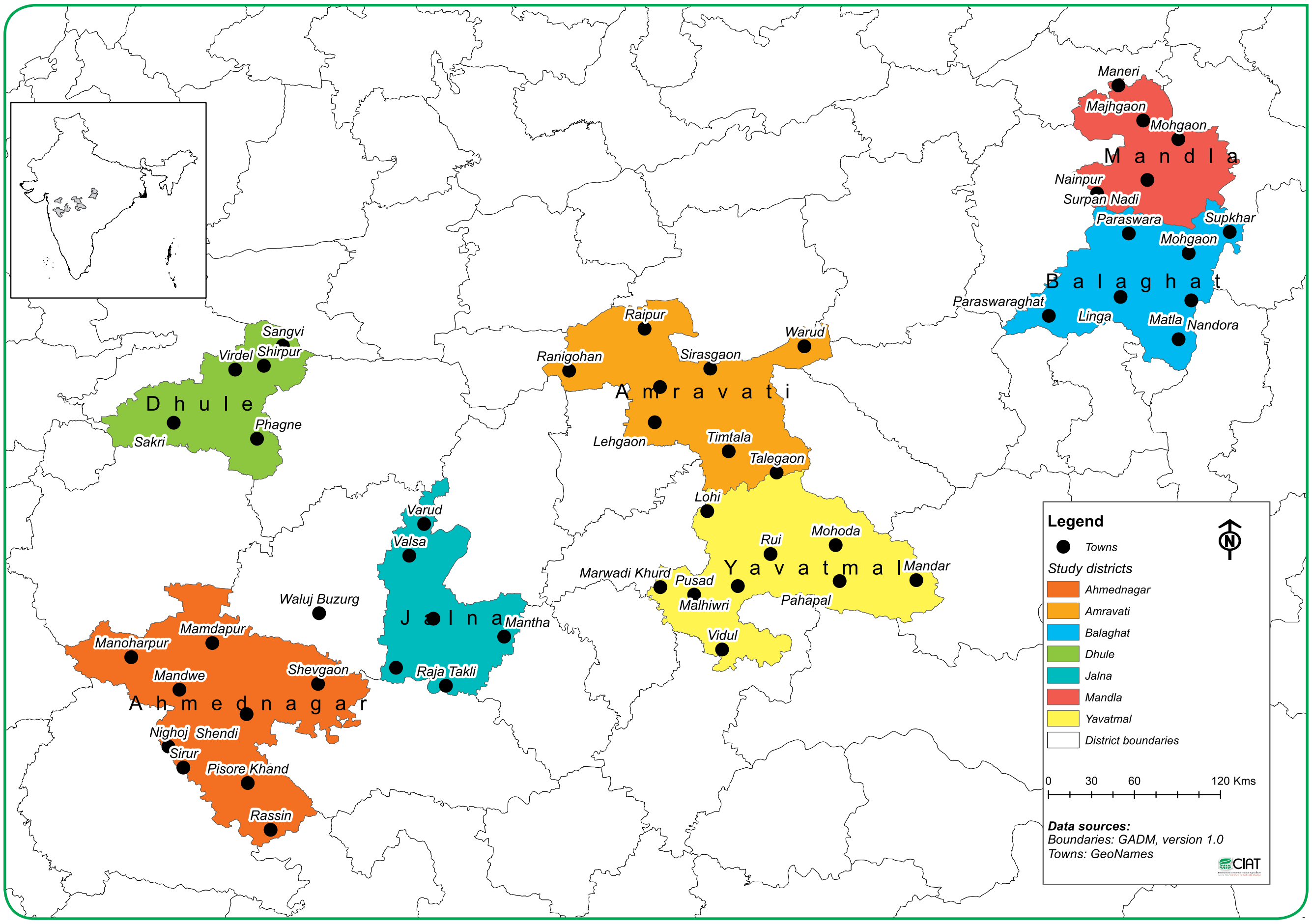


Figure 1. GIZ-India Soil Protection and Rehabilitation for Food Security project regions (map, courtesy of I. Ghosh, GIZ).

Livestock in India

Cultivation in Maharashtra, India

2. Methodology

Following the participatory workshop that identified 4-6 farming system types per country, potential representative farms were jointly identified by CIAT, GIZ and ministry staff for a rapid assessment. The rapid assessment is based on a case study approach thus only one farm per type was selected and sampled. The head of the household was interviewed and household data collected using a questionnaire similar to that used within IMPACTlite (http://bit.ly/2h3KAZf). Information about crops and livestock was collected including data about plot sizes, yields, use of crop products and crop residues, labour activities and inputs. Similar information was gathered for the livestock activities if any. In some cases, soil samples were taken from different plots.

The data collected served as input for the model used for the rapid assessment. The rapid assessment model, named *Kalkulator*, calculates the following indicators according to different methodologies:

Productivity: Farm productivity was calculated based on the energy (calories) produced on farm – crop and livestock products – and compared to the energy requirement of an adult male equivalent to 2500 kcal per day (AME). Energy from direct consumption of on farm produce was calculated by multiplying the energy content of ever crop and livestock product with the produced amount. It is thus important to note that the indicator only represents food/energy production from the own farm, not funds that the household might use to purchase additional food. Energy contents were based on a standard product list developed by the US Department of Agriculture (USDA) (source: http://bit.ly/1g33Puq). The total amount of energy produced on the farm was then divided by 2500 kcal to obtain the number of days for which 1 AME is secured. For the sake of cross-farm comparability, these data were then also expressed on a per-hectare basis.

Soil nitrogen balance: This balance was calculated at the plot level following the empirical approach of NUTMON as described in Bosch et al. (1998). The following soil N-inputs were considered i) mineral fertilizers, ii) manure, iii) symbiotic fixation by legumes crops, iv) non-symbiotic fixation, and v) atmospheric deposition. The N-outputs are i) crops and residues exported off the field, ii) leaching of nitrate, iii) gaseous loss of nitrogen (NH_3 and N_2O) and iv)soil erosion. For calculating N inputs from manure and fertilizer, and N outputs from crop and residues, farmer reported data on quantities from the household survey was used. For N inputs from N fixation and deposition as well as N outputs from leaching, gaseous losses and soil erosion, transfer functions were used that are based on the rainfall and soil clay content of the specific site. The N balance is calculated for each plot (kg N/plot) and then summed to obtain the field balance expressed in kg N per farm. These results are then, again, converted into kg N per ha.

Soil erosion: Soil erosion is calculated at plot individual field level following the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1991; Amdihum et al., 2014).

$$\text{Soil loss (t/ha/year)} = R^*K^*LS^*C^*P$$

where,

R = Erosivity factor (a function of rainfall in mm/month)

K = Erodibility factor

LS = Slope length factor (function of the length and gradient of the slope)

C = Crop cover factor (function of the crop type)

P = Management factor (function of agricultural management practices).

Further information on each factor can be found at: http://www.iwr.msu.edu/rusle/factors.htm

GHG emissions: The GHG emissions are calculated at farm level following the guidelines of the International Panel on Climate Change (IPCC, 2006). Emissions from livestock (methane from enteric fermentation), manure (methane and nitrous oxide), and field emissions (nitrous oxide) are taken into account as illustrated in the graph below. Household survey data on livestock feed, livestock numbers and whereabouts, manure and fertilizer use, crop areas, and residue allocation was used as input data for the calculations. Most of the calculations follow IPCC Tier 1 methods, while Tier 2 calculations were performed for enteric fermentation and manure production (Figure 2).

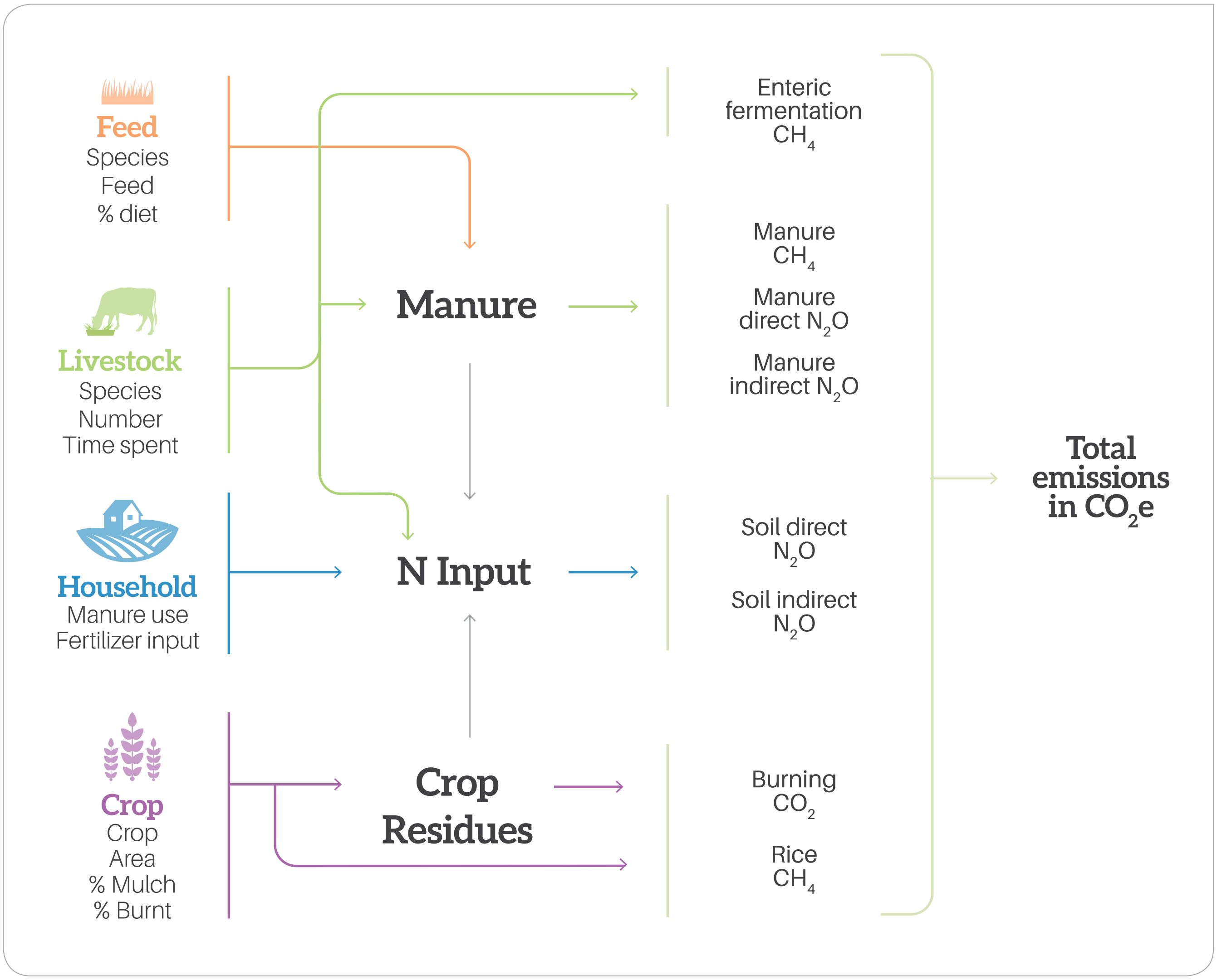


Figure 2. Scheme of the GHG emission calculations.

3. Farming system types

3.1 Diversified dryland farmer

About 5% of all farms in the project areas fall under this category. Diversified dryland farmers have many things in common with the "regular" dryland farmers (ii below). However, the size of land holding of a diversified dryland farmer, with 2 to 10 ha, is larger than that of the dryland farmer. Intercropping is practiced on both dryland farms. Major crops grown are intercropped cotton and pigeon pea (grown in the Kharif season, July-October), and intercropped soybean and sorghum (grown in the Rabi season, October-March). The intercropping pattern is 4 rows cotton to 1-2 rows pigeon pea, and 6 rows soybean to 1 row sorghum. Dryland farms receive very limited rainfall; about 400 to 700 mm per annum. The dominant soil types are black cotton and sandy soil. Cotton, soybean, pigeon pea and chickpea are produced commercially while the other crops are generally for home consumption. About 5% of these diversified dryland farmers intercrop pigeon pea, moth bean (*Vigna aconitifolia*), horse gram (*Macrotyloma uniflorum*) and pearl millet. Around 20% of the diversified dryland farmers keep livestock, and if so, approximately one cow, some goats, and poultry. Grazing on communal land is common as well as cut and carry fodder, and dairy products are mostly for self-consumption. Livestock products are mostly raised for home consumption in Yavatmal and Amaravati, while mostly sold outside the household in Ahmednagar. Income can be generated from selling surplus crop yields (mostly found in Yavatmal, Amaravati and Jalna) and also from dairy products (mostly found in Ahmednagar), as well as from seasonal off-farm wages. About 70% of the households under this category use farm mechanization on a rental basis (tractors and other machinery/equipment). Agricultural produce is mostly sold in local markets. Literacy rates range between 65 and 70%.

