

Water and Agricultural Transformation in India

A Symbiotic Relationship—I

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An argument for twin propositions is presented in this two-part paper: (i) that solving India's water problem requires a paradigm shift in agriculture (Part I), and (ii) that the crisis in Indian agriculture cannot be resolved without a paradigm shift in water management and governance (Part II). If farming takes up 90% of India's water and just three water-intensive crops continue to use 80% of agricultural water, the basic water needs of millions of people, for drinking water or protective irrigation, cannot be met. This first part argues that the paradigm shift in agriculture requires a shift in cropping patterns suited to each agroecological region, a movement from monoculture to polycultural crop biodiversity, a decisive move towards agroecological farming, and greater emphasis on soil rejuvenation.

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This paper traces the roots of India's water and farm crises to the onset of the green revolution in agriculture, which has now been ongoing for the past 50 years and could be said to have entered its terminal phase at the turn of the century. We suggest that if the right lessons are drawn from the experience of the green revolution, then it is, indeed, possible to address the crisis facing India's farmers, while also solving India's water problem. Not doing so would, on the other hand, leave both crises unresolved, even aggravated.

The Green Revolution Paradigm

Recent revisionist scholarship¹ on the green revolution has conclusively established that the assumption of a stagnant food sector in the first two decades after independence is a myth (Balakrishnan 2007). It also shows that neo-Malthusian fears of starvation in the Indian context were, indeed, exaggerated.² At the same time, there is also no denying that the Indian political leadership was deeply troubled by the excessive dependence on wheat shipments under the PL-480 food aid programme of the United States (US).³ We cannot overlook the fact that 90% of the food that the government distributed through the public distribution system (PDS) between 1956 and 1960 came from imports and remained as high as 75% even during the period of 1961 to 1965. In 1965–66, the US shipped 10 million tonnes of wheat to India (Tomlinson 2013). At that point, India had less than half the food needed to provide a basic subsidised ration to the poorest 25% of the population (Krishna 1972). Hence, there was a nationalist impulse that propelled the green revolution and it cannot be seen as merely a conspiracy of imperialist capital, although it is certainly the case that corporations supplying key inputs to green revolution agriculture were major beneficiaries of this radical policy shift.⁴

What also needs to be acknowledged is that, following the green revolution, India achieved self-sufficiency in food like never before. The buffer stock, which was hardly three million tonnes in the early 1970s, had already reached 60 million tonnes in 2012–13 (Table 1), and recently peaked at almost 100 million tonnes in July 2020 (Drèze 2021). The fact most worth noting here is that in the early 1970s

Table 1: Foodgrain Procurement and Buffer Stock, 1972–2018 (million tonnes)

Year	Procurement	Buffer Stock
1972–73	7.51	2.60
1982–83	14.85	11.10
1992–93	17.16	12.67
2002–03	38.03	32.81
2012–13	72.19	59.76
2017–18	68.20	43.31

Source: Department of Agriculture and Cooperation (DAC 2020).

itself, the net sown area had almost reached 140 million hectares, and this figure has remained more or less unchanged over the past five decades. During the same period, the gross cropped area has risen steadily with the cropping intensity growing from 119% to 140% (Table 2).

It can then be argued, somewhat more debatably, that without the intensification that occurred under the green revolution, the degradation of common lands and forests could have advanced at an even more rapid rate than it has done during this period.⁵

