Statewise Report Cards on Ecological Sustainability of Agriculture in India

DIVYA VELUGURI, RAMANJANEYULU G V, LINDSAY JAACKS

The dependence of agriculture on natural resources requires sustainable management of these resources for risk mitigation and management, particularly in the context of increasing farmer distress and vulnerability to risks associated with climate change. Using a framework of indicators in the domains of pest management, fertiliser use, soil health, water conservation, biodiversity, and efficient use of inputs, statewise report cards on ecological sustainability of agriculture are provided. There is much variation in the sustainability of production practices across the country, with some states characterised by high use of pesticides, low soil organic content, depletion of groundwater levels, low crop diversity, high energy use, and widespread nitrate contamination of groundwater.

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Divya Veluguri (*dveluguri@hsph.harvard.edu*) is a research associate, Harvard TH Chan School of Public Health. Ramanjaneyulu G V (*ramoo@csa-india.org*) is executive director, Centre for Sustainable Agriculture. Lindsay Jaacks (*jaacks@hsph.harvard.edu*) teaches global health at the Harvard TH Chan School of Public Health.

Agricultural productivity has increased dramatically in India over the past 50 years. Grain production has kept pace with the increasing population, with yields of rice and wheat exceeding current consumption (Department of Agriculture Cooperation and Farmers Welfare 2017) and requirements for buffer stocks (Hussain 2018). Despite this unprecedented rise in food crop production, agriculture in India is in crisis. The past year has seen an eruption of farmers' protests, with Gaon Bandh (*Hindu* 2018), Kisan Long March (Dhawale 2018) and Kisan Mukti March (Jeelani 2018) receiving widespread media coverage. Increasing input costs, decreasing returns and increasing cost of living (Department of Agriculture Cooperation and Farmers Welfare 2017) have together led to low per capita income, high indebtedness, high poverty rate and high levels of agrarian distress as is evident in such mass protests. To address this issue, the government had set a goal of doubling farmers' income by 2022 (Chand 2017), leading to much discussion on the economic crisis and solutions thereof.

An important and often overlooked aspect of the current crisis in India is the ecological sustainability of agriculture. Agriculture, by its very nature, is dependent on natural resources and ecosystem services. Thus, any plan for sustainable development in the agricultural sector must be cognisant of the need to preserve such natural resources as soil, arable land and water.

The United Nations (UN) Sustainable Development Goals (SDGs), including, "Zero Hunger" (Goal 2), which India has committed itself to achieving, recognise the need for sustainable production practices in agriculture while "doubling the productivity and incomes of small-scale food producers," aiming to

> ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality. (SDGs 2015)

To alleviate farmers' distress, it is crucial to manage the risks involved in production.[1] A holistic approach to risk management needs to go beyond insuring for production loss, towards prevention. In recent years, there has been a fall in groundwater levels across the country, reduced crop diversity, increased incidence of pests and disease and increased soil degradation (Department of Agriculture Cooperation and Farmers Welfare 2017), all of which contribute to an increased risk of production loss. Consecutive droughts in Maharashtra, for example, where groundwater sources have dried up in water-intensive sugar cane cultivated areas, partly due to high extraction for irrigation, have impacted not only the sustainability of agriculture in the region, but have also compounded social distress (Chitnis 2018).

Traditionally, the primary metric of success in agriculture has been crop yields. However, M S Swaminathan's fifth and final report (2006) of the National Commission on Farmers (NCF) called for a shift away from this metric towards a new metric—net farmer income—as the primary indicator of agricultural success. We pose that it is also high time we consider the ecological dimension of farming as a preventative measure against farmer distress. It needs to be taken into account that there are natural limitations on increasing agricultural productivity, like the availability of soil, soil nutrients, water and energy for irrigation. Hence, all initiatives in agriculture—whether they be investments, incentives or regulations to encourage or discourage particular agricultural products, processes or practices—should consider dimensions of ecological sustainability, so to preserve natural resources for long-term use and promote farmer and environmental health.

Agricultural practices vary significantly across India, partly driven by eco-regional variations (Sehgal et al 1990). However, with agriculture being a state subject, state policies can have a large influence on production and sustainability. This creates a need for measuring sustainability at the state level for targeted policy action. This article is a first attempt to use existing, publicly available data reported by various departments of the Government of India to quantify, statewise, the ecological impacts of agriculture in India. Whilst we recognise that agriculture broadly encompasses crops, livestock, fisheries, aquaculture and forestry, the focus of this article will be limited to cropping systems.

Theoretical Framework

The Food and Agriculture Organization (FAO) of the UN has been tasked with measuring progress against SDG 2.4.1 (sustainable food production systems). In fulfilling this task, it has recently published a literature review, which summarises the "existing frameworks and methods for measuring and monitoring sustainable agriculture" (FAO 2017a). The FAO has compiled a list of 24 indicators of ecological sustainability, summarised in Table 1.