3.2 Dryland farmer

The dryland farmer type is similar to the diversified dryland farmer type in rainfall, soils, livestock ownership (about 20%), sources of income, mechanization and literacy rates. However, being less "diversified" i.e. growing a less diverse portfolio of crops, an approximate 5% of all farms in the project areas belong to this farm type. The average land holding size is 0.5 to 2 ha. In the Kharif season, these farms generally produce the following crops: cotton, pigeon pea, green gram (also known as mung bean, *Vigna radiata*), soybean, sorghum, pearl millet, maize, and chickpea. Soybean follows in the Rabi season. In Yavatmal and Amaravati clusters, the majority of the farmers practice mixed-cropping.

3.3 Rice farmer

About 20% of all farms in the project area fall into this typology. The average land size is about 2 ha. The agro-ecological potential includes average annual rainfall of 900 mm, the dominant soil type is a silty loam, with an average soil depth of 40 to 60 cm. The main crop grown in the Kharif season is rice (about one quarter of the 2 ha farm), while the remaining area is often used to produce finger millet, soybean groundnut and maize. During the Rabi season farmers take advantage of residual moisture in paddy fields and plant chickpea. Rice is grown under flooded conditions only (paddy). An average rice farmer has the following numbers of indigenous livestock: 2 bullocks, 2 cows, 3 goats, and 10-15 poultry. Livestock grazes common lands and also receives groundnut, soybean, maize and rice crop residues. Rice farmers in this region practice mostly subsistence agriculture with 70% of the agricultural production and 90% of the livestock production going toward domestic consumption, while the remainder is sold in local markets. The prominently visible technology adopted is System of Rice Intensification (SRI) in about 10% of all paddy farms. Adoption of high yielding varieties is limited, fertilizer/pesticide use is low, and lack of organic certification and marketing arrangements for the produce, and no value addition knowledge/practice are some main characteristics of this farm typology. Average household sources of income include agriculture (55%), selling labour off farm especially with high seasonal migration in Jalna (30%), selling livestock products (10%) and other businesses (5%). Paddy farmers are mostly members of tribal communities with around 34% literacy.

3.4 Specialized irrigation farmer

About 25% of households fall under this category. The average landholding size is 2 ha. Irrigated crop production dominates and is supported by livestock rearing. The agro ecological potential includes average annual rainfall of 500-600 mm, the dominant soil types are sandy clay loam and black cotton soil, and the average soil depth is 45 to 60 cm. The main crops grown in the Kharif season are soybean, green gram, maize and onion, while crops grown in the Rabi season include wheat, onion, chickpea and other vegetables. About 15% of the agricultural produce is used for home consumption while 85% is sold via the Agriculture Produce Market Committee (APMC) and in local markets. An average specialized irrigation farmer has 2 bullocks, one indigenous cow, 1 to 2 crossbred cows, 5 goats, and 10 to 15 poultry. Livestock is mostly stall-fed (70%) on maize, green gram, wheat and chickpea crop residues as well as guinea grass (*Megathyrsus maximus*) grown on bunds. Approximately 30% of livestock products are used for home consumption and the rest sold in markets. Average sources of

Livestock in India

household income include agriculture (70%), livestock (20%) and others (10%). Literacy is around 70%. Specialized irrigation farmers have adopted certain technologies, such as using high yielding varieties, applying chemical fertilizers and pesticides, and mechanized farming using tractors and threshers, while value addition is largely absent.

The percentage distribution of farm types per research region is shown in Table 1. Not only does this distribution vary, so does also the distribution within regions by clusters (Table 2).

Table 1. Percentages of farm types per research region.

District	Dryland farmer	Dryland diversified farmer	Rice farmer	Specialized irrigation farmer
	%			
Ahmednagar	23	5	7	65
Dhule	50	5	35	10
Jalna	60	35	0	5
Yavatmal	15	70	0	15
Amaravati	10	75	0	15
Overall project area	5	50	20	25

Table 2. Percentages of farm types per cluster.

Cluster	Dryland farmer	Dryland diversified farmer	Rice farmer	Specialized irrigation farmer
	%			
Bhalawani (Ahmednagar)	25	5	0	70
Pimpalner (Dhule)	10	5	75	10
Bhokardan (Jalna)	70	20	0	10
Dhamangaon (Amaravati)	10	75	0	15
Asoli, Devdhari & Atmurdi (Yavatmal)	10	75	0	15

One case study farm was selected for each of the farm types. The farms chosen were representative farms of the farmers within each farm type.

Most of the specialized irrigation farmers are found in the Bhalawani cluster in Ahmednagar, and most of the rice farmers in the Pimpalner cluster (Dhule). Therefore, the two representative farms were selected from these two districts. The Asoli cluster (Yavatmal) has 75% farmers in the dryland diversified farmer typology, hence the representative farm for this typology was selected from Asoli village. A representative dryland farmer was selected from Dhamangaon village (Amaravati), since dryland farmers and dryland diversified farmers are often interchangeable depending on the availability of irrigation water.

A rice thresher

Soil fertility improvement technologies

4. Technology descriptions and scenarios

The following scenarios were chosen to represent soil rehabilitation interventions that are currently promoted by GIZ in India or that are under discussion for future promotion. All assumptions are described according to impact dimensions summarized under the Appendix 'Scenario Assumptions.'

1. Composting/green manure/farm yard manure
2. Intercropping/ crop rotation and rhizobium inoculation
3. Reduced tillage + mulch (dryland farms only), or mulching only (rice farmer and specialized irrigation farmer only)
4. System of rice intensification (rice farmer only)

Soil fertility improvement technologies comprised two components, composting/green manure application and rhizobia inoculation, of which the latter was merged with intercropping/double cropping.

In the composting/green manure/farm yard manure scenario, two thirds of the crop residues were removed from the fields after harvest for composting. The amount of compost or farm yard manure (FYM) applied to the fields ranged between 2.5 and 7 t/ha across the farms. Further assumptions on the impact dimensions of composting included reduction in manure application by 20% and increase in crop yield by 7-25% across the farms.

In the intercropping/double cropping with rhizobia inoculation scenario, cereal crop yields were assumed to reduce by 15% due to the competition with the intercropped beans, and fields that were left fallow during the short rainy season were instead rotated with chickpea. Rhizobia inoculation was done on all legumes, and assumed to have no impact on yields, but instead imply savings in mineral N-fertilizer application by 5-20%.

The reduced tillage and mulch scenario entailed a 67% residue retention on crop fields, 10% reduction in organic and inorganic fertilizer application, and increase in crop productivity by 5-22.5%. As a result, milk production was estimated to increase by 5% in the specialized farm, while the anticipated in increase in crop yields in the other farm types were assumed too little to have any effect on milk production.

The System of Rice Intensification (SRI) scenario was assumed to increase rice yields by 10%, without any associated change in milk production, as rice straw feed is of only poor quality.

Onion harvest in Maharashtra, India

Farm visit in Maharashtra, India

5. Results

5.1 Productivity pillar

5.1.1 Baseline productivity

On farm productivity was calculated by summing up all the calories from crop and livestock products produced on farm and dividing by the calorie requirements of an average adult (AME: Adult Male Equivalent; 2500 k cal/day). Productivity is thus expressed in number of AME days (Figure 3).

The rice farm has the highest productivity – per farm and per hectare, mainly because of the significant addition of calories from milk from the (exceptionally) high numbers of dairy cows. Interestingly here, rice ranks only third in terms of calories added, despite the fact that the farm type is named for the activity of rice cultivation. Pigeon pea and soybean add notably to the productivity of the two dryland farms. The specialized irrigation farm has the lowest productivity, whereas sorghum is the most important source of calories, while milk from the 2 goats adds only little. However, it must be noted that the interviewed farmer of this type had 22 goats – only the aforementioned (on average) 2 producing milk. The meat production from these animals will add to the overall farm productivity, but has not been included in this report.

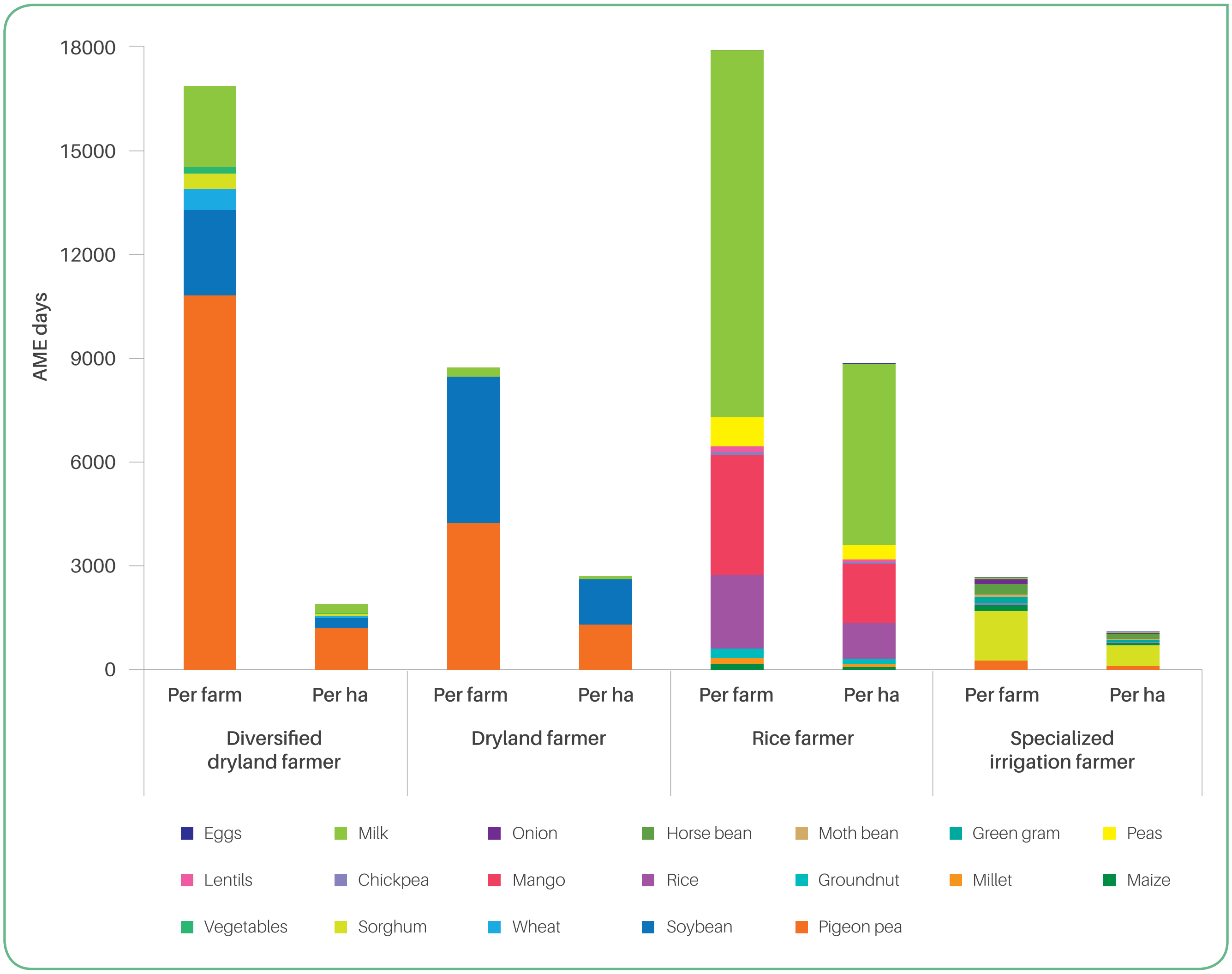


Figure 3. Baseline productivity and contribution from the different products across farm types. *Productivity is expressed in days of equivalent calories an adult male (AME).*

5.1.2 Changes in productivity

Productivity changes little across all farms in response to the implementation of the five different technologies (Figure 4). This is by large a result of the technology selection per se. Selected technologies primarily aim at protecting and rehabilitating soils. On the other hand, it is noteworthy that none of the technologies had a negative impact on farm productivity overall. Composting sticks out somewhat, which should not be surprising given the notable amounts of compost and farm yard manure added to the fields in this scenario.