Table 2: All-India Net Sown Area and Gross Cropped Area, 1950–2015

Period	Net Sown Area (NSA) ('000 ha)	Gross Cropped Area (GCA) ('000 ha)	NSA/Total Geographical Area (TGA) (%)	GCA/TGA (%)	GCA/NSA (Cropping Intensity) (%)
1950–51 to 1954–55	1,23,248	1,37,874	37	42	112
1955–56 to 1959–60	1,30,770	1,49,418	40	45	114
1960–61 to 1964–65	1,35,908	1,56,387	41	48	115
1965–66 to 1969–70	1,37,863	1,59,632	42	49	116
1970–71 to 1974–75	1,39,587	1,65,438	42	50	119
1975–76 to 1979–80	1,40,993	1,71,051	43	52	121
1980–81 to 1984–85	1,41,467	1,75,604	43	53	124
1985–86 to 1989–90	1,39,759	1,78,031	43	54	127
1990–91 to 1994–95	1,42,505	1,85,650	43	56	130
1995–96 to 1999–2000	1,42,178	1,89,401	43	58	133
2000–01 to 2004–05	1,39,073	1,85,602	42	56	133
2005–06 to 2009–10	1,40,614	1,92,971	43	59	137
2010–11 to 2014–15	1,40,806	1,97,405	43	60	140

Source: DAC (2020).

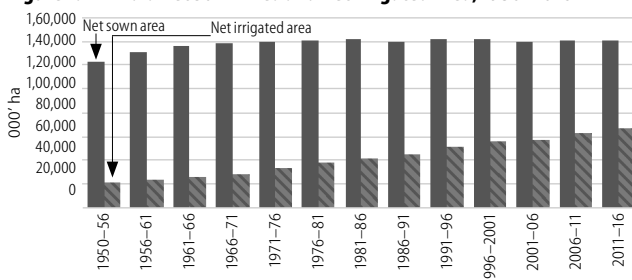
It is important to recognise that the green revolution was a package deal, a combination of radical changes in the political economy of Indian agriculture, with several path-breaking interventions. These included the following:

Higher-yielding seeds and concomitant use of chemical fertilisers and pesticides:

The consumption of fertilisers rose dramatically from two million tonnes in 1970–71 to more than 27 million tonnes in 2018–19 (Table 3). Similarly, synthetic pesticide consumption has grown sharply over the past decade (Table 4).

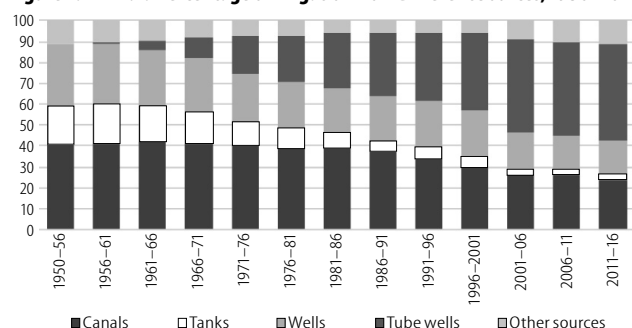
Breakthrough in irrigation: Following the green revolution, there was a sea change in the extent of irrigation as well as in the way India irrigated its fields. Irrigated area more than doubled, both in absolute terms and as a percentage of net sown area (Figure 1). Over time, groundwater, especially that provided by deep tube wells, has become the single largest source of irrigation (Figure 2). This form of irrigation allows farmers greater control over water—as and when and in the volumes

Figure 1: All-India Net Sown Area and Net Irrigated Area, 1950–2016



Source: DAC (2020).

Figure 2: All-India Percentage of Irrigation from Different Sources, 1950–2016



“Other Sources” largely includes groundwater sources, such as dug-cum-bore wells. Hence, groundwater could well be said to account for nearly 70% of irrigation today. Source: DAC (2020).

that crops require it. Over the last four decades, around 84% of total addition to the net irrigated area has come from groundwater. At 250 billion cubic metres, India draws more groundwater every year than any other country in the world. India’s annual consumption is more than that of China and the us (the second and third largest groundwater using countries) put together (Vijayshankar et al 2011).

