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COUNCIL ON ENERGY, ENVIRONMENT AND WATER
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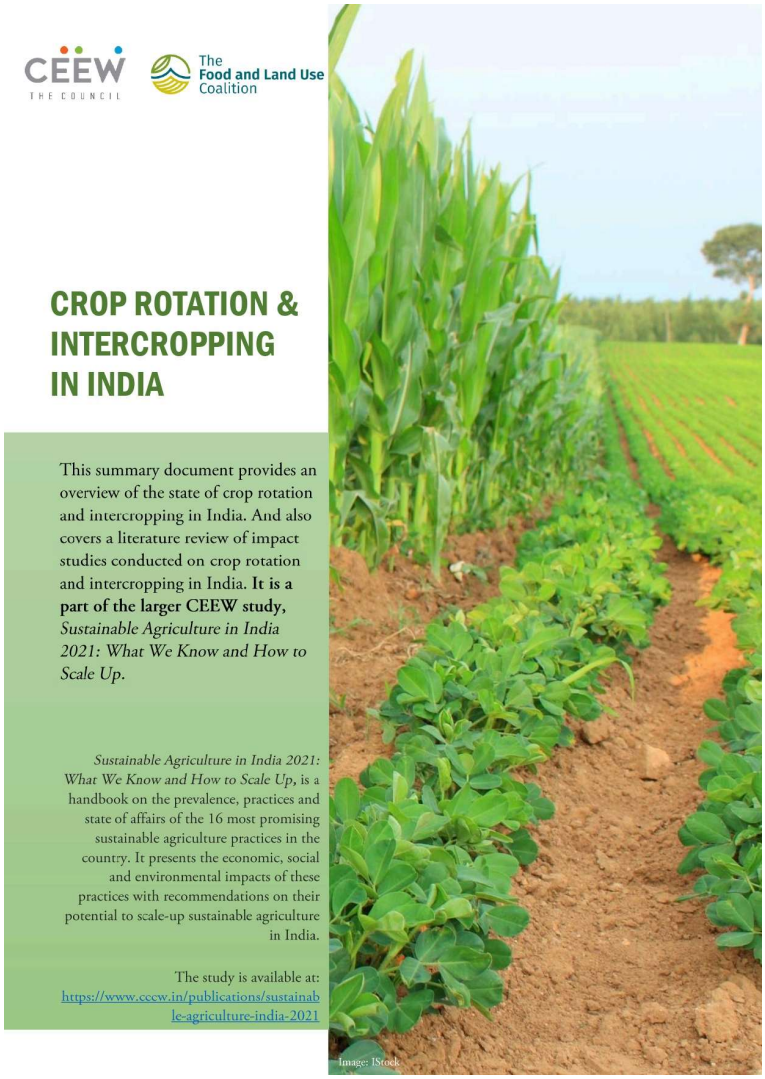
Crop Rotation & Intercropping in India



Crop rotation and intercropping are two different types of cropping patterns followed on a farm to diversify crops and enhance cropping intensity (Re below). Temporal crop diversification includes crop rotation, while spatial crop diversification is achieved through intercropping.[1] Crop rotation is undertaken to maximize profit without large investments and without impeding soil fertility. It can also break the cycle of pests and diseases. Intercropping is practiced to produce more crops from a unit of land by efficient utilization of resources while providing insurance against total crop failure due to weather aberrations, particularly under rainfed conditions.

Terminology: Crop rotation and Intercropping

Crop rotation is the practice of planting two or more crops sequentially on the same plot of land to improve soil health, optimize nutrients, and comba pest and weed pressure. Simple rotation may involve two or three crops, while a complex rotation may incorporate a dozen or more.[2] Crops can be rotated on a field within the same year, over two years, or more extended periods. Crop rotation requires the succeeding crops to be of a different species or subspecies (variety) than the previous crop, such as legumes grown after wheat and cereals, however, cereal-cereal crop rotations are predominant in the country with farmers growing green manure before sowing rice for building soil health (stakeholders consulted at ICAR-IFSMR).

Intercropping is the growing of two or more crops simultaneously in the same field. Sowing of the base and intercrop is either done simultaneously or phases. It involves the practical application of ecological principles such as diversity, crop interaction, and other natural regulation mechanisms. Intercropping can be classified into the following types:[3]

Mixed intercropping: When two or more crops are grown simultaneously with no distinct row arrangement

Row intercropping: When two or more crops are grown simultaneously on the same piece of land with a distinct row arrangement.