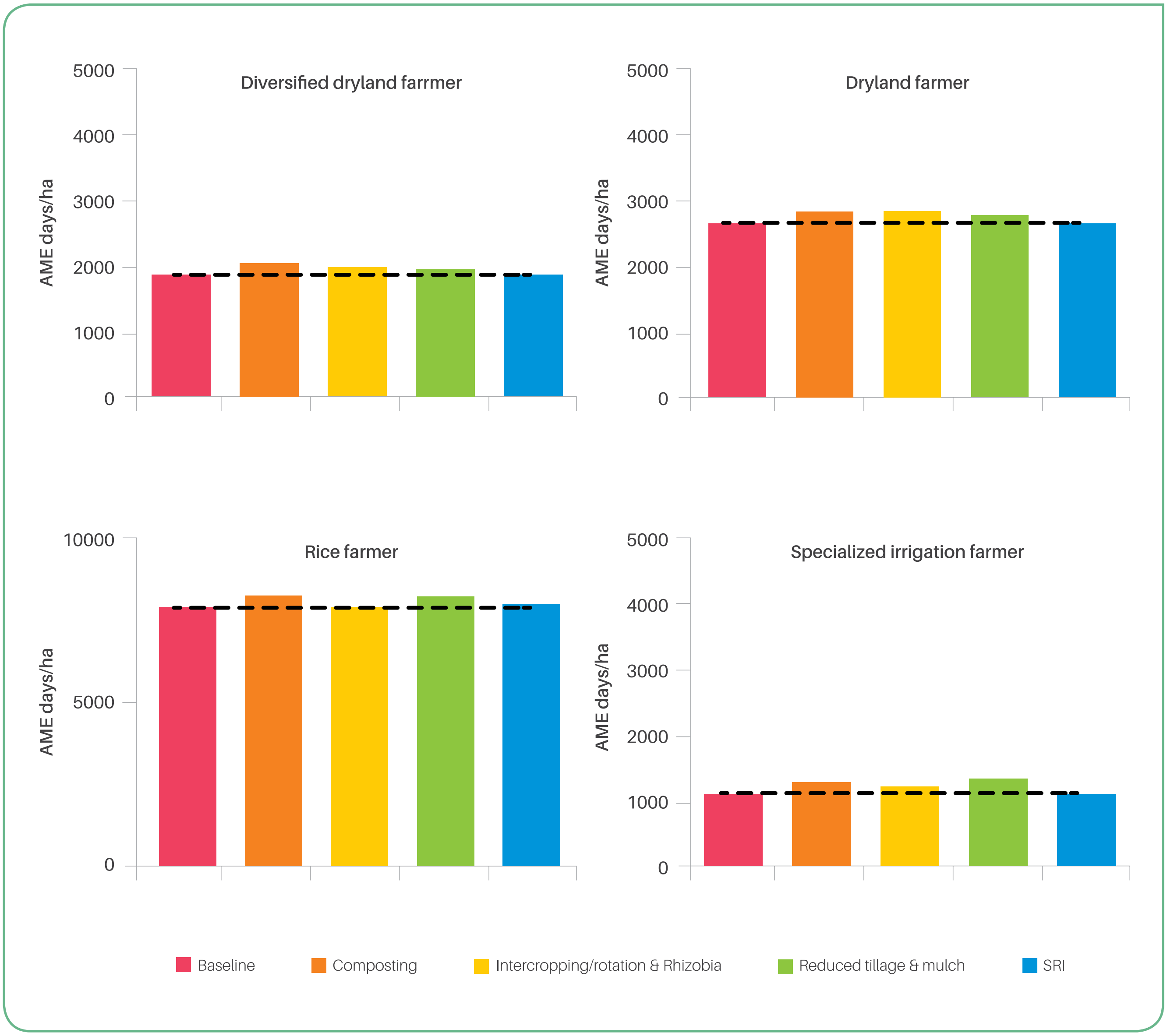


Figure 4. Baseline and scenario productivity per farm type. *Results are expressed in days of Adult Male Equivalent calories (AME = 2500 kcal/day) on a per hectare basis.*

5.2 Resilience pillar

5.2.1 Baseline N balances

The nitrogen (N) balance is calculated at the field level (please refer to the appendix for further details on the calculations). The per-farm N balance is the sum of N balance of the individual fields, and the per hectare balance equal to the per-farm balance divided by the acreage of the farm.

The N balance is positive on all farms (Figure 5). Excessive fertilizer application to cotton and pigeon pea are mostly responsible for the positive balance of the diversified dryland farm and the dryland farm.

Soybean production with more N fertilizer applied than N withdrawn during harvest adds to the positive balance of the latter farm. The addition of about 300 kg N/ha (most of it coming from manure) to the rice crop that yields only 2 t/ha grains, is also more N than required, and thus results in a positive overall N balance on the rice farm. In the case of the specialized irrigation farmer, N inputs hardly compensate for the N extracted with the harvested products for all crops grown in the Rabi season, and all but onions (receiving 160 kg N/ha through mineral

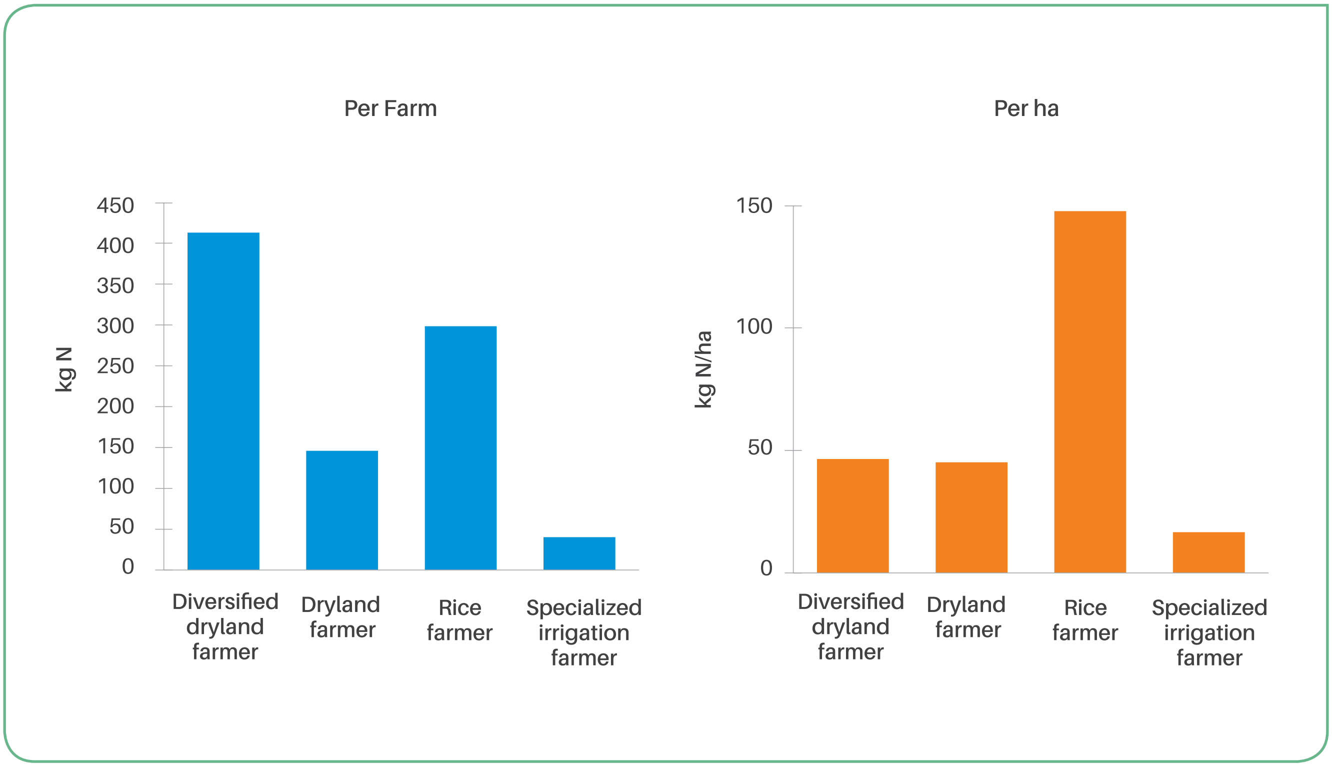


Figure 5. Baseline N balance at field level per farm and hectare across farm types.

fertilizer) in the Kharif season. In total, this farm is thus very close to a fully balanced N budget.

5.2.2 Changes in N balance

Composting results in the highest increase in N balance across most farm types, because too much N is added in the form of compost in comparison to the anticipated increases in yield and the foreseen reduction in mineral N fertilizer rates (Figure 6). This is especially visible in the specialized irrigation farm, where a) assumed rates of compost or farmyard manure as in the case of all the specialized farm types (7.5 t/ha) were the highest in comparison to the other farms, and b) compost addition was very high in comparison to baseline N inputs. Thus, there is scope to re-evaluate/optimize the way this technology is implemented against the anticipated impacts. Reduced tillage in combination with mulch ranks second and increases the N balance by 22 kg N/ha (rice farm) to maximum 37 kg N/ha (dryland farm), which is largely due to increased residue retention as opposed to the conventional residue management system of removing all crop residue from the field. However, this technology reduces the N balance by 7 kg N/ha on the specialized irrigation farmer, yet the balance remains positive. Introducing the System of rice intensification (SRI) and intercropping/double cropping with rhizobia inoculation affect the N balance the least. The accompanying reduction in mineral N fertilizer rates decreases the surpluses of N added to the system, while the (humble) assumed increases in yields increase N use efficiency.

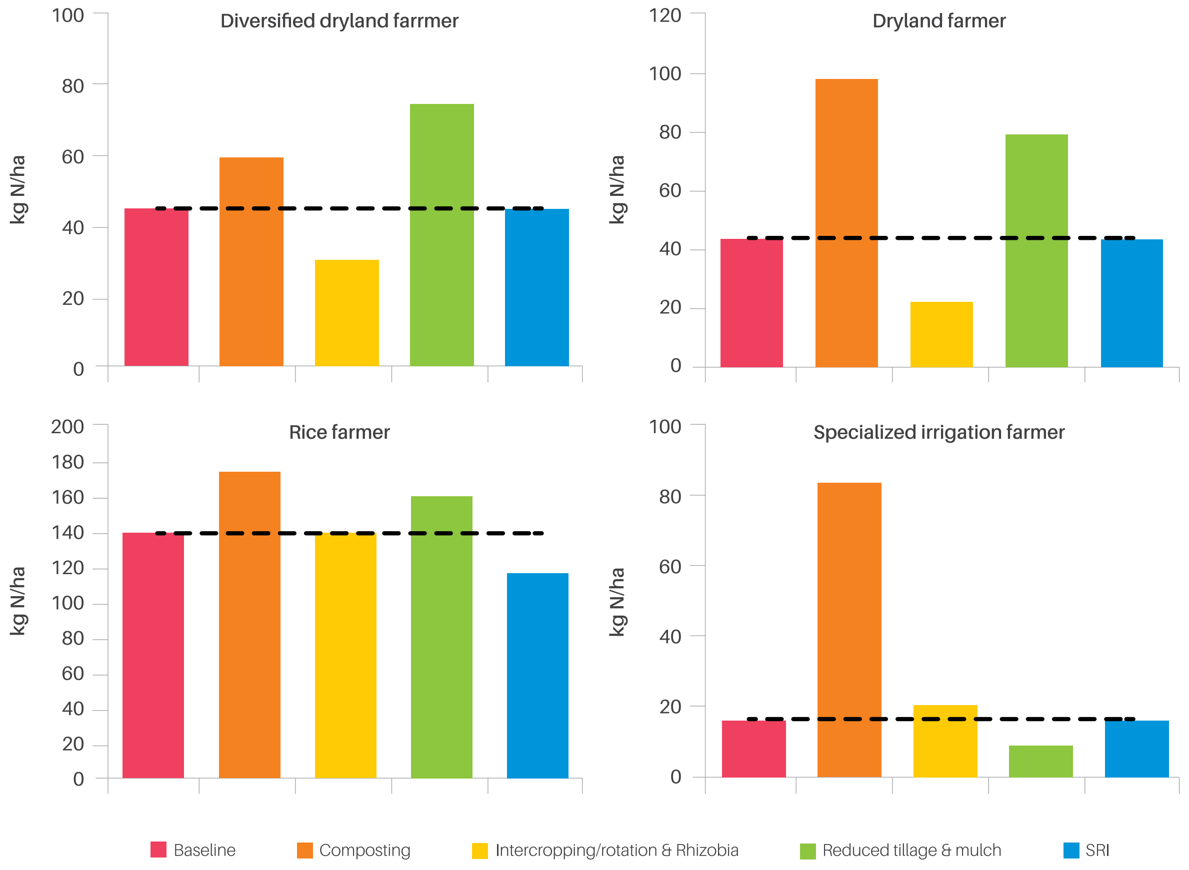


Figure 6. Nitrogen balance baselines and scenarios across farms (kg/ha).