Easier availability of credit: The access to seeds, fertilisers, pesticides, and new irrigation technology was made possible by the easier availability of credit. The nationalisation of 14 banks in 1969 was a landmark step in the direction of improving access to reasonably priced credit in rural India. Recent arguments in favour of reprivatization overlook the fact that before nationalisation, not even 1% of India’s villages were served by commercial banks. Furthermore, the share of banks in rural credit was no more than 2.4%, with most of these loans being made to plantation owners, not farmers. Easier availability of credit fuelled the investments that drove India’s green revolution (Shah 2007).⁶

Role of agricultural extension system: Since the green revolution meant a completely new way of farming, a critical role was played by the state-supported agricultural extension system. Today, it may be quite difficult to imagine what a humongous task this was, covering hundreds of thousands of farmers. Of course, this paradigm of agricultural extension was what may be described as “top-down, persuasive and paternalistic technology transfer,” which provided specific recommendations to farmers about the practices they should adopt. If an alternative is to be found to the green revolution

Table 3: Fertiliser Consumption in India, 1950–2019

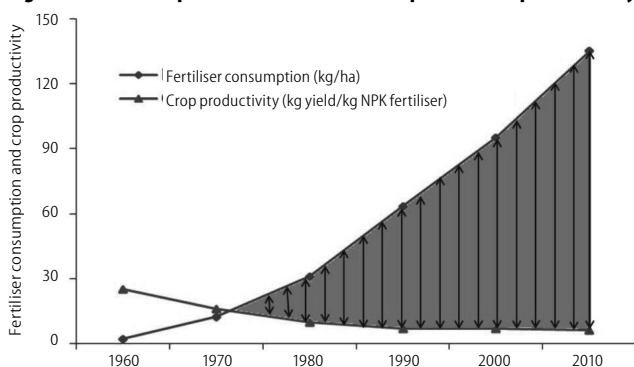
Year	Fertiliser Use ('000 tonnes)
1950–51	70
1960–61	294
1970–71	2,257
1980–81	5,516
1990–91	12,546
2000–01	16,702
2010–11	28,122
2018–19	27,228

Source: Fertiliser Association of India (2020).

Table 4: Synthetic Pesticide Consumption in India, 2001–20

Period	Consumption ('000 tonnes)
2001–04	45.46
2004–07	41.28
2007–10	42.44
2010–13	51.38
2013–16	56.84
2016–19	60.46
2019–20	60.56

Source: DAC (2019).

Figure 3: Relationship between Fertiliser Consumption and Crop Productivity

Source: Indoria et al (2018, Figure 2, p 2053).

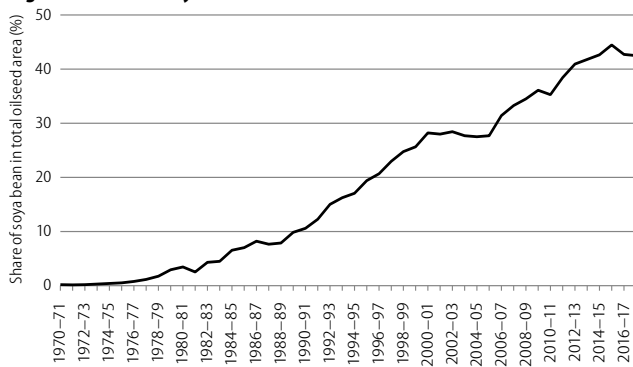
today, great effort will be needed to re-energise and reorient this extension system, which today finds itself in a state of almost total collapse. It will also be necessary to move towards a much more “farmer-to-farmer participatory extension system.”

A stable market: The setting up of the Food Corporation of India (FCI) in 1965 and the ensuing and expanding procurement operations at minimum support prices (MSPs) ensured a stable market for the farmers.⁷ Without this state intervention, left to the vagaries of the free market, the green revolution would not have taken off, as the expanded output could have created problems for the farmers, due to a fall in price at times of bumper harvest.⁸

Wheels Come Off

While it is undeniable that the green revolution paradigm represents a powerful break from the past that provided India with comfortable food security,⁹ it is also true that over the decades that followed, it sowed the seeds of its own destruction, leading to a grave farming crisis in India today. More than 3,00,000 farmers have died by suicide in the last 30 years, a phenomenon completely unprecedented in Indian history.¹⁰ There is growing evidence of a steady decline in water tables and water quality. At least 60% of India’s districts are either facing a problem of over-exploitation or severe contamination of groundwater (Vijayshankar et al 2011).