Strip intercropping: When two or more crops are grown simultaneously in alternate strips of lp pplng: P! uniform width and on the same field.

Relay intercropping: When two or more crops are grown simultaneously but with overlapping life cycles, such that a second crop is planted before the first cro matures.

Crop Rotation & Intercropping's linkages to FAO's agroecological elements

In principle, Crop Rotation & Intercropping adheres to and promotes most of the agroecological elements as defined by the FAO

ELEMENTS	DESCRIPTION
Diversity	Increasing the diversity of cultivated crops helps preserve biodiversity and enhance ecosystem services in the agricultural landscape.
Co-creation and sharing of knowledge	Crop rotations and intercropping are knowledge-intensive practices. To achieve significant yields requires knowledge that farmers often attain by experimenting with different crop combinations over the years and/or by sharing knowledge within the farming community.
Synergies	It promotes diversified systems by selectively combining annual and perennia crops to enhance synergies and complementarities in terms of nutrient and water requirements. It also enhances biological and ecological synergies, contributing to human and livestock nutrition and multiple other benefits.
Efficiency	Rotation and intercropping strategies allow for efficient use of water, nutrients, and solar energy. The approach reduces the need for organic and inorganic fertilizers, thus saving costs.
Recycling	Rotating crops serves an essential function of exploiting nutrients at deeper levels of the soil and recycling them to make them available for crops, thus acting as biological pumps. Intercropping also leads to better nutrient recyclir (FAO 2020b).
Resilience	Crop rotation and intercropping have the potential to lead to higher and more stable yields, as well as increase profitability. Intercropping ensures a regular income from a field, helping to make a farmer more economically resilient. Further, these practices are essential for weed, pest, and disease control and contribute to the resilience of the agroecosystems in the long term.
Human and social values	Crop diversification through rotation, intercropping, and mixed cropping is vital to improve incomes, provide employment, and enhance rural livelihoods. It also allows for the development of value chains for minor crops that contribute to socio-economic benefits too.
Culture and food traditions	Rotating crops and intercropping is an essential strategy to improve food and nutritional security. Traditionally, farmers have experimented with intercropping, mixed cropping, and rotations in their cropping systems to stabilize yields through trial and error.

A brief context in India

India's tropical and subtropical climate offers scope for growing two or more crops per year. However, Crop rotations are location-specific depending their economic utility, which varies under diverse socioeconomic and agroecological conditions. Intercropping is known to be a feasible solution as a hedge against crop failure, especially in rainfed regions, as it minimizes the risk for farmers and ensures equitable returns.

Both practices are mentioned in several policy documents and schemes at the national and state level. At the national level, the Soil Health Management (SHM) program under the National Mission for Sustainable Agriculture (NMSA) has provisions for field-level demonstrations on organic farm packages that include crop rotation. The program promotes legume intercropping through self-help groups.[4] Crop rotation with commercial cro is one of the main objectives of the National Food Security MissionCommercial Crops (NFSM-CC) for increasing soil fertility.[5] Crop rotation and mixed farming are also part of the Research and Technology Development component of Rajasthan Organic Farming Policy.[6]

Intercropping of oilseed crops with other trees and crops is promoted by the Submission on Agroforestry to make current practices more sustainable.[7] The National Mission on Oilseeds and Oil Palm (NMOOP) has provisions to financially assist farmers with intercropping of oilseeds with cereals, pulses and sugarcane.[8] The Policy Note of the Agriculture Department, Tamil Nadu (2020-2021) promotes and assists with intercropping of pulses in cotton. The state agricultural policy for Odisha focuses on crop rotation techniques to reduce salinity levels and encourages intercropping of oilseed and pulse crops with paddy and sugarcane.[9] ICAR has demonstrated the use of intercropping for livelihood security and resilience to climate variability under the NICRA[1] project.[10]

Crop rotation and intercropping: acreage, geographies, and cultivation details

How much area in India is under crop rotation and intercropping? Stakeholders consulted at the ICAR-Indian Institute of Farming Systems Resear (Modipuram), estimate the area under crop rotation to be around 30 million ha, which includes cereal-cereal cropping systems and the area under intercropping to be around 1 million ha, however, this excludes intercropping in horticultural crops.