This seems most beneficial for systems, where N balance surpluses are already present in the baseline, and a reduction rather than increase of N-inputs is required.

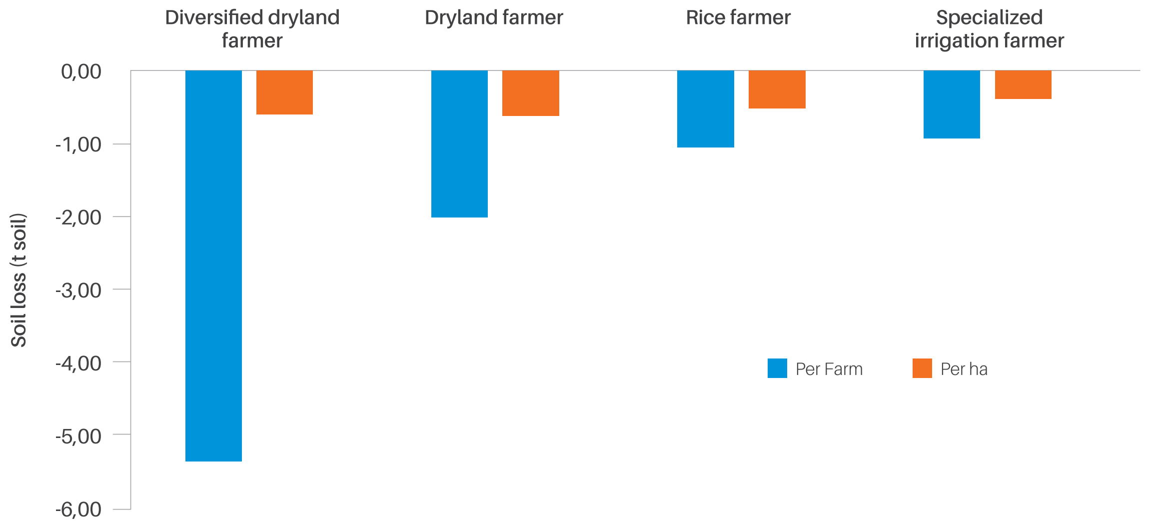


Figure 7. Baseline soil erosion (t soil/year) per farm and per hectare.

5.2.3 Baseline erosion

Soil erosion is negligible with all farms losing less than 2.5 t/ha/year except the diversified dryland farm which loses about 5 t/ha/year. This is attributed to the fact that the land is rather flat.

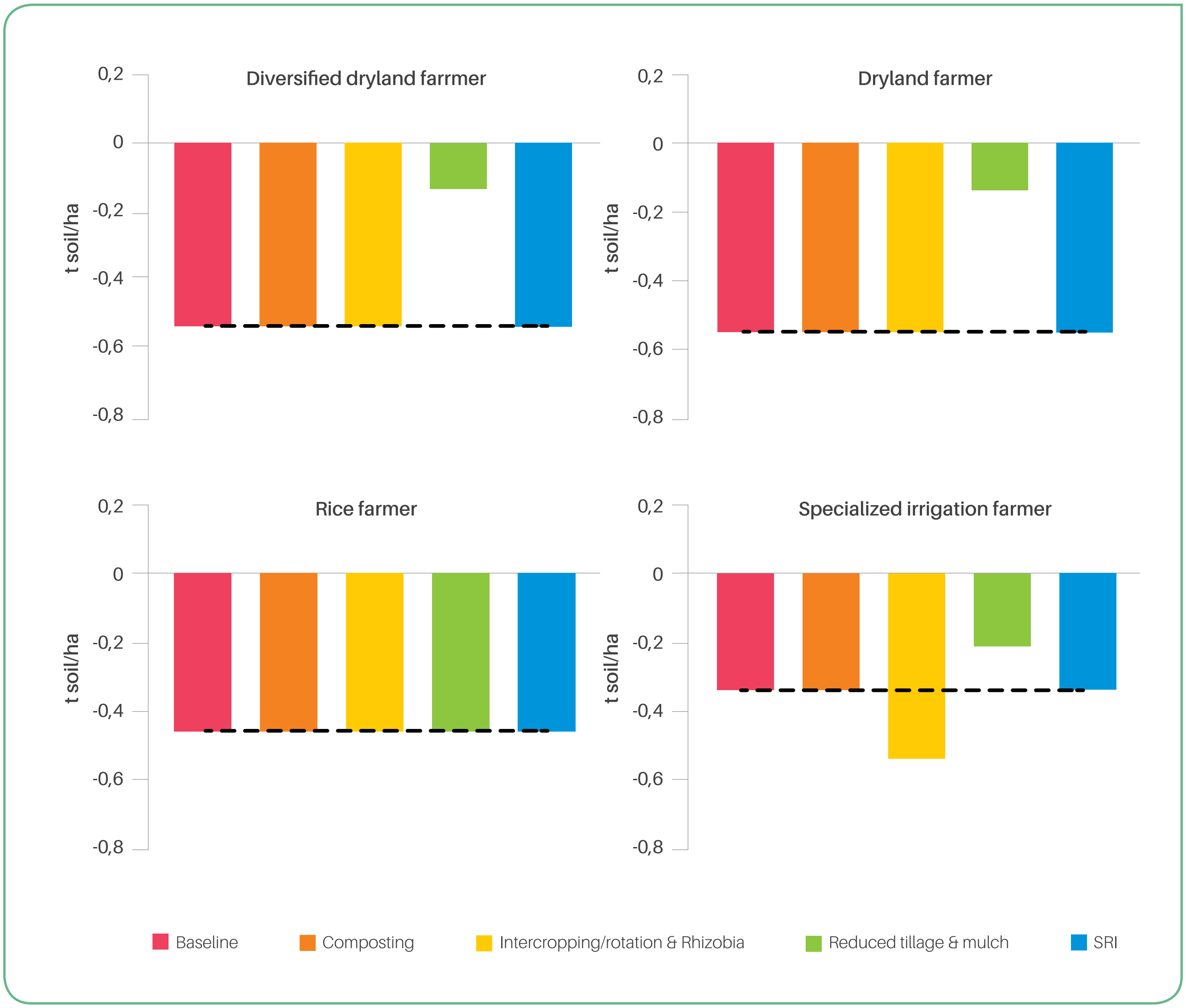


Figure 8. Soil erosion baselines and scenarios across farms (t soil/ha).

5.2.4 Change in erosion

Erosion rate remains the same across all technologies in all farm types except reduced tillage which reduces erosion by 0.4 t/ha.

5.3 Mitigation pillar

5.3.1 Baseline greenhouse gas emissions

Soil emissions of nitrous oxide (N_2O) constitute the major share of total GHG emissions in the two drylands farms (Figure 9). Even though, for instance, in the diversified dryland farm these are less than 2 kg N_2O N/ha on average, as N_2O is a very potent GHG (~310 times more detrimental than CO_2), small emissions translate into notable CO_2 equivalents.

Enteric fermentation of ruminants and related emissions of methane contributes further, and constitutes the highest share in the rice farm (with its 12 dairy cows). Methane emissions from rice fields is also an important GHG contributor, while GHG emissions from manure adds comparably little.

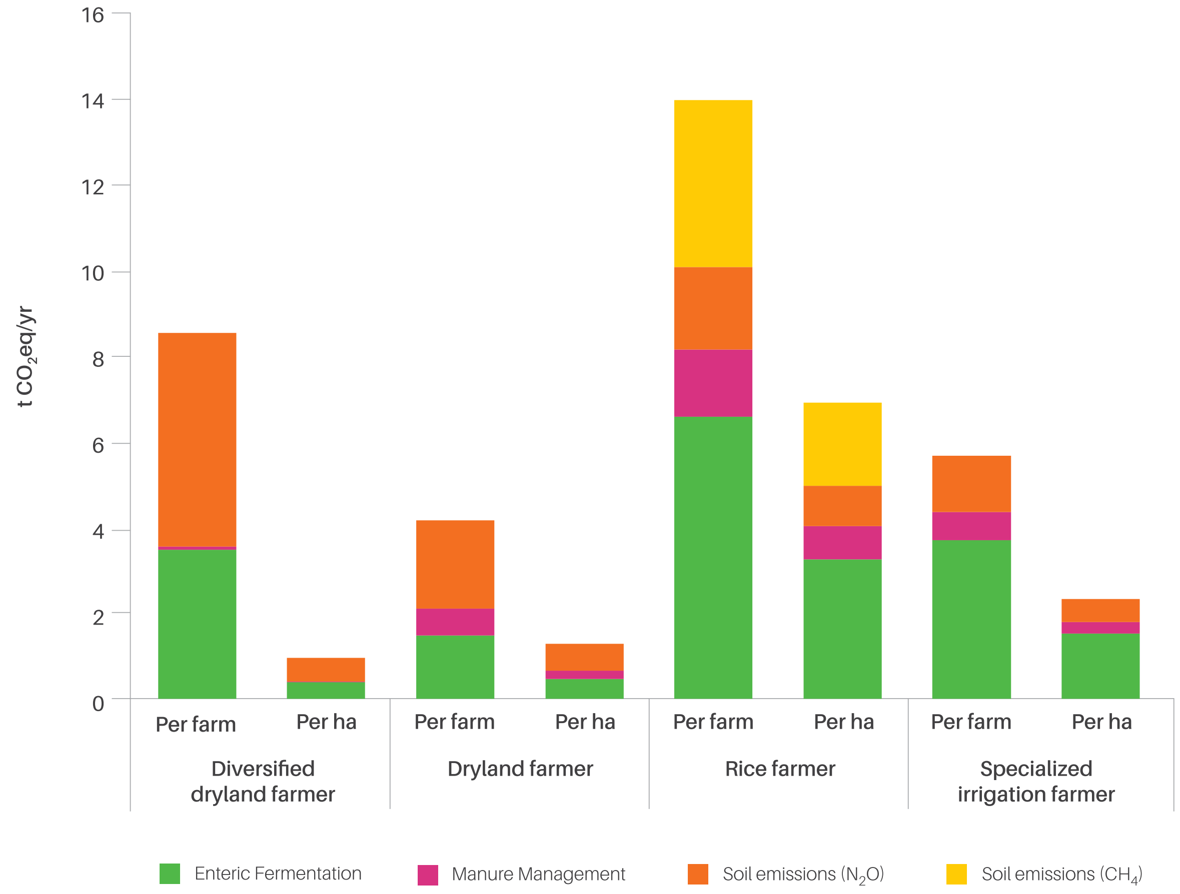


Figure 9. Baseline GHG emissions from enteric fermentation, manure management and soils across farm types.