There is evidence of fluoride, arsenic, mercury, and even uranium and manganese in groundwater in some areas. The increasing levels of nitrates and pesticide pollutants in groundwater have serious health implications. The major health issues resulting from the intake of nitrates are methaemoglobinaemia and cancer (WHO 2011). The major health hazards of pesticide intake through food and water include cancers, tumours, skin diseases, cellular and DNA damage, suppression of the immune system, and other intergenerational effects (Margni et al 2002).¹¹ Repetto and Baliga (1996) provide experimental and epidemiological evidence that many pesticides widely used around the world are immune-suppressive. Nicolopoulou-Stamati et al (2016) provide evidence of pesticide induced temporary or permanent alterations in the immune systems, and Corsini et al (2008) show how such immune alteration could lead to several diseases.

Figure 4: Share of Soya Bean in Total Area under Oilseeds

Source: DAC (2018).

Agricultural workers spraying pesticides are a particularly vulnerable group, especially in India where they are rarely provided protective gear. A study of farm workers in Punjab found significantly higher frequency of chromosomal aberrations in peripheral blood lymphocytes of workers exposed to pesticides, compared to those not exposed (Ahluwalia and Kaur 2020). A recent study of 659 pesticides, which examined their acute and chronic risks to human health and environmental risks, concludes that

[E]vidence demonstrates the negative health and environmental effects of pesticides, and there is widespread understanding that intensive pesticide application can increase the vulnerability of agricultural systems to pest outbreaks and lock in continued reliance on their use. (Jepson et al 2020: 2)

It is also clear that the yield response to the application of increasingly more expensive chemical inputs is falling. Indoria et al (2018) show that the average crop response to fertiliser use has fallen from around 25 kg grain/kg of nitrogen, phosphorus and potassium (NPK) fertiliser during the 1960s to a mere 6 kg grain/kg NPK by 2010 (Figure 3). This has meant higher costs of cultivation, without a corresponding rise in output, even as this intensified application of inputs compels farmers to draw more and more water from below the ground.

Moreover, despite overflowing granaries, the Global Hunger Index Report 2020 ranked India 94th out of 107 countries.¹² FAO et al (2020) estimate that more than 189 million people remained malnourished in India during 2017–19, which is more than a quarter of the total of such people in the world. In 2019, India had 28% (40.3 million) of the world’s stunted children (low height-for-age) and 43% (20.1 million) of the world’s wasted children (low weight-for-height) under five years of age.¹³ Paradoxically, at the same time, diabetics have increased in every Indian state between 1990 and 2016, even among the poor, rising from 26 million in 1990 to 65 million in 2016. This number is projected to double by 2030 (Shah 2019).

To outline precisely how we can institute a paradigm shift in farming, we must first understand why this multifold unravelling was inherent in the very architecture of the green revolution. It is now widely recognised that the green revolution was, simply, a wheat–rice revolution.¹⁴

As can be seen from Tables 5 and 6 (p 46), over the past 50 years, the share of nutri-cereals in cropped area has gone down

Table 5: All-India and Region-wise Cropped Area

('000 ha)