At what farm size is crop rotation and intercropping practiced? Crop rotation is followed by both small and large farmers in irrigated and rainfed regions alike, except in canal-irrigated areas and areas with climatic limitations, according to stakeholders at NRRI. Despite the mechanization constraints, intercropping is practiced by smallholder farmers because it offers flexibility in planting and sowing, minimizes risk, and helps meet their nutritional needs.[11]

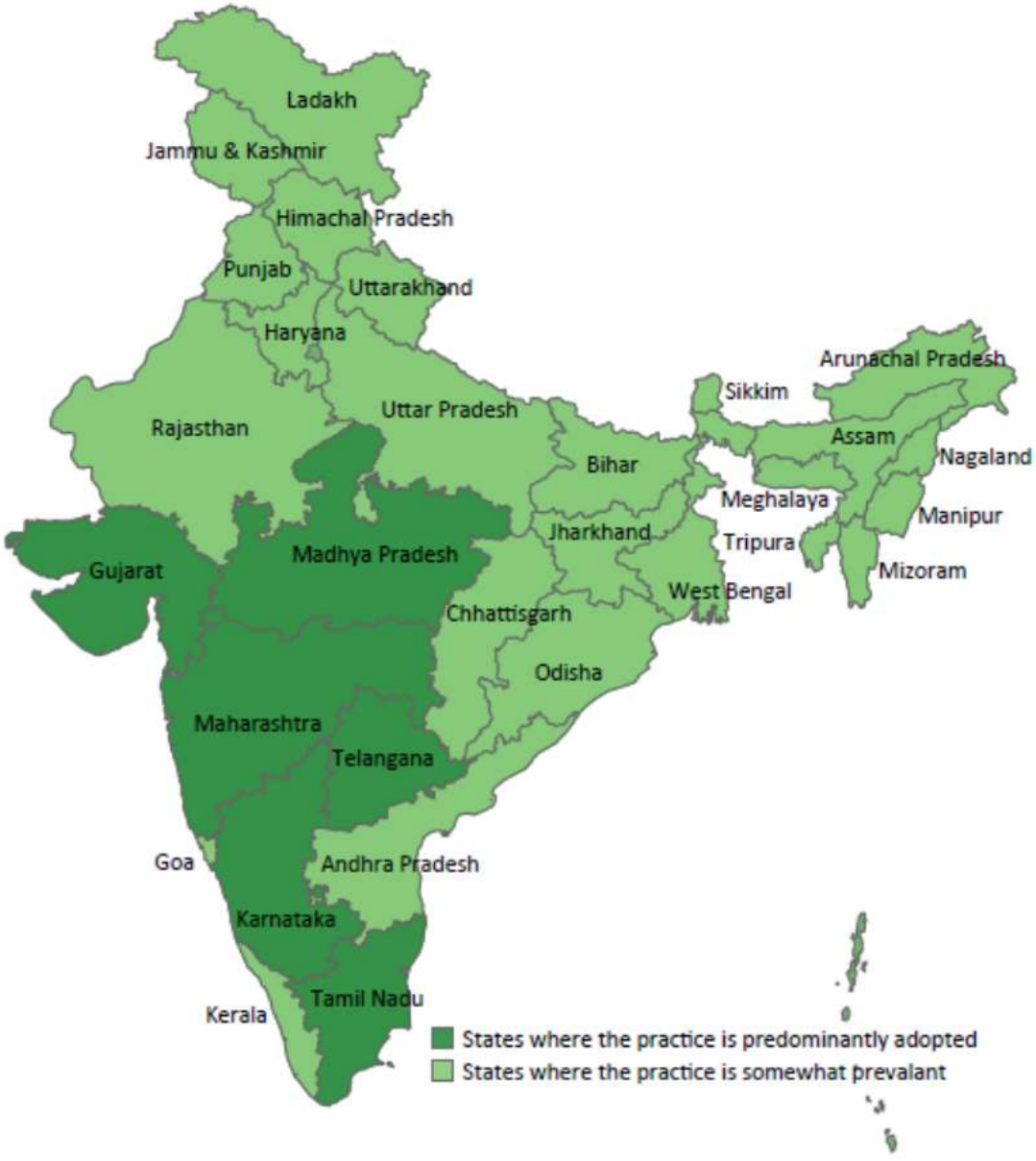
How many farmers in India are practicing crop rotation and intercropping? Stakeholders consulted at the ICAR-IIFSR estimate the number of farmers who are practicing crop rotation to be between 12 and 15 million and those practicing intercropping to be between 0.70 and 0.90 million.