5.3.2 Changes in greenhouse gas emissions

Technologies impact GHG emission relatively little overall with the exception of composting for the specialized irrigation farm (Figure 10). Composting and addition of manure, on the one hand, increased N-addition to the soil and thus N_2O emissions of most farm types. This, on the other hand, was more or less counterbalanced by less methane (CH_4) emissions from rice fields (where compost results in comparably less CH_4 emissions than manure) and livestock, as composting competes for residues and less is thus available for livestock feed.

Reduced tillage and mulching had also a moderate mitigating impact on GHG emissions for both dryland farm types, because this was assumed to be implemented along with a reduction in mineral N-fertilizer, and thus lower N_2O emissions from soils.

Intercropping/double cropping with rhizobia inoculation results in very little reduction in GHG emissions, which can be attributed to decreased use of inorganic fertilizers against an increase in incorporation of N-fixing legumes into the cropping systems.

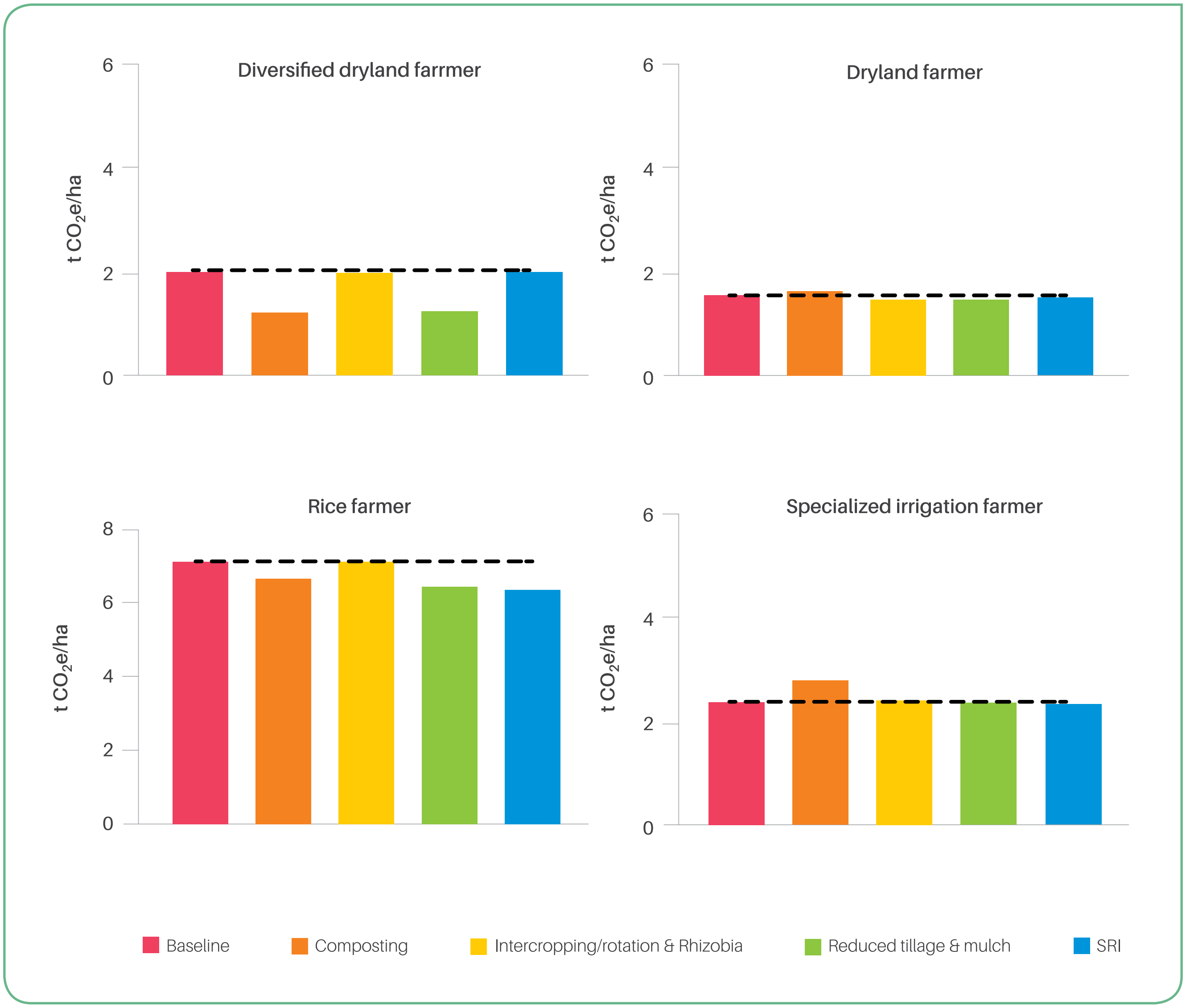


Figure 10. Greenhouse gas emission intensity baselines and scenarios per farm type (CO_2 equivalent/ha).

5.4 Trade-offs between productivity, N balance and GHG emission intensity

Trade-offs occur when improvement in one dimension of farm performance cause deterioration in another dimension. We plotted changes in productivity – as a food security indicator – against the changes in adaptation (N balance, Figure 8) and mitigation (GHG emission intensity, Figure 9). These figures show trade-off and synergy patterns across farm types and soil technology scenarios.

Usually, in a trade-off analysis, when comparing two indicators/impact dimensions and plotting one against the other, win-win situations are described by data points located in the upper right quadrant of the figure (i.e. positive changes in both impact dimensions).

This is the case for most of the scenarios comparing changes in the N balance against changes in productivity (Figure 11). However, in the particular case of India, further increases in the overall N balances, are less desirable, as N balances are already positive to start with. Thus, selecting soil protection and rehabilitation solutions that aim at reducing such N balance surpluses seems to be a (climate) smarter way to go. This is the case for the intercropping/rotation plus rhizobia inoculation scenarios in most farm types.

Similar patterns appear when comparing changes GHG emissions with changes in productivity (Figure 12). In this case, we are looking for win-win situations in the lower right quadrant where productivity increases and GHG emissions decrease. Here it is certainly desirable to reject options that come with a large increase in GHG emissions. Reduced tillage + mulch is one such technology in the case of the specialized irrigation farmer. But, the increases in GHG emissions in general are not alarmingly large, which means that adapting any of the tested technologies should not be of concern in terms of negatively affecting the third pillar, mitigation, of climate smartness.

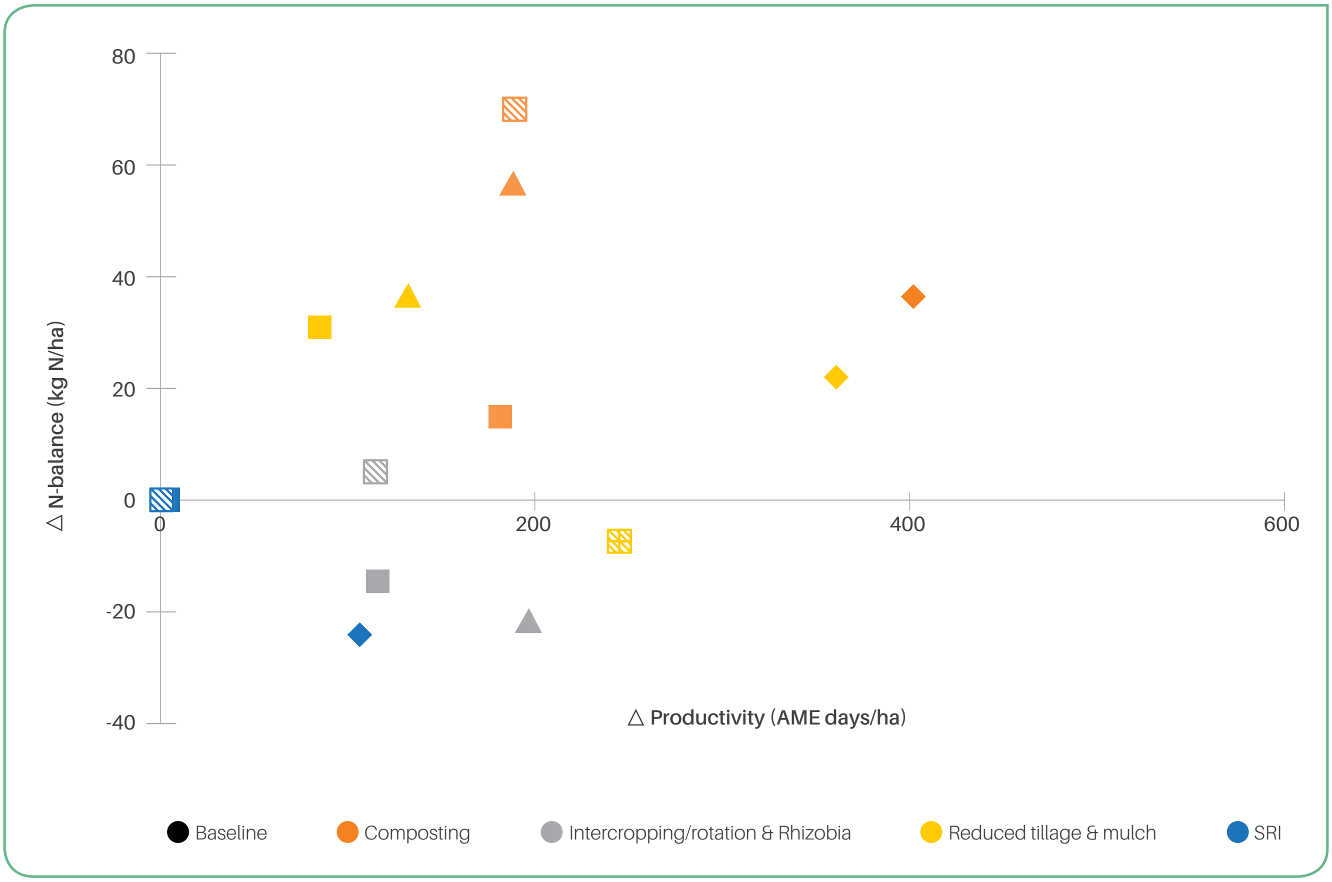


Figure 11. Trade-offs between changes in productivity (days/ha) and changes in N balance (kg N/ha). *Colour represents the scenarios (see legend) and shapes the farm types (□=diversified dryland farm, △=Dryland farm, ◇=Rice farm, ▨with patterns=Specialized irrigation farm).*