Region	Period	Rice	Wheat	Nutri-cereals ¹⁵	Pulses	Oilseeds	Sugar Cane	Others	Total
North-west	1962–65	5,152	6,724	7,795	7,059	4,115	1,539	1,004	33,455
	1980–83	7,376	13,160	6,250	4,193	4,154	1,825	1,941	38,821
	1990–93	7,991	13,459	4,512	3,403	2,409	1,988	4,588	38,236
	2003–06	9,096	14,752	3,797	2,848	1,819	2,215	5,141	39,549
	2012–14	9,680	15,291	3,319	2,410	1,659	2,252	4,741	39,511
East	1962–65	14,623	667	1,719	3,643	770	231	4,105	25,655
	1980–83	15,828	2,018	2,046	3,382	1,563	227	3,410	28,416
	1990–93	15,948	2,121	1,307	2,847	1,830	203	4,648	29,050
	2003–06	14,885	2,193	1,014	1,700	1,234	603	5,757	27,413
	2012–14	16,358	2,596	1,228	1,507	1,396	307	4,466	27,915
Central	1962–65	5,934	5,400	21,421	9,375	6,765	237	10,087	59,338
	1980–83	6,494	6,494	21,975	10,889	7,347	394	11,807	65,596
	1990–93	6,822	6,409	19,571	11,301	12,128	551	12,404	68,911
	2003–06	7,001	7,075	16,434	12,086	15,255	590	15,476	73,697
	2012–14	7,495	9,918	9,767	11,887	17,944	1,211	17,414	75,711
South	1962–65	7,613	319	11,212	2,930	3,727	255	5,733	31,852
	1980–83	7,371	314	8,908	3,388	4,140	502	6,587	31,366
	1990–93	7,169	196	6,580	3,830	6,776	655	7,529	32,736
	2003–06	6,613	250	5,771	4,211	5,740	655	7,798	31,193
	2012–14	7,902	210	5,595	4,755	5,455	1,294	9,790	34,966
All-India	1962–65	34,500	13,467	42,368	23,151	14,829	2,270	21,184	1,51,315
	1980–83	37,779	21,541	39,602	21,872	17,233	2,983	24,855	1,65,698
	1990–93	38,828	21,946	31,400	24,310	22,453	3,376	27,011	1,68,817
	2003–06	38,913	24,147	26,926	20,846	23,973	3,648	34,744	1,73,718
	2012–14	39,616	27,965	23,304	20,973	26,530	5,019	35,852	1,79,260

(1) Tables 5 and 6 are based on calculations that are an update of the pioneering work of Bhalla and Singh (2009) extended till 2012–14 based on Indian agricultural statistics.

(2) As in Bhalla and Singh (2009), in these calculations, all states of the North East, except Assam, are excluded and only the 44 major crops are included.

(3) North-west: Haryana, Himachal Pradesh, erstwhile Jammu and Kashmir, Uttar Pradesh and Uttarakhand; East: Assam, Bihar, Odisha, Jharkhand, West Bengal; Central: Chhattisgarh, Gujarat, Madhya Pradesh, Maharashtra, Rajasthan; South: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Telangana.

Table 6: All-India and Region-wise Distribution of Cropped Area

(%)

Region	Period	Rice	Wheat	Nutri-cereals	Pulses	Oilseeds	Sugar Cane	Others	Total
North-west	1962–65	15	20	23	21	12	5	3	100
	1980–83	19	34	16	11	11	5	5	100
	1990–93	21	35	12	9	6	5	12	100
	2003–06	23	37	10	7	5	6	13	100
	2012–14	25	39	8	6	4	6	12	100
East	1962–65	57	3	7	14	3	1	16	100
	1980–83	56	7	7	12	6	1	12	100
	1990–93	55	7	5	10	6	1	16	100
	2003–06	54	8	4	6	5	2	21	100
	2012–14	59	9	4	5	5	1	16	100
Central	1962–65	10	9	36	16	11	0	17	100
	1980–83	10	10	34	17	11	1	18	100
	1990–93	10	9	28	16	18	1	18	100
	2003–06	10	10	22	16	21	1	21	100
	2012–14	10	13	13	16	24	2	23	100
South	1962–65	24	1	35	9	12	1	18	100
	1980–83	24	1	28	11	13	2	21	100
	1990–93	22	1	20	12	21	2	23	100
	2003–06	21	1	19	14	18	2	25	100
	2012–14	23	1	16	14	16	4	28	100
All India	1962–65	23	9	28	15	10	2	14	100
	1980–83	23	13	24	13	10	2	15	100
	1990–93	23	13	19	14	13	2	16	100
	2003–06	22	14	16	12	14	2	20	100
	2012–14	22	16	13	12	15	3	20	100

Same as Table 5.

dramatically in all parts of India. Even in absolute terms, the acreage under these cereals has almost halved between 1962–65 and 2012–14. The share of pulses has also drastically come down in Assam, Bihar, Haryana, Himachal Pradesh, erstwhile Jammu and Kashmir, Jharkhand, Odisha, Uttar Pradesh, Uttarakhand and West Bengal. The share of oilseeds appears to have risen, but that is mainly on account of the rise in acreage under soya.¹⁶ Figure 4 (p 45) shows that the share of soya bean in oilseeds acreage rose from less than 1% in the early 1970s to over 40% in 2016–17, even as the share of the other eight oilseeds has stagnated. Other than soya bean, the only other crops showing a rise in acreage during the period of the green revolution are wheat, rice, and sugar cane.