Based on this systematic review, the FAO has decided on the following individual indicators to evaluate progress on SDG 2.4.1. (FAO 2017b):

(i) In the domain of soil health: farm area affected by soil degradation.

(ii) In the domain of water conservation: inter-annual groundwater level detected over last five years.

(iii) In the domain of water conservation: nitrogen concentration in rivers and aquifers.

(iv) In the domain of biodiversity: Shannon Evenness Index[2] above 0.3, average patch size lower than 2 hectare (ha) and edge density below 0.01.

Ideally, farm-level surveys will be used to collect these data and are aggregated at the country level. However, the methodological framework written for the indicator suggests that a combination of existing national data sets and remote-sensing satellite data may also be used for country-level reporting (FAO 2017b). It remains unclear how India's SDG 2.4.1. indicators will be calculated and whether state-level calculations will be made. Moreover, these four individual indicators fail to capture key domains of ecological sustainability especially relevant to the Indian context like pest management and efficient use of inputs. Thus, we have proposed an expanded model.

Selection of Indicators

We identified data in India that matched the indicators in Table 1 and met the following criteria: (i) publicly available, (ii) state level, and (iii) periodically updated. Of the seven domains, we were able to identify suitable indicators for all but one, "Quality of Food." We included an overarching indicator, the existence of a sustainable/natural/organic farming policy. Such a policy can be considered an important step in building a policy framework that is cognisant of agriculture's dependence and impact on natural resources. In sum, we included 11 indicators in the state-wise report cards across six of seven domains. The rationale for each is provided in this section, whereas the source of the data is described in the following section.

In the domain of "Pest Management," we used per hectare use of pesticides (kg/ha) as the indicator. A major limitation of our chosen indicator is that it is non-specific, and pesticides have a wide range of toxicities, mobility and persistence. Moreover, these data are self-reported at point of sale by pesticide dealers

Table 1: Summary of Seven Domains and Associated Composite Indicators of Ecological Sustainability Adapted from a Systematic Review Conducted by the Food and Agriculture Organization of the United Nations in 2016

Domain	Composite Indicators
Pest management	• Use of pesticides, including insecticides, herbicides and fungicides
	• Integrated pest management
	• Ecotoxicity
Fertiliser use	• Use of chemical fertiliser
	• Use of green manures
	• Use of animal and plant-based manures
Soil health	• Soil management
	• Crop rotation
	• Use of fallow system
	• Conservation tillage: none or minimum
	• Cover crop/mulch
	• Erosion control
	• Microbial biomass in soil
Water conservation	• Improved management of water resources
	• Depth of water table
Biodiversity	• Crop diversification
	• Cropping pattern
	• Land use
Efficient use of inputs	• Physical inputs
	• Physical yield
	• Energy and use of fossil fuels
Quality of food	• Protein content of crops
	• Fat content of crops
	• Total antioxidants in crops

Adapted from a systematic review conducted by the FAO (2016).

and therefore are likely to be underestimates. Nonetheless, this indicator is highly relevant to the Indian context because research suggests that environmental samples are highly contaminated with pesticides (Sharma et al 2014) and the cultivated area treated with pesticides is increasing (Ministry of Agriculture and Farmers Welfare 2016). Chemical pollution of water, land and air; the accumulation of persistent pollutants in biological systems; and loss of biodiversity are the direct ecological consequences of today's industrialised agriculture system. Over the past 50 years, the species richness of pollinators has declined with a few pollinators even going extinct, a trend at least partially due to increased use of insecticides (Goulson et al 2015). The production of pesticides is also an energy-intensive process, having significant indirect effects on the environment through greenhouse gas emissions (Audsley et al 2009).

In the domain of "Fertiliser Use," per hectare use of farm yard manure was used as the indicator.[3] Availability of soil nutrients is a natural limiting factor of agricultural productivity, creating a dependency on synthetic fertiliser to maintain high yield. Such fertilisers are energy-intensive to produce, contributing to global warming. However, a majority of landholdings in India are small or marginal (Department of Agriculture Cooperation and Farmers Welfare 2016) and the country is home to one of the largest populations of cattle and buffaloes in the world (FAOSTAT 2016b). Together, this creates a huge potential for meeting soil nutrient requirements through efficient use of farm yard manure. Waste from cattle available on farms can be efficiently processed into biogas and slurry to be used as manure. This reduces emissions through decomposition and dependency on firewood or cooking gas while providing manure for plant growth. Although adoption of such practices is rapidly increasing, data on the extent is currently unavailable, so per hectare use of farm yard manure was chosen as an indicator. Farm yard manure has beneficial impacts on soil organic carbon (Purakayastha et al 2008) and overall soil health, and the use of farm yard manure can also reduce dependency on expensive inputs such as synthetic fertiliser with co-benefits for the environment (Schröder 2005). The Input Survey, conducted every five years by the Government of India, is a valuable source of information on the farm-level use of synthetic and organic fertilisers. We only included per hectare use of farm yard manure from the Input Survey. We did not include the use of green manure nor the use of synthetic fertilisers as indicators for this study because: (i) only 1% of total landholdings sampled across India used green manure (Agriculture Census 2016),[4] and (ii) synthetic fertiliser use recommendations vary depending on the cropping pattern and specific nutrient deficiencies of any given plot of soil.