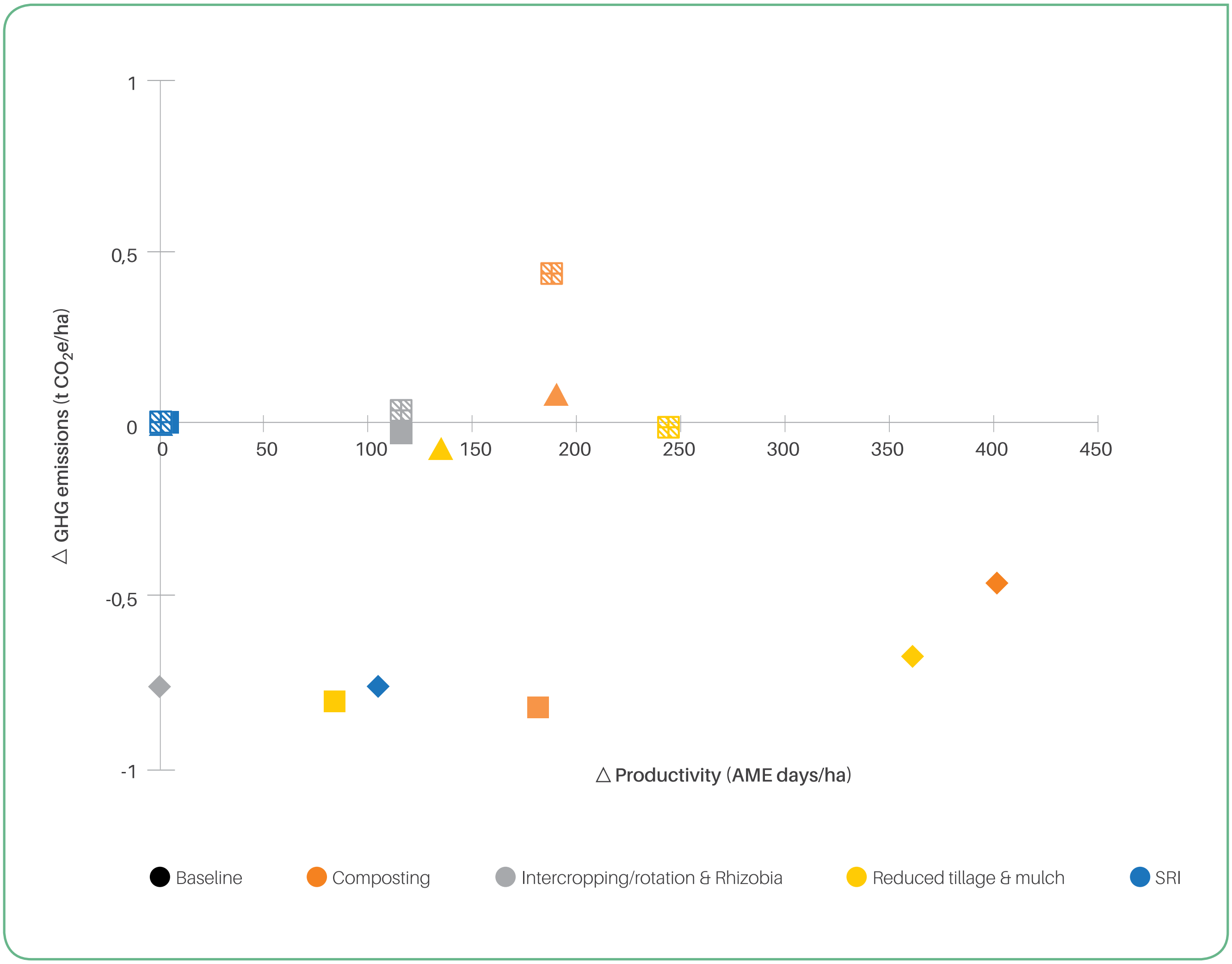


Figure 12. Trade-offs between changes in productivity (AME days/ha) and changes in GHG emissions (t CO_2e/ha). *Colour represents the scenarios (see legend) and shape the farm types (□ diversified dryland farm, △=Dryland farm, ◇=Rice farm, ▧ with patterns=Specialized irrigation farm)*

6. Conclusions and recommendations

In this report a fairly simple set of three indicators was used for assessing the climate smartness of farm types and soil protection and rehabilitation measures in the various research clusters in the Indian State of Maharashtra. This allowed for a truly rapid assessment that can feed into decision-making processes in the on-going GIZ Soil Program.

The choice of indicators has its limitations. The use of calorie-based productivity assessment lacks the importance of nutritional security, to which livestock products add significantly. In other words: "It is not only about calories produced". Adding up calories produced from the various crops and livestock products and comparing business-as-usual with best-bets, is however a simple and easy-to-grasp way of indicating changes. Focusing on soil fertility as the resilience indicator excludes a large number of important issues that contribute to farmers' resilience to climate change, such as income stability, access to skills, capital and information, crop/livestock diversity, etc. The three indicators taken into account in this rapid assessment will therefore be expanded in the next stage of the project during the in-depth assessment.

Despite the shortcomings of the indicators used, the rapid assessment clearly shows that there is some variation in the baseline climate smartness across different case study farms representing different farm types. The rice farmer sticks out a little bit, which is mainly due to some farm-specific peculiarities, such as high number of dairy cows (adding significantly to productivity and GHG emissions) and notable addition of calories from mango fruits. Furthermore, such a high livestock density translates into large amounts of manure available for fertilization on small acreage. This high amount of manure applied to the rice fields of this particular farm explain the high N balance. Hence, optimal use of on-farm manure can also be a good strategy for farmers. For example, surpluses of manure could be sold to farmers with no livestock. Without these two components, the rice farmer would rank lowest in productivity per hectare – together with the specialized irrigation farmer. The rice farm type actually describes potentially food insecure and poor farm households. This is not the case for the specialized irrigation farm type. Specialized irrigation farms are usually better off, have specialized in the production of high-value crops, and thus, even though they are not producing large amounts of calories themselves, are certainly in a position to purchase food if required. This issue highlights on the one hand the diversity of farm types in this region, which is difficult to capture with a limited set of rapid single-household assessments, but on the other hand, also shows that similar performance regarding certain CSA indicators may have very different drivers and consequences. The mostly positive N balances leave room for optimizing farm nutrient recommendations, towards "less is possible" for desired production levels. Here, the compost technology in particular could be optimized: if the goal is really to add up to 7.5 t of compost per hectare – which is certainly desirable as far as soil health and soil organic matter/carbon build up is concerned – then this should entail a more drastic reduction in accompanying application of mineral fertilizer. This especially applies to rain fed only production systems, where water rather than nutrients may be the limiting factor for growth. Better alignment of recommendation for compost rates with expected yields and associated withdrawals of nutrients seems advisable.

Livestock is the major cause of GHGs emissions, followed by methane emissions from rice and nitrous oxide emissions from soils. The latter is a direct consequence of the application of N-fertilizer. However, our rapid assessment analysis does not account for carbon (C) sequestration in soils as a consequence of compost addition and/or reduced tillage and surface residue retention. Such C-sequestration has the potential to completely offset nitrous oxide emissions from soils. As mentioned earlier, livestock often plays a crucial role in securing farm household livelihoods and nutrition, and reducing their numbers is most likely not a feasible nor desirable climate change mitigation option. It is rather the emission intensities that can be addressed, by producing more livestock products while not increasing emissions. This is usually achieved through feeding higher-quality feed/forages grown on-farm and optimising manure management to limit nutrient losses throughout the different stages of handling. Investigating option for forages production could be an interesting addition to the set of technologies tested in the region.

Appendix I: Surveyed farm details

Table 3. Household size (no.), land sizes (ha).

Farm type	Farm size	Area under cultivation	Number of household members
Diversified dryland farm	8.8	8.8	6
Dryland farm	3.2	3.2	6
Rice farm	2.0	2.0	6
Specialized irrigation farm	2.4	2.4	5

Table 4. Crops yields per farm type. Not applicable (NA) indicates that the respective crop is not grown on the farm. All yields are reported in fresh weight (FW/ha/year).

Farm type	Cash crop yields		Legume yields										Cereals yields			Vegetable yields			Fruit tree yields
	Cotton	Marigold	Rice	Groundnut	Pigeon pea	Chickpea	Soyabean	Lentils	Peas	Green gram	Moth bean	Horse bean	Wheat	Sorghum	Maize	Millet	Traditional vegetables	Onion	Mango
Diversified dryland farm	2451	NA	NA	NA	244	NA	614	NA	NA	NA	NA	NA	320	120	NA	NA	400	NA	NA
Dryland far	1040	NA	NA	NA	220	NA	1000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Rice farm	NA	NA	320	72	NA	100	NA	80	120	NA	NA	NA	NA	NA	320	400	NA	NA	5
Specialized irrigation farm	NA	480	NA	NA	80	160	NA	NA	NA	240	120	80	NA	135	4000	NA	NA	4000	NA

Table 5. Fertilizer application rates (kg N/ha/year).

Farm type	Cotton			Pigeonpea			Soyabean			Sorghum			Wheat			Maize			Marigol flower		
	NPK	Urea	DAP	NPK	Urea	DAP	NPK	Urea	DAP	NPK	Urea	DAP	NPK	Urea	DAP	NPK	Urea	DAP	NPK	Urea	DAP
Diversified dryland farm	12.5	57.5	22.5	37.5	57.5	22.5	50.0	57.5	0.0	12.5	28.8	0.0	12.5	28.8	0.0	NA	NA	NA	NA	NA	NA
Dryland far	12.5	57.5	22.5	18.8	86.3	33.8	12.5	28.8	11.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Rice farm	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0	0.0	0.0	NA	NA	NA
Specialized irrigation farm	NA	NA	NA	0.0	0.0	0.0	NA	NA	NA	61.9	0.0	0.0	NA	NA	NA	5.6	0.0	0.0	43.8	0.0	0.0

Table 6. Livestock herd composition (no.) and total TLU.

Farm type	Local dairy cattle	Improved dairy cattle	Other cattle (male and heifers)	Calves	Sheep	Goats	Poultry	Total TLU
Diversified dryland farm	3	0	4	1	0	0	0	**4**
Dryland farm	1	0	2	1	0	0	0	**2**
Rice farm	12	0	4	2	0	5	12	**9.6**
Specialized irrigation farm	0	0	0	0	0	22	30	**2.7**

Table 7. Ruminants (cows and goats) feed basket (%).

Farm type	Pasture	Chickpea, pigeon pea, green grams and lentils straw	Cotton seed cake	Maize, sorghum and millet straw	Rice straw
	Fraction fed to cows and goats				
Diversified dryland farm	35.0	60.0	5.0	0.0	0.0
Dryland farm	35.0	60.0	5.0	0.0	0.0
Rice farm	45.0	20.0	0.0	20.0	15.0
Specialized irrigation farm	25.0	30.0	5.0	40.0	0.0

Table 8. Crop residue management.

Farm type	Cash crops	Legumes	Cereals	Vegetables	Mango
	Fraction fed to cows and goats				
Diversified dryland farm	1.0	1.0	1.0	1.0	1.0
Dryland farm	1.0	1.0	1.0	1.0	1.0
Rice farm	1.0	1.0	1.0	1.0	1.0
Specialized irrigation farm	1.0	1.0	1.0	1.0	1.0

Cash crops: cotton, marigold flower and rice.
Legumes: Groundnut, pigeon pea, chickpea, soybean, lentils, peas, green grams, moth bean and horse bean.
Cereals: wheat, sorghum, maize and millet.
Vegetables: traditional vegetables and onions.

Appendix II: Scenario assumptions

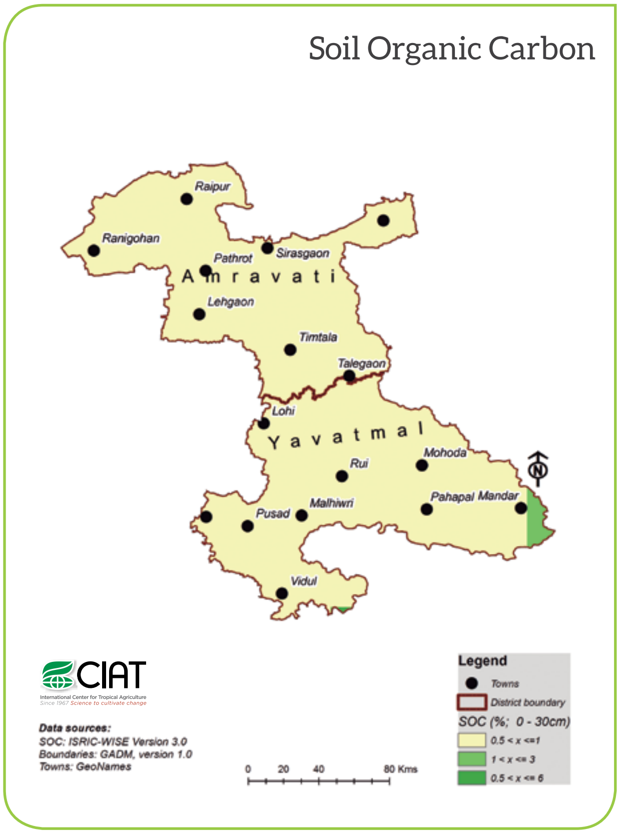
Farm type	Impact dimension	Composting/ green manure/ farm yard manure	Intercropping/ crop rotation/ Rhizobium inoculation	Reduced tillage + mulch (farm type 1 & 2) Mulching only (type 3 & 4)	SRI (System of rice intensification)
Diversified dryland farmer	Land use change	No change	No change	No change	NA
Dryland farmer	Land use change	No change	No change	No change	NA
Rice farmer	Land use change	No change	NA	No change	No change
Specialized irrigation farmer	Land use change	No change	Intercropping: no change; Crop rotation: introduce chickpea to fallow plots (long rains: 1.3 ha; short rains: 0.7 ha); Rhizobium: no impact.	No change	NA
Diversified dryland farmer	Fertilizer application	**20%** reduction	Rhizobia: 20% mineral fertilizer reduction (legumes)	No change	NA
Dryland farmer	Fertilizer application	**20%** reduction	Rhizobia: 20% mineral fertilizer reduction (legumes)	No change	NA
Rice farmer	Fertilizer application	**20%** reduction	NA	**10%** reduction	No change
Specialized irrigation farmer	Fertilizer application	**20%** reduction	Rhizobia: 20% mineral fertilizer reduction (legumes) Intercrop/rot.: 5% mineral fertilizer reduction	**10%** reduction	NA
Diversified dryland farmer	Organic fertilizer application	(increase to) 2.5 t/ha vermi-compost	No change	No change	NA
Dryland farmer	Organic fertilizer application	(increase to) 5 t/ha vermi-compost	No change	No change	NA
Rice farmer	Organic fertilizer application	(increase to) 5 t/ha vermi-compost	NA	**10%** Increase	No change
Specialized irrigation farmer	Organic fertilizer application	(increase to) 7 t/ha vermi-compost	No change	**10%** Increase	NA
Diversified dryland farmer	Crop yield	**12.5%** increase	**7.5%** increase (legumes)	**5%** increase	NA
Dryland farmer	Crop yield	**7.5%** increase	**7.5%** increase (legumes)	**5%** increase	NA
Rice farmer	Crop yield	**25%** increase	NA	**10%** increase	**10%** increase
Specialized irrigation farmer	Crop yield	**17.5%** increase	No change	**22.5%** increase	NA