Where in India is crop rotation and intercropping prevalent? Crop rotation is a vital traditional farming system of the Indian semi-arid tropics,[12] bu it is practiced in almost every state in the country. Intercropping is mostly practiced in India's semi-arid and arid tropical areas.[13] It is more common in southern (Karnataka, Telangana, Tamil Nadu, Maharashtra); and western (Gujarat) regions and Madhya Pradesh (Figure 1), though it is also adopted in many more states.

Which are the major crops cultivated under rotation and intercropping in India? Stakeholders consulted at the ICAR-TTFSR mention the predominant crop rotations being cereal-cereal based like rice-rice, ricewheat, and maize-wheat which comprise about 74 percent of the calories of th Indian diet. Many of the farmers usually grow green manure crops (leguminous crops) before planting rice for building soil health purposes. Legumes are essential in any rotation and should comprise 30 to 50 percent of the cropland.[14]

Though intercropping is practiced in various crops (cereals, pulses, horticulture) and agricultural production systems (agroforestry, integrated farming systems), it is suitable[2] for wide-spaced crops like maize, cotton, sugarcane, etc (NRRI stakeholder). Pigeonpea is commonly intercropped with cereal crops (sorghum, pearl millet, maize, finger millet, etc.) as well as with short-duration pulse crops (green gram, black gram, chickpea).[15] Pulses are intercropped with oilseeds, cereals, coarse grains, and commercial crops. A few of the crops grown under both practices are shown in Table 1.

Figure 1. Intercropping is more predominant in the southern and western regions of the country



Source: Authors' compilation from literature reviews and stakeholder consultations

Impact of crop rotation and intercropping

ECONOMIC IMPACT

1. Yields

According to the literature, crop yield improvements are one of the immediate economic benefits of both crop rotation and intercropping. As continuous monocropping on the same area of land tends to deplete soil health and reduce yields, these practices — alongside other measures (weed control, applying secondary and micronutrients) — are said to bridge yield gaps mostly in dryland rainfed areas with low productivity. For example, an analysis done in Karnataka's dryland zone indicates over 50 percent of the yield could be increased by following crop rotation and intercropping for major crops (finger millet, pigeon pea, maize, cowpea, horse gram, groundnut, sunflower).[16]

An experiment was conducted to observe crop rotation performance in leguminous and non-leguminous crops in Rajasthan. In the winter, cumin and psyllium were grown in rotation with sesame and cluster beans. Results showed that yields of 566 kgs/hectare for cumin and 808 kgs/hectare for psyllium were obtained in the treatments of organic inputs and cluster beans in rotation. Here the legumes were found to play a key role, contributing 20-25 percent in yield growth for the next crop of cumin.[17] Another study that evaluated the gross productivity across several locations showed that rice rotations with oilseed, wheat, pulse, and maize gave a rice equivalent yield (REY)?® of between 7.0 to 10.2 tonnes/ hectare.[18]

In intercropping, various factors affect its performance, including solar radiation, water, nutrients, the maturity of the crop, growth rate, root systems, allelopathic effect, planting pattern, etc.[19] Most studies indicate the benefits of intercropping over monocropping to yield stability and enhanced crop productivity.[20] For instance, cereal + legume intercropping has reported higher yield stability and lower probability of failure than crops grown alone in rainfed areas. In a few instances, although yields in vegetables grown as intercrops under a fruit canopy were reduced due to shading, the yield potential of shallow-rooted and short-duration intercrops was not affected by perennial trees.[21] Under the NICRA project, intercropping demonstrated in locations across the country reported yield advantages that ranged from 10.5 to 85.2 percent for crops that included maize, cowpea, pigeon pea, pearl millet, etc.[22]

However, the success of intercropping lies in the crop choices, environmental and locational factors, and availability of proper sowing implements. Often yield advantages are prominent when crops do not compete for similar ecological niches, and when component crops have different growing periods.