In the domain of "Soil Health," we used two indicators: (i) soil organic carbon and (ii) percent agricultural land undergoing desertification/degradation. As the primary source of nutrients for crops, healthy soil is an essential component of agriculture, as having healthy foods is essential for human health. The measurement of soil quality is complex and involves various chemical, physical and biological indicators. The first of our chosen indicators, soil organic carbon, is one of the most important components of soil (USDA 2009). It is a source of energy for soil microorganisms and plants and increases nutrient and moisture retention capacity of the soil (Cornell University Cooperative Extension 2016). High soil organic carbon indicates higher microbe diversity, which may improve crops' resistance to pests and disease (USDA 2009). Moreover, soil organic carbon plays an important direct role in climate change mitigation: well-managed soil can be an important carbon sink (USDA 2001). While there are state-level data available on soil pH, soil N:P:K ratio and soil micronutrients, we chose not to include these indicators because it is difficult to interpret them without information on the cropping patterns and nutritional deficiencies of any given plot of soil.

Closely related to declines in soil organic carbon is land degradation, defined as, "the temporary or permanent decline in the productive capacity of the land and the diminution of the productive potential" (Stocking 2001). This is relevant in the Indian context because an estimated 29% (ISRO 2016) of the total land area of the country is undergoing degradation or desertification, with important implications for the sustainability of current agricultural practices. We selected the overall indicator of agricultural land classified as "degraded." More specific data on land degradation due to soil salinity are also available at the state level, but all states had degradation due to salinity levels less than 1% of total land area, with the exception of Gujarat at 4% (ISRO 2016).

In the domain of "Water Conservation," we used three indicators: (i) percent groundwater development, (ii) percent wells classified as "safe," and (iii) percent districts with nitrate concentration above permissible limits. As per the 2010–11 Agriculture Census, only 46% of cultivated area in India was irrigated, with 62% of irrigated area fed by groundwater, the rest being fed mostly by canals (25%) and tanks (6%). Yet, nearly 90% of extracted groundwater in India is used for irrigation, compared to just 9% for domestic and industrial use (CGWB 2017a). The Water Resources Institute reports that 54% of groundwater sources in India have decreasing water levels (Shiao 2015). Many states provide highly subsidised or free electricity for agriculture and some also subsidise drilling for new wells. Improvements in technology like cheap and easily accessible solar panels (Gulati and Pahuja 2012) will make it more difficult for the government to regulate exploitation of groundwater resources. Hence, it is crucial to monitor year-on-year depletion of aquifers and implement an effective water management strategy.

Groundwater development is defined as the current annual groundwater draft divided by the net annual groundwater availability, expressed as a percent (CGWB 2015). Groundwater development is a year-on-year measurement and can signal changes in groundwater use. The Groundwater Board of India measures the depth of blocks/watersheds/mandals/talukas/firkas across the country. The natural recharge capacity of these units is used to determine the quantity of water that is safe for extraction during a year. Units are considered "safe" if the stage of groundwater development is no more than 90%

and there has been no significant decline in pre- or post-monsoon levels over the past 10 years. "Significant" decline is defined by the Central Ground Water Board (CGWB) as a decline in water level of 10–20 cm per year over a 10-year period (CGWB 2015). A lower percentage of groundwater sources being classified as "safe" indicates poor long-term performance.

The FAO-SDG measurement of sustainability considers nitrogen levels in groundwater as an indicator of water quality and sustainability. High levels of nitrogen in drinking water are harmful for human health (Ward et al 2005) and use of nitrogen fertiliser is the largest source of nitrogen in Indian watersheds (Swaney et al 2015). Existing publicly available data on nitrate contamination in groundwater at the district level were used for this indicator (CGWB 2016). However, key limitations of these data are that they do not indicate what percent of groundwater units are contaminated, nor the level of contamination. Contamination of rivers and streams with agricultural run-off is also a major cause for concern. Low use efficiency, of both synthetic fertiliser or farm yard manure means that nutrients can be leached from the soil, polluting waterbodies and damaging both freshwater and marine ecosystems. However, river basins are spread across multiple states, and state-level data on water quality of all waterbodies, along with source of contamination is currently unavailable.