Farm type	Impact dimension	Composting/ green manure/ farm yard manure	Intercropping/ crop rotation/ Rhizobium inoculation	Reduced tillage + mulch (farm type 1 & 2) Mulching only (type 3 & 4)	SRI (System of rice intensification)
Diversified dryland farmer	Milk yield	10% reduction	No change (effect very small)	No change	NA
Dryland farmer	Milk yield	10% reduction	No change (effect very small)	No change	NA
Rice farmer	Milk yield	10% reduction	No change (effect very small)	No change	No change
Specialized irrigation farmer	Milk yield	NA	NA	**5**% increase	NA
Diversified dryland farmer	Residue management	All residues removed- 50% for compost and 50% for feeding	No change	**2/3** residue retained	NA
Dryland farmer	Residue management	All residues removed- 50% for compost and 50% for feeding	No change	**2/3** residue retained	NA
Rice farmer	Residue management	All residues removed- 50% for compost and 50% for feeding	NA	**2/3** residue retained	No change
Specialized irrigation farmer	Residue management	All residues removed- 50% for compost and 50% for feeding	Incorporating residue into the soil from the legumes introduced (chickpea and bean)	**2/3** residue retained	NA
Diversified dryland farmer	Soil erosion	No change	No change	Reduced soil conservation factor (P) to 0.2	NA
Dryland farmer	Soil erosion	No change	No change	Reduced soil conservation factor (P) to 0.2	NA
Rice farmer	Soil erosion	No change	NA	NA	No change
Specialized irrigation farmer	Soil erosion	No change	No change	Reduced soil conservation factor (P) to 0.5	NA

Onion cultivation in Maharashtra, India

Appendix III: Reference maps of study sites

BAIF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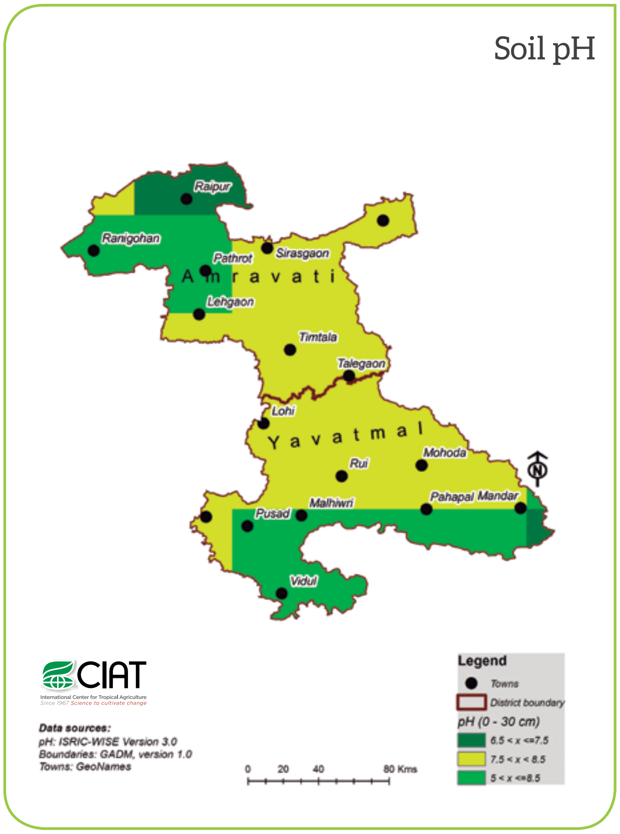
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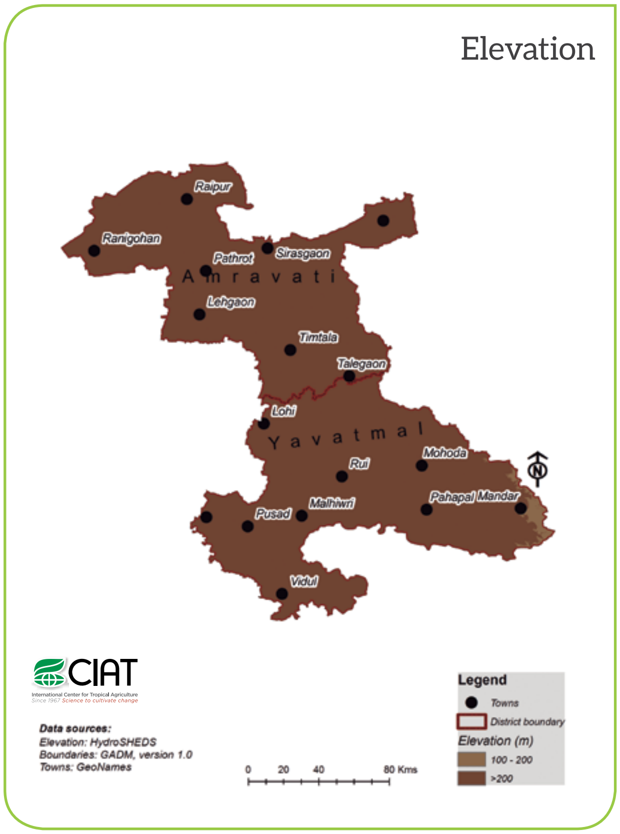
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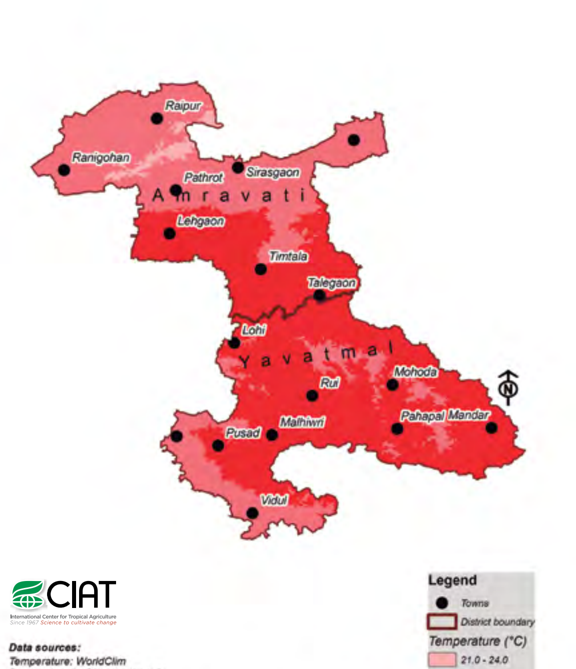

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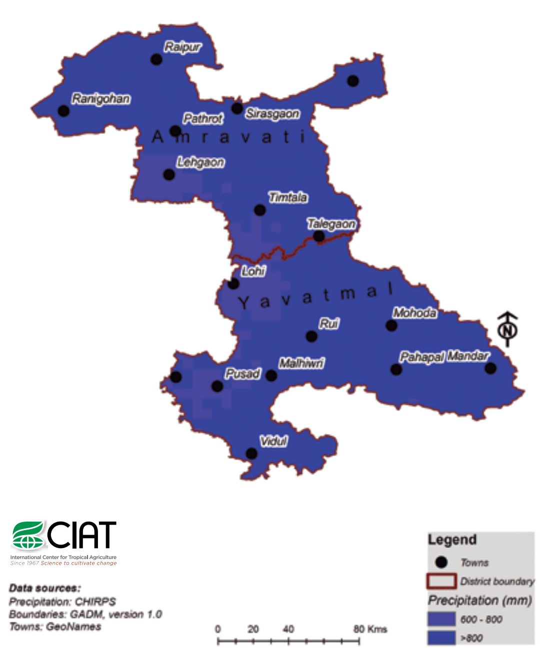

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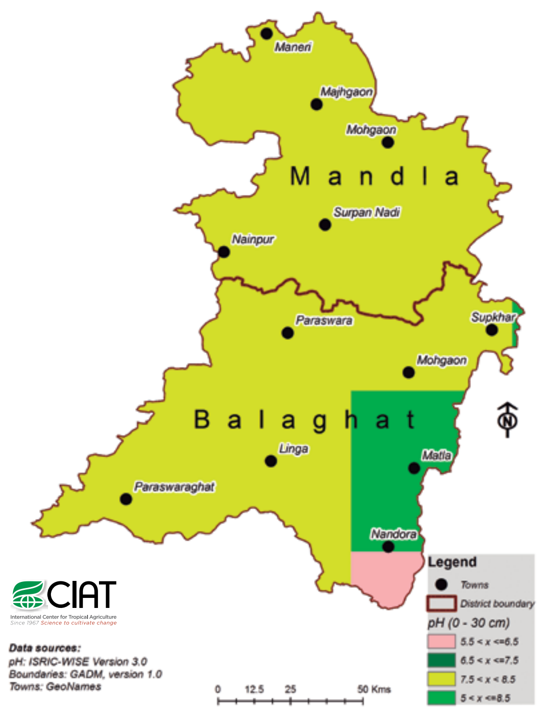

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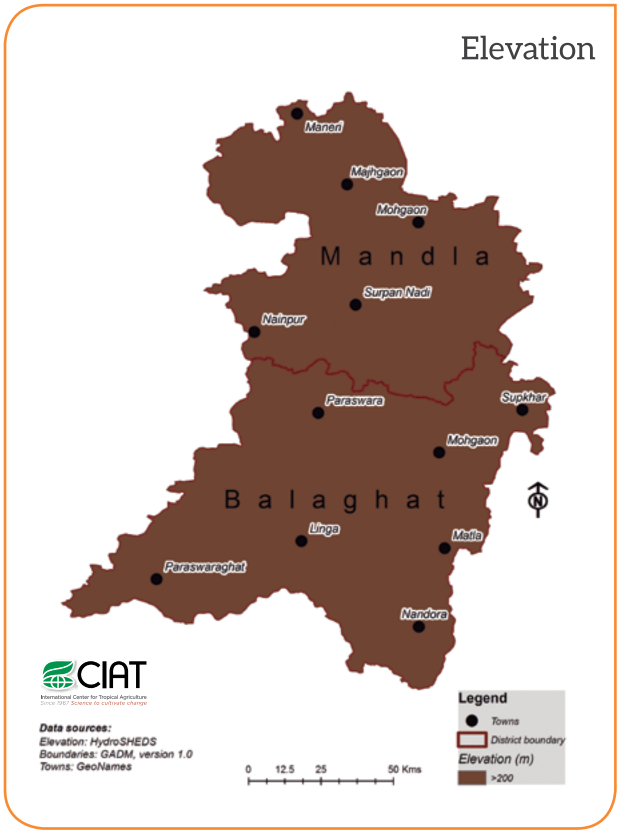