2. Income

'The literature on income for crop rotation and intercropping practices suggests the practices offer much potential to enhance farmers' income and profitability by diversifying crops over time or space. Crop rotation provides a steady and assured income in times of crop failure, as the next harvest can yield some of the income. A study conducted to determine the gross return of different rice-based cropping systems across the country found that rice rotations with oilseed, wheat, pulse, and maize gave returns of between INR 40,472/ hectare (USD 548/ha) and 59,110/ hectare (USD 800/ hectare).[24]

Intercropping of fruit trees with short-duration crops (pulses, spices, vegetables) is found to offer considerable potential for farmers to gain income before the fruit trees become productive and can double farmers' incomes once the fruit trees start producing.[25] In particular, several studies mention the high potential of horticulture-based intercropping for giving additional returns to farm families. For example, vegetable-based intercropping gave additional income in a study of fruit orchards, for instance, the intercropping of coconut + black pepper + pineapple was profitable, with a high net return of INR 45600 per hectare (USD 619).[26] Growing cotton, pigeonpea, and millets is a coping strategy in low rainfall areas, allowing farmers to make a profit.[27] The NICRA project found that across the country where crops like cotton, soybean, pigeonpea, cowpea, millets, etc. were intercropped, the perceived benefit-cost ratio was in the range of 1.3 to 4.2 compared to conventional practices. In places where maize+cowpea was intercropped, the higher returns for cowpea observed were due to the fact that almost no inputs were required other than seed.[28]

Intercropping is also more remunerative than sole cropping in delayed monsoon situations.[29] But a challenge of the practice is its labour-intensive nature, which can boost employment generation in terms of more days of on-farm employment. This can be beneficial when family members are involved in farming, as in the case of small and marginal sugarcane growers.[30] However, it can pose a problem where labour is scarce. Another significant caveat is the difficulty of operating farm machinery in intercropped fields, which requires the use of manual labour for sowing, and removing weeds. This involves additional expenses which can be a deterrent for resource-limited farmers.

SOCIAL IMPACT

1. Human Health

We did not find any relevant evidence on the impact of crop rotation on human health; more in-depth studies are required.

Studies of intercropping found a higher demand for intercropping vegetables due to their contribution to improved diets.[31] Legumes grown on marginal lands in intercropping systems are mentioned as an essential source of protein for people's diets, offering the potential to end malnutrition in the country.[32] However, we found no other significant studies on intercropping impacting human health so further research is needed.

2. Gender

There is little research on the impact of crop rotations and intercropping on women. However, a study conducted on crop rotation in a Central Himalayan ecosystem village (Garhwal Himalayas) found it increased women's contribution in terms of working hours, accounting for over 75 percent total labour (farm and off-farm activities).[33] This shows the increasing role of women in the practice which is encouraging, but simultaneously it also increases the workload for women farmers. Nonetheless, the topic is still under research and more experimental studies could enhance the understanding of its impact on women.

ENVIRONMENTAL IMPACT

1. Soil and Nutrients

Crop rotation mitigates soil health problems by controlling weeds and insect pests, decreasing soil run-off, and building soil health and structure through root systems and plants that have different nutrient demands. In general, sowing restorative crops that build soil health has immense importance in crop rotation practices. Crops' different rooting systems absorb essential nutrients from various soil depths utilizing nutrients more

efficiently than sole cropping. Mainly, alternating shallow and deep-rooted crops restores soils.[34] Generally, crops which demand high nutrients shoul both precede and follow legume-dominated crop combinations. Topographical features also affect crop selection; for instance, alternate cropping of erosion-promoting crops (millet) and erosion-resistant crops (legumes) can be adopted on erosion-prone sloping lands.[35]

Similar to crop rotation, intercropping plays a vital role in reducing pests and diseases. It also prevents erosion by covering more ground area than monocropping; for instance, intercropped maize-cowpea reduces soil erosion, and tall crops like maize play an essential role as a windbreak.[36] In rainfed, salt-affected, problematic soil areas, alternative cropping systems like inter, mixed, and alley cropping are beneficial.[37]

The literature widely mentions the significant advantage of legumes (the 'legume effect') in both crop rotation and intercropping for fixing atmospheri nitrogen, reducing the need for nitrogen fertilizers.[38,39,40,41,42,43]

2. Water

With proper planning, resources like water, space, and land are used efficiently in both practices. The crop types rotated tend to depend on the availability of water and usually two or three crops are taken on a similar field in a year under irrigated conditions. But, one of the crops rotated shoul be a dry one or one that requires less water to avoid damage to the soil by continuous watering. In rainfed areas, after the harvest of Kharif crops, cro requiring less moisture are sown like pulses and cereals. This crop rotation involving less water-intensive successive crops helps balance water requirements.[44]

"When rotated, crops with different root depths tend to use soil moisture more efficiently. For example, sunflower extracts water from deeper soil layers, while shallow-rooted crops (cabbage) draw it from nearer the surface. Greater water percolation occurs in these systems due to the varied roo structure. Both crop rotation and intercropping reduce water and wind erosion.