In the domain of "Biodiversity," we used the number of crops that cover half of the total cropped area as the indicator. India is one of the most agro-biodiverse regions in the world. However, the introduction of hybrid seed varieties as part of the green revolution has led to the replacement of many indigenous seeds in cultivation (Chaudhuri 2005). While this has increased yields, it has also led to decreased crop diversity and monocropping in many states across the country. As a simplified indicator of diversity in the cropping pattern, the number for most-cultivated crops covering 50% of total cropped area in a given year was calculated. For example, if 50% or more of total cropped land is rice paddy, then this indicator would be 1. The Directorate of Economics and Statistics reports cropped area under rice, wheat, maize, millets, pulses, oilseeds, sugar cane, fiber crops and horticulture crops. Various coarse grains (including millets), pulses and oilseeds were considered individual crops and not aggregated. For horticulture crops, fruits, vegetables and plantation crops were considered individually but cropped area under flowers, spices and aromatic and medicinal plants was aggregated. There are several limitations to this indicator, including that it fails to consider the diversity within each crop type.

In the domain of "Efficient Use of Inputs," we used three indicators: (i) per hectare electricity use in agriculture (kWh/ha), and two proxy indicators of greenhouse gas emissions, (ii) percent area of paddy under irrigation (as a proxy of methane emissions), and (iii) per hectare use of nitrogen fertiliser (as a proxy of nitrous oxide emissions). For agriculture to be resource-efficient, it must also be energy efficient. Consumption of electricity is an important indicator for India since the country is heavily dependent on thermal power (CEA 2018), a major source of greenhouse gases and other pollutants. High use of electricity could also signal low water-use efficiency as the provision of free or subsidised electricity provides most farmers with little incentive to adopt practices to reduce energy use or increase water-use efficiency (Gulati and Pahuja 2012).

Agriculture accounted for 18.3% of national greenhouse gas emissions in India in 2015, primarily methane and nitrous oxide (MOEFCC 2015). This is an underestimate because it does not account for emissions from manufacturing of fertilisers and pesticides. We could not identify state-level agriculture sector emission data within the past 10 years. India's agricultural emissions inventory reported to the United Nations Framework Convention on Climate Change calculates emissions from five sources: enteric fermentation, manure management, rice cultivation, agricultural soils and field burning of crop residues. Emissions through enteric fermentation and manure management are dependent on livestock systems, which were not the focus of this study of cropping systems. Crop residue burning accounted for 2% of total greenhouse emissions reported from agriculture but no recent estimate of proportion of residue burned by state were available. Thus, we focused on agricultural soils and rice cultivation.

Agricultural soils are an important source of nitrous oxide. While nitrous oxide is released as part of the natural nitrogen cycle, 83% of total nitrous oxide is from direct emissions.[5] The most recent estimate for India, based on 2007 data (Bhatia et al 2013), indicates that the use of synthetic fertiliser accounts for 69% of direct nitrous oxide emissions in India. As no other state-level agriculture emissions data within the past 10 years could be identified, per hectare consumption of nitrogen fertiliser was used as a proxy indicator (Patra 2017). Rice cultivation is an important source of methane due to the anaerobic conditions under which rice is grown. Rice cultivation accounts for 18% of total agricultural emissions and 44.5% of emissions from cropping systems, with irrigated, continuously flooded cultivation of rice being the predominant source (Manjunath et al 2015; MoEFCC 2012). Rice cultivated using single or multiple aerations, or under rain-fed conditions, has significantly lower emissions (MOEFCC 2012). As the recent state-level disaggregated data on rice paddy area under different water regimes is unavailable, total area under irrigated rice paddy cultivation was used for this indicator (Gupta et al 2009; Manjunath et al 2015).

Data Sources and Methodology

Table 2 (p 23) is a summary of the methodology used to calculate each indicator, along with the associated cut-points to categorise states into bins of "poor performance," "mediocre performance" or "high performance." Each indicator is chosen to measure performance in a broad domain. The source of data for each indicator is listed along with the publication date. The year of the data is listed in a separate column. Any calculations made by the authors are specified, along with the applicable formulas. All cut-points based on the mean of states were defined as <mean, high performance; mean +1 SD, mediocre performance; >mean +1 SD, poor performance, except for use of farm yard manure, which was defined as <mean, low

Table 2: Summary of Methodological Approach for Calculating Indicators and Classifying States