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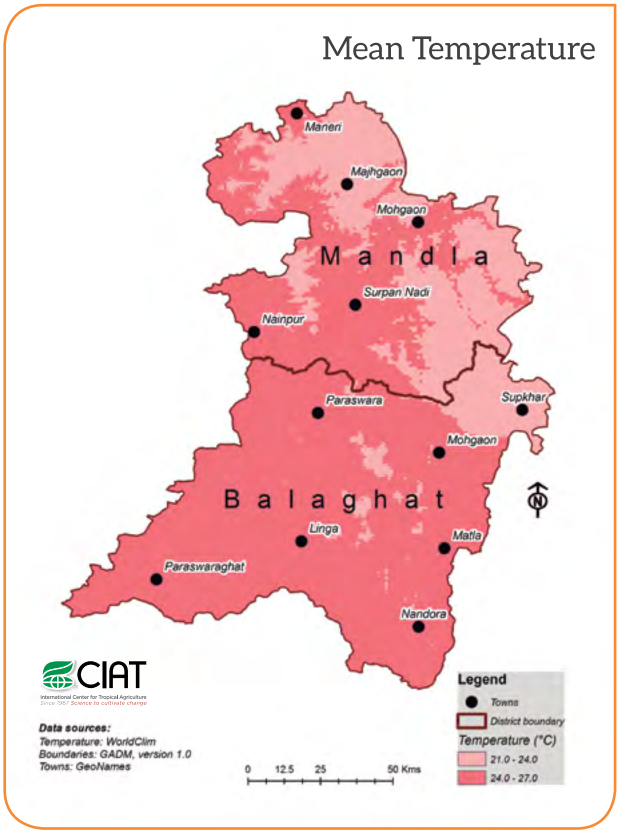

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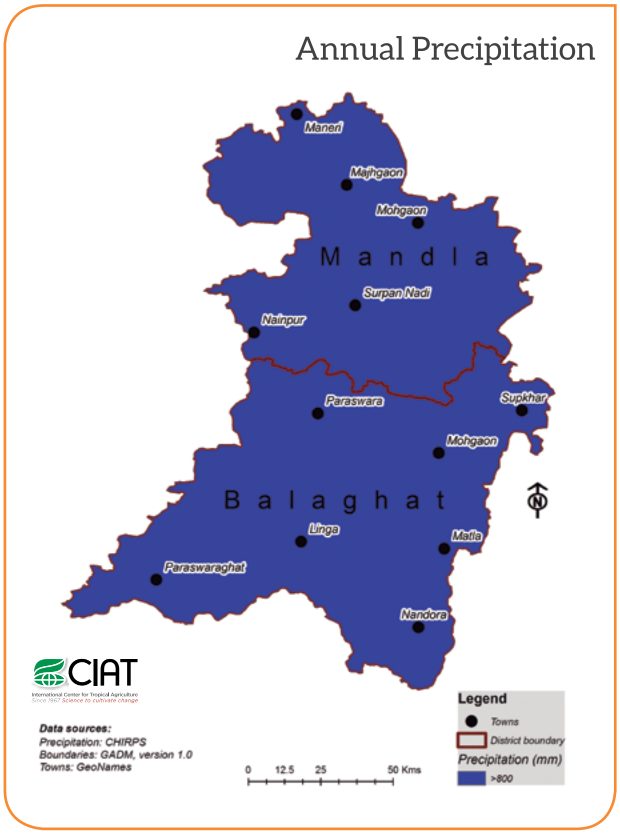

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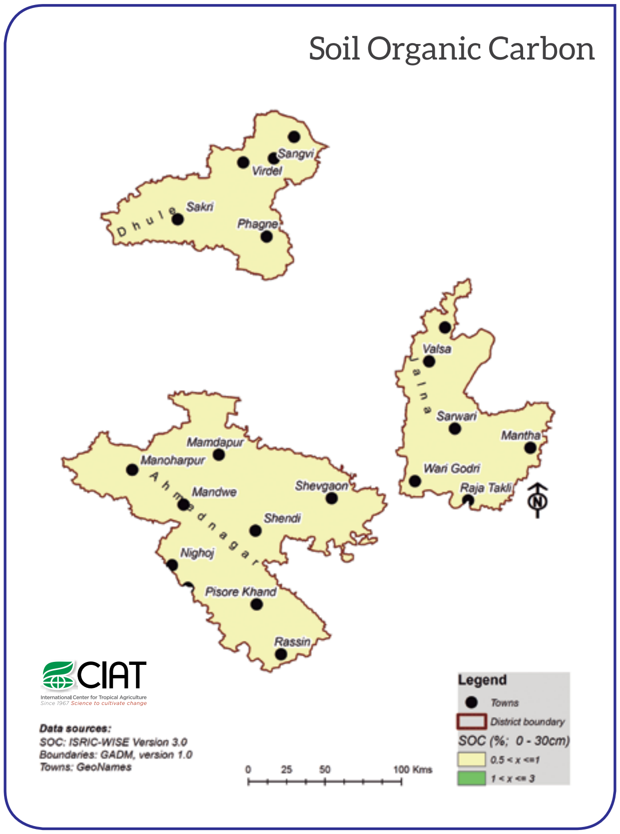
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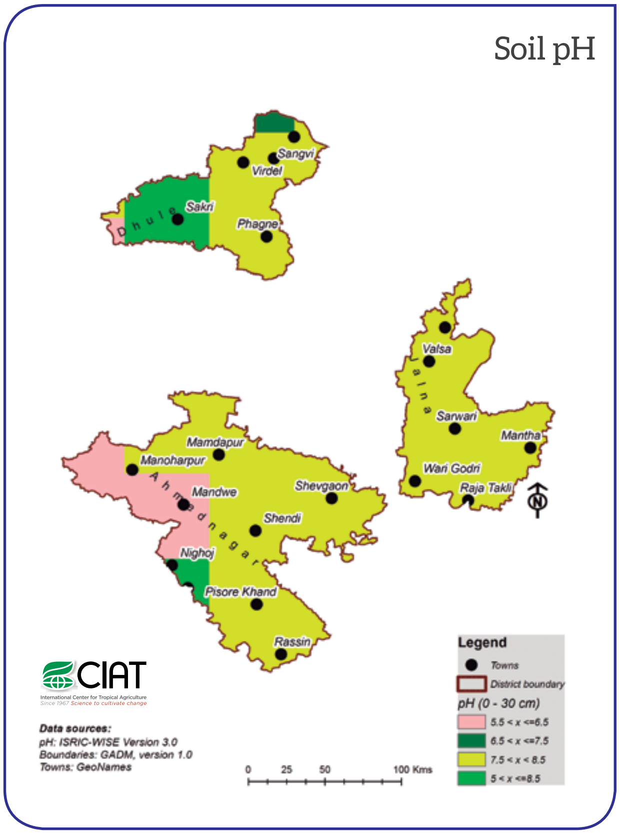
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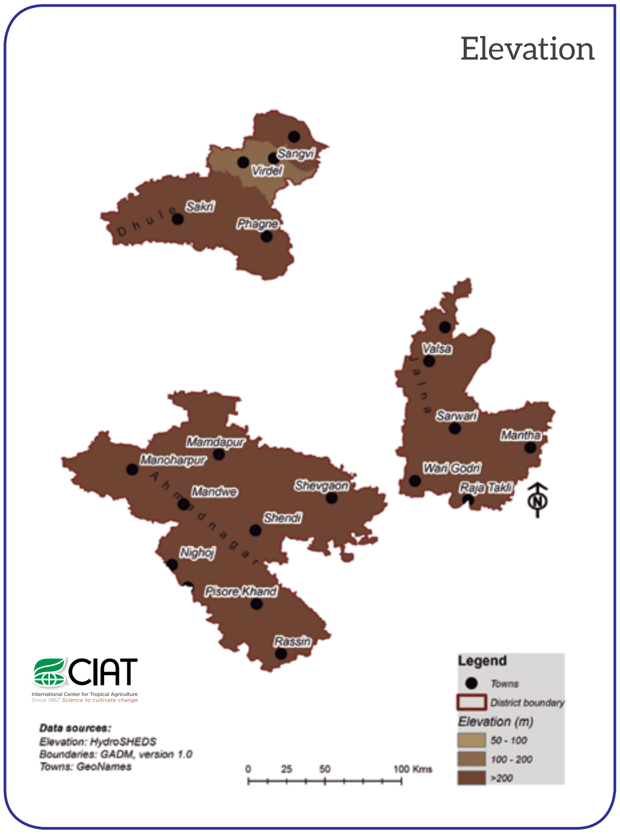
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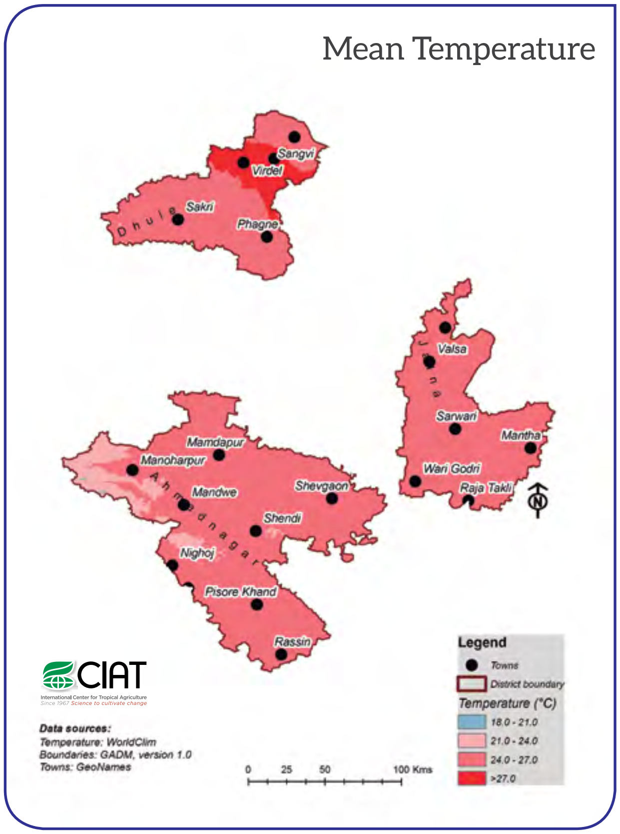
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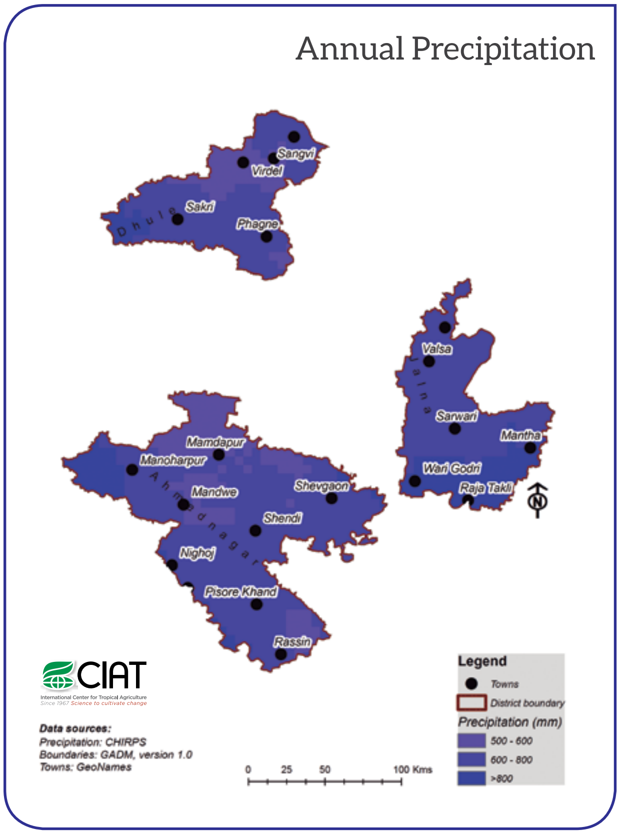
Annual Precipitation

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