Relay intercropping systems have the potential to increase water productivity considerably. A concept known as 'complementary intensive intercroppi systems' that involves raising morphologically and physiologically different crops that complement each other and succeeding crops has immense potential under declining water conditions, but more studies need to be done on this strategy.

3. Energy

We found no relevant studies on the impact of crop rotations on energy.

Intercropping is considered to be an energy-efficient and sustainable practice in rainfed regions,[45] there are limited studies on the impact of intercropping on energy use. In the literature, energy is mentioned in the context of the ability of a few intercrop species (elephant foot yam, colocasia turmeric and ginger, growing tuber) to transfer solar energy efficiently.[46]

Second, certain crop combinations in intercropping have proved to be more energy-efficient, such as cereal+legumes, due to the nitrogen-fixing ability of legumes.[47] Maize+groundnut intercropped in a row ratio of 1:5 resulted in a better energy performance than solo maize in terms of energy input a output efficiency in the Eastern Himalayas (Arunachal Pradesh).[48]

4. Emissions

Although the studies are few, it seems that certain crop rotations tend to reduce emissions more than monocropping. For example, field experiments the Indo-Gangetic plains found lower average annual CO_2 emissions in wheat crop rotations (wheat-fallow-paddy, wheat-fallow, wheat-maize, wheat-pulses, wheat-sugarcane, wheat-sorghum, and wheat-vegetable) than from vegetable crops, which showed higher emission rates. In a similar study, compared to sole wheat (0.71 grams per m^2 per hour), sorghum-berseem rotation (fodder crops) had the highest rate of CO_2 emissions (0.75 grams p m^2 per hour), followed by vegetables grown alone (0.72 grams per m^2 per hour) and vegetables in rotation with mustard (0.72 grams per m^2 per hour) In these crops, the moisture seemed to be responsible for higher emissions rates.[49]

No other systematic studies were found on the impact on emissions or carbon sequestration.

5. Biodiversity

Introducing a range of varieties to an agroecosystem leads to an increase in natural biodiversity and strengthens the agroecosystem's ability to respo to the stresses created by monocropping.[50] Rotating crops lead to diverse soil biodiversity (flora and fauna) as the leguminous roots excrete organic substances attracting bacteria and fungi. Intercropping and mixed cropping can promote on-farm biodiversity by supporting more organisms than is possible in a single-crop environment.[51] However, no systematic studies were found probing deeper into these impacts on biodiversity.

Despite the known advantages, there is a lack of systematic studies on the impact on biodiversity.

Impact evidence

State of available research discussing the impact of conservation farming on various outcomes.

Evidence type	Yield	Income	Health	Gender	Soil & nutrients	Water	Energy	GHG emissions	Bio-diversi
Journals	9	7	0	1	17	5	0	2	2
Reports	2	2	0	0	10	0	0	0	0
Articles/case-studies	0	0	0	0	0	0	0	0	0
Others**	0	0	0	0	0	0	0	0	0

Total	11	9	0	1	27	5	0	2	2

** *Thesis, guidelines, conference papers, etc Source: Authors' compilation*

Note — The evidence is from the first 75 results examined in Google Scholar Advanced search and the first 30 results from Google Advanced Search. Only those papers which clearly established the evidence for different indicators were selected.

Stakeholder mapping

The following institutions are involved in the research and promotion of conservation farming; a few were consulted for this research:

Government institutions	Research/implementation institutions	NGOs/Civil society organisations
ICAR - Indian Agricultural Research Institute	Indian Head Agricultural Research Foundation	bioRe Association India
ICAR - National Rice Research Institute (NRRI)	The National Academy of Sciences India	Natural Capital
Central Research Institute for Dryland Agriculture (CRIDA)	Punjab Agricultural University, Ludhiana	Living Farms
ICAR - Indian Institute of Farming Systems Research (ITFSR)	University of Agricultural Sciences, Bangalore	Centre for Dignity
Central Arid Zone Research Institute (CAZRI)		Manjari Foundation

Source: Authors' compilation

Note — The stakeholders list is indicative and not *exhaustive*

Endnotes

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