FAO Domain	Indicator	Data Source	Year of Data	Calculation	Source of Cut-point Definition	Cut-points		
						Poor	Mediocre	High
Pest management	Pesticide consumption (kg/ha)	Chemical and Petrochemical Statistics at a Glance, Department of Chemicals and Petrochemicals Statistics and Monitoring Division, 2017 Table 5A (Ministry of Chemicals and Fertilisers 2017)	2016–17	Consumption of selected pesticides (Tech. Grade) divided by total cropped area of state (ha)	(FAOSTAT 2016a)	>3.03 kg/ha	0.37–3.03 kg/ha	<0.37 kg/ha
Fertiliser use	Use of farm yard manure (kg/ha)	(Agriculture Census 2016)	2011–12	Total quantity of FYM divided by Gross Cropped Area	Mean	<1037 kg/ha	1037–2108 kg/ha	>2108 kg/ha
Soil health	Organic carbon content of soils	Soil Health Card (SHC) Scheme, Macro Nutrient status for cycle I (2015–16 to 2016–17) (Soil Health Card 2017)	2015–16 to 2016–17	Reported by SHC as percentage of samples in "Low <0.5 Medium 0.5–0.75 High >7.5" % organic carbon	Majority in high, medium, low	N/A	N/A	N/A
	Percent agricultural land undergoing desertification/ degradation	Desertification and Land Degradation Atlas of India, Indian Space Research Organisation (ISRO 2016)	2011–13	Degraded land area under various classifications reported, 12 of which are agricultural land categories. Calculated as: Sum of agricultural land area undergoing degradation (ha)/ Total Cultivable Land (ha) (2014–15)	Based on mean of states	>43%	19%–43%	<19%
Water conservation	Percent groundwater development	Dynamic Groundwater Resources of India (published 2017), Central Ground Water Board, Annexure I (CGWB 2017a) Sikkim data: Annual Report 2015–16 (Published 2017), Central Ground Water Board (GWB), Table 10.1 (CGWB 2017b)	As on March 2013 Sikkim data as on March 2011	Taken as reported	GWB defines 70% as unsafe (PP), MP is defined as mean to 70%, HP as <mean	>70%	<47%–70%	<47%
	Percent wells classified as "safe"	Dynamic Groundwater Resources of India (published 2017), Central Ground Water Board, Annexure III (CGWB 2017a) Sikkim data: Annual Report 2015–16 (published 2017), Central Ground Water Board (GWB), Table 10.2 (CGWB 2017b)	As on March 2013 Sikkim data as on March 2011	Taken as reported	>Mean (HP), Mean – 50 (MP), <50 (PP)	<50%	50%–80%	>80%
	Percent districts with nitrate concentration above permissible limits	Unstarred question No 402, Asked in Lok Sabha, Answered on 25.02.2016 (CGWB 2016)	2015–16	No of districts with nitrate concentration above permissible limits/total no. of districts in state	Based on mean of states	>85%	45%–85%	<45%
Biodiversity	Number of crops that cover half of total cropped area	Agricultural Statistics at a glance, Department of Agriculture Cooperation and Farmers Welfare, 2016 (Department of Agriculture Cooperation and Farmers Welfare 2016)	2015–16	Net sown area under most cultivated crops in each state was added, from greatest to smallest. Sum divided by total cropped area for percentage	Chosen by authors	1	2–3	>=3
Efficient use of inputs	Per hectare electricity use in agriculture (kWh/ ha)	Agricultural Statistics at a glance, Department of Agriculture Cooperation and Farmers Welfare, 2016, Table 14.8 (b): State-wise Consumption of Electricity for Agriculture (Department of Agriculture Cooperation and Farmers Welfare 2016)	2013–14	Total electricity consumption (in gWh/state)/ total cropped area (thousands of ha) and multiplied by 1000 (1000000 kWh per gWh) to get kWh/ha consumption	Based on mean of states	>1408 kWh/ ha	591–1408 kWh/ha	<591 kWh/ha
	Percent area of paddy under irrigation	Agricultural Statistics at a glance, Department of Agriculture cooperation and Farmers Welfare, 2016, Table 4.6 (b) (Department of Agriculture Cooperation and Farmers Welfare 2016)	2013–14	As reported	Based on mean of states	>93%	61%–93%	<61%
	Per hectare use of nitrous fertiliser (kg/ha)	Fertilizer Scenario, 2017, Department of Fertiliers, Ministry of Chemicals and Fertilisers. Table 21 (Department of Fertilisers 2017)	2016–17	As reported	Based on mean of states	>117 kg/ha	64–117 kg/ha	<64 kg/ha
N/A – Policy	Existence of sustainable/ natural/organic farming policy	State agriculture department websites	2018	N/A	N/A	Yes	Existence of state-sponsored Mission, Scheme, or Draft Policy	No

performance; mean +1 SD, mediocre performance; >mean +1 SD, high performance.

State-level Report Card

A summary of the state-level values and classification (black [poor performance], grey [mediocre performance] and white [high performance]) for each of the eleven indicators is presented in Figure 1. States are organised geographically, approximately north to south, grouped together broadly based on the Indian Council of Agricultural Research's agroclimatic zones (Sehgal et al 1990). The zones represented in each state are given in the left-most column.

We found strong, scientific evidence of variations in the ecological sustainability of agricultural practices across states in India. Several notable trends emerged. First, states with a higher portion of agricultural area performed worse across indicators. Punjab and Haryana (the "bread basket" of India), with the highest percentage of agricultural land, were characterised by high use of pesticides, low soil organic content, depletion of groundwater levels, a dominant rice–wheat crop cycle, high use of electricity, 100% paddy under irrigation and widespread nitrate contamination of groundwater. Telangana is performing similarly, with over 50% of total agricultural land cultivated with cotton and rice. None of the three states have a farming policy on the books outlining plans for improving the sustainability of practices.

Second, soil health is clearly one of the biggest challenges facing India's agricultural system in terms of ecological sustainability. Nearly half (14/29; 48%) of the states were characterised by low soil organic carbon and for 38% of states, more than one-fifth of their agricultural land was degraded. Indeed, in Jharkhand, Odisha and Tripura, more than half of agricultural land is classified as degraded. This is likely a result of the terrain and meteorological conditions in these states, such as heavy rainfall concentrated in a few months of the year, characteristic of the Indian monsoon. There is a need to take up special efforts to conserve agricultural soils in these states. In order to replenish soil organic carbon and promote soil health, several sustainable options have yet to be fully explored. For example, the use of farm yard manure was low across states, with only five states using more than 2,000 kg per hectare; so untapped opportunities exist to increase the use of farm yard manure. Reducing burning and incorporation of crop residues can also help increase organic carbon in many states.

Third, states with the highest rate of energy usage and per cent of paddy under irrigation (for example, Andhra Pradesh/Telangana, Tamil Nadu, Karnataka, Punjab and Haryana) tended to have the greatest groundwater development with the exceptions of Uttar Pradesh and Rajasthan where energy usage was relatively lower. Importantly, whilst the states of Andhra Pradesh and Uttar Pradesh had similar performance in terms of wells classified as "safe" (74%), Uttar Pradesh is drawing a larger percentage of groundwater annually (74% compared to 44% in Andhra Pradesh), indicating greater concern about the sustainability of the state's aquifers. To address water conservation across states, increased water use efficiency, watershed management and water budgeting, supplemented with a combination of pricing policy, direct transfer to farmers or community-led management of water resources are needed (Gulati and Pahuja 2012).

Figure 1: State-level Indicators of Ecological Sustainability

Zones	% Agri.L	State / Indicator	1	2	3	4	5	6	7	8	9	10	11	12
1	5%	Jammu and Kashmir	1.86	3530	H	9%	100%	24%	2	238	NA	39	18%	MSD
1	15%	Himichal Pradesh	0.37	3792	H	29%	75%	51%	2	52	NA	35	50%	MSD
1	79%	Uttarakhand	0.12	2078	L	1%	89%	50%	2	314	NA	138	23%	Yes
2	5%	Arunachal Pradesh	0.06	65	H	0%	100%	0%	NA	0	NA	0	0%	MSD
2	14%	Sikkim	NA	3749	H	0%	100%	26%	NA	0	NA	0	0%	Yes
2	17%	Manipur	0.09	494	H	2%	100%	1%	NA	4	NA	24	0%	No
2	47%	Meghalaya	NA	375	H	4%	100%	0%	NA	1	NA	0	0%	MSD
2	17%	Mizoram	NA	6	L	2%	100%	3%	NA	0	NA	17	25%	Yes
2	42%	Nagaland	NA	5	H	0%	100%	2%	NA	0	NA	16	0%	No
2	26%	Tripura	0.62	2169	H	64%	100%	7%	NA	61	NA	25	0%	No
2	43%	Assam	0.07	227	H	5%	100%	16%	1	9	11%	27	0%	No
3	64%	West Bengal	0.27	1559	H	24%	71%	45%	1	122	47%	82	9%	MSD
4	70%	Bihar	0.11	621	M	7%	97%	45%	2	42	63%	139	26%	MSD
4,5	29%	Uttar Pradesh	0.39	144	L	3%	74%	74%	2	391	83%	104	63%	No
6	85%	Punjab	0.74	928	L	0%	19%	149%	2	1301	100%	178	91%	No
6	83%	Haryana	0.62	324	L	5%	25%	135%	2	1306	100%	164	86%	No
6,8,14	75%	Rajasthan	0.05	442	L	41%	18%	140%	5	712		40	100%	Yes
15	65%	Gujarat	0.13	243	L	39%	78%	68%	5	1153	62%	91	67%	Yes
7	54%	Jharkhand	0.35	597	L	93%	94%	23%	1	59	5%	34	4%	No
7	41%	Chhattisgarh	0.26	336	L	11%	86%	37%	1	435	35%	59	44%	MSD
7,11	44%	Odisha	0.15	1306	L	66%	98%	30%	1	33	33%	35	93%	Yes
7,8,9	56%	Madya Pradesh	0.03	425	M	2%	73%	57%	3	498	30%	51	96%	Yes
9,12	69%	Maharashtra	0.57	727	L	36%	92%	54%	4	948	26%	63	83%	Yes
10	61%	Telangana	0.72	1110	L	43%	70%	58%	2	2842	97%	164	100%	No
10,11	56%	Andhra Pradesh	0.24	1110	H	10%	74%	44%	4	2842	97%	124	100%	MSD
10,12	67%	Karnataka	0.10	1379	L	38%	56%	66%	6	1476	75%	88	73%	Yes
10,11,13	62%	Tamil Nadu	0.33	1497	L	0%	38%	77%	3	2051	93%	87	84%	MSD
12	53%	Goa	0.14	129	H	22%	100%	37%	NA	133	NA	22	0%	MSD
12	58%	Kerala	0.41	711	H	1%	86%	47%	4	121	77%	15	79%	Yes

Legend	Indicator
Zones	Ago-climatic zones in the state
% Agri.L	Agricultural land as a percentage of total geographic area
1	Pesticide consumption (kg/ha)
2	Use of Farm Yard Manure (kg/ha)
3	Highest % samples classified as "Low" (L) Medium" (M) or "High" (H)
4	% of degraded agricultural land
5	% wells classified as "Safe"
6	% of Ground water Development
7	No. of most sown crops to cover 50% of Total Cropped Area
8	Per hectrare electricity use in agriculture (kWh/ha)
9	% area of paddy under irrigation
10	Per hectare use of inorganic nitrogen fertilizer (kg/ha)
11	% districts with nitrate concentration over permissible limits
12	Existence of sustainable/natural/organic farming policy
MSD	Mission/Scheme/Draft Policy

Values are from most recent data on specified indicator. Performance classification is as follows: black (poor performance), grey (mediocre performance) and white (high performance). Per hectare use of farm yard manure and electricity in agriculture for Andhra Pradesh and Telangana are from data collected pre-bifurcation.

Only six out of 21 states with data had more than three crops covering half of land area. With government schemes, such as "Bringing Green Revolution to Eastern India," aimed at promoting production and productivity in eastern India (Department of Agriculture and Cooperation 2015), there is a need to ensure effective strategies for crop diversification in the states targeted by the scheme, that is, West Bengal, Assam, Bihar, Jharkhand, Chhattisgarh, Odisha, Eastern Uttar Pradesh, all of which have only one or two crops covering a majority of total cropped area (Figure 1). Several opportunities exist to support crop diversification, for example, India currently imports 60% of its oilseeds (Ghosal 2017), but these could instead be produced domestically.

Nine states had more than 61% of paddy under irrigation, a significant source of methane emissions. With the exception of Odisha and Kerala, all of these states are also seeing low or mediocre performance on groundwater indicators. A shift towards practices like SRI (System of Rice Intensification) (Uphoff 2003), with single or multiple aerations, could have a ninefold reduction in emissions and promote water conservation in these states (MOEFCC 2012). With respect to per hectare use of nitrous fertiliser, a proxy of nitrous oxide emissions, four states with highest emissions were also those with highest proxy emissions of methane: Punjab, Haryana, Telangana and Andhra Pradesh. Bihar and Uttarakhand also had notably high proxy emissions of nitrous oxide, though relatively low proxy emissions of methane.

The Government of India has been promoting organic farming through various schemes like the Paramparagat Krishi Vikas Yojana, Rashtriya Krishi Vikas Yojana, National Programme for Organic Production, National Mission for Organic Agriculture and is also implementing a mission to improve the organic value chain in the North East (ASFAC 2016). Other states have also taken steps towards sustainable practices by adopting suitable policies. For example, Kerala's organic farming policy was adopted in 2009, and is being bolstered by the state's organic farming scheme (Directorate of Agriculture 2016). Sikkim is the first state in India to be declared fully organic (PTI 2016). Andhra Pradesh has adopted the Zero Budget Natural Farming model of organic agriculture and aims to transition the state's 6 million farmers into chemical-free agriculture by 2024 (United Nations Environment Programme 2018). Ten states have adopted organic farming policies, but various other states, like Arunachal Pradesh, Goa and Chhattisgarh, have declared schemes or missions to promote organic farming. Tripura and Manipur are considering following in Sikkim's footsteps to be fully organic. However, beyond the adoption of Zero Budget Natural Farming, states also need to take note of decreasing water resources and crop diversity.

Other states like Telangana and Tamil Nadu have draft organic farming policies. Punjab has put in place a statutory body called the "Punjab State Farmers' and Farm Workers' Commission" for the welfare of those dependent on agriculture. The draft farmers' policy published by the commission takes clear note of the resource constraints being faced by the state, along with the ecological impact of production practices and aims to conserve resources and promote organic farming (PSFC 2018).

Gaps and Suggestions

The data used for this report card are aggregate numbers at the state level, but farm-level numbers are likely to vary substantially within a state for most of these indicators. Survey-based data collection in India is done every five years for agricultural inputs through the Input Survey, and could be expanded and used to collect farm-level data on sustainability in line with the FAO recommended methodology. Like the National Family Health Survey, data collection must become more frequent for timely management and reliable information for policymakers. Seventy-one agricultural universities are recognised across the country by the Indian Council of Agricultural Research (Research ICoA 2018), and students can be deployed for more frequent data collection, with the co-benefit of providing valuable field experience. The ability to aggregate data on all sustainability indicators at the block, district and state levels will support decentralised planning and action.

In order to address limitations, particularly related to the specificity and breadth of our indicators, we propose that the following additional data could be collected:

(i) Disaggregated data on type of pesticides (including type and quantity of active ingredient) sold and used (by crop) should be available at the state level. A centrally controlled tracking system, similar to the one used for tracking of fertiliser sales, may be implemented. This would enable the calculation of an Environmental Impact Quotient (Kovach et al 1992) or similar calculation for a more accurate understanding of the health and environmental impact of various pesticides.

(ii) Farm-level estimations of soil health and fertiliser application rates must be paired with information on the recommended use of quantity by crop type. The currently published Soil Health Card data with aggregated soil quality indicators at the state level can also be used to calculate state-level deviation from recommended use of fertiliser (if made available for all crops based on existing nutrient deficiency), but will not be able to capture intra-state, farm-to-farm variability.

(iii) Data published by the CGWB should be updated annually. The most recent available data is from 2013, but the extraction of groundwater may have changed significantly in the past five years. Water Resources Information and Management System of the Andhra Pradesh Water Resources Department is an example of a positive step in this direction for the dynamic measurement and evaluation of water availability through various sources in the state. The portal currently reports changes in groundwater level with a one-year reference, but a longer-term comparison could prove useful for better planning. A similar system to report national, statewise data could prove invaluable.

(iv) As emissions from rice paddy vary based on the type of cultivation, this data must be available at the state level. Currently available data is a national estimate, that is used to calculate India's emissions inventory reported to the United Nations Framework Convention on Climate Change (UNFCCC).

(v) Up-to-date disaggregated data on the cropping patterns for the eight smallest states (with total sown area under 5,00,000 ha) is not reported by the National Statistics Office. Availability of this data will allow for the calculation of the proxy indicator proposed in this article.

(vi) As India is one of the most agro-biodiverse regions in the world, a systematic effort to collect and report the diversity in cultivated crops should be taken up. While some universities and research centres across India have made an effort to collect and preserve indigenous crop varieties, cultivation of these diverse varieties could help agriculture in India become more resilient to the risks posed by climate change.

(vii) While the burning of crop residues in the north-west of the country has garnered much attention, the practice is prevalent and perhaps increasing across many other states. Estimates of crop residue burned should be reported by the agricultural departments of each state as a first step towards prevention. Existing estimates show that some amount of burning happens in all states, but is most prevalent in Uttar Pradesh, Punjab, West Bengal, Haryana, Maharashtra, Karnataka, West Bengal, Tamil Nadu, Gujarat, Bihar and Andhra Pradesh (Bhatia et al 2013).

(viii) There is currently no data available on practices of intercropping or mixed cropping. Calculating a diversity index at the farm level will help fill this gap in information. The Shannon evenness index proposed by the FAO may also be used if reported at the state level.

(ix) There is evidence to suggest that changing environmental conditions may decrease the nutritional quality of food (Myers et al 2015). Assessments of the nutritional values of food grown in India can be done periodically to monitor the possible impact.

Looking ahead to the future, these report cards should be updated every two years. Several studies have suggested that if states pursue unsustainable paths and continue to deplete soil quality, leading to further degradation of land and water resources, productivity will decline. The ongoing monitoring of agricultural practices through these report cards should lead to better use of on-farm resources, reductions of external inputs and greater cropping diversity, thereby promoting not only ecological sustainability and resilience, but also economic sustainability among farmers in India.

NOTES

1 The Pradhan Mantri Fasal Bhima Yojana has been launched to insure farmers against such risks. However, increasingly unreliable production has driven up the cost of the premium. Insurance rates for certain crops in Rajasthan, Maharashtra and Telangana have ranged between 30% and 60% of the cost of cultivation, often times more than the profit made by the cultivating farmers.

2 Shannon evenness index is a measure of the composition of species in a given land area. It ranges between zero (indicating no evenness) and one (indicating complete evenness that is, all species counted in the area are equally abundant).

3 Farmyard manure is prepared by putting agricultural wastes in a pit for decomposition and composting.

4 Green manure refers to cultivation of a specific type of vegetation with the intention of ploughing it back into the soil when the leaves are tender and easily decomposable.

5 Calculated from use of synthetic or organic fertilisers, deposited manure, crop residues and compost. "Indirect" emissions are based on nitrogen run-off from fertilised soils.

6 As delineated in Sehgal et al (1990).

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