The rise in the acreage of wheat and rice is a direct consequence of the procurement and price support offered by the state. In the case of sugar cane and soya bean, the rise in acreage is due to the purchase by sugar mills and soya factories. But the main story of the green revolution is the story of rice and wheat, which remain the overwhelming majority of crops procured by the government even today, even after a few states have taken tentative steps towards diversification of their procurement basket to include nutri-cereals and pulses (Table 7, p 47). What is worse, public procurement covers a very low proportion of India's regions and farmers (Khera et al 2020).

This also reflects the fact that the primary target of procurement is the consumer, not so much the farmer. Thus, procurement gets limited to what is needed to meet the requirements of consumers. This showed up in the way imports of pulses were ramped up during 2016–18, even though it had been decided to try and expand procurement of pulses. The latter suffered as a result and pulse growers were the losers. Thus, the pathway for reforms becomes very clear: we need to greatly expand the basket of public procurement to include more crops, more regions, and more farmers.¹⁷ By doing so, we can make a huge dent in solving India's water problem while at the same time tackling farmer distress and India's nutritional crisis.

Paradigm Shift for Agriculture

Crop diversification as per agroecology: A recent study supported by the National Bank for Agriculture and Rural Development (NABARD)

and Indian Council for Research on International Economic Relations (ICRIER) estimated that about 78% of India's water is consumed in agriculture (Sharma et al 2018). FAO's AQUASTAT database puts this figure closer to 90% (FAO 2019). The NABARD-ICRIER study identified three "water guzzler" crops—rice, wheat and sugar cane—which occupy about 41% of the gross cropped area and consume more than 80% of irrigation water. Shah (2019) suggests that sugar cane, which occupies just 4% of cropped area, uses up 65% of irrigation water in Maharashtra. In Karnataka, rice and sugar cane, which cover 20% of cropped area, consume as much as 70% of irrigation water (Karnataka Knowledge Commission 2019). This has meant grave inequity in the distribution of irrigation water across crops and farmers, and also a terrible mismatch between existing water endowments and the water demanded by these water-guzzling crops. The main reason why farmers grow such crops, even in areas of patent water shortage, is the structure of incentives, as they find that these crops have steady markets. Even a small reduction in the area under these crops, in a region-specific manner and in a way that does not endanger food security, would go a long way in addressing India's water problem.

Table 7: Share of Crops in Public Procurement, 2007–19 (%)

Year	Rice	Wheat	Nutri-cereals	Pulses	Total
2007–08	70	29	1	0	100
2008–09	58	40	2	0	100
2009–10	52	41	7	0	100
2010–11	53	45	2	0	100
2011–12	55	44	1	0	100
2012–13	47	52	1	0	100
2013–14	55	43	2	0	100
2014–15	53	46	1	1	100
2015–16	55	45	0	0	100
2016–17	61	36	0	3	100
2017–18	54	44	0	2	100
2018–19	37	58	0	5	100

Source: DAC (2018).

Thus, the first element of the paradigm shift required in Indian agriculture is to change this distorted structure of incentives. The most important step in this direction is for the government to diversify its crop procurement operations in a carefully calibrated, location-specific manner, to align with local agroecologies. The best way of doing this is to start procurement of crops that match the agroecology of each region.

India's cropping pattern before the green revolution included a much higher share of millets, pulses, and oilseeds. These agroecologically appropriate crops must urgently find a place in public procurement operations. As this picks up pace, farmers will also gradually diversify their cropping patterns in alignment with this new structure of incentives. The largest outlet for the millets, oilseeds, and pulses procured in this manner would be the supplementary nutrition and meals provided under the Integrated Child Development Services (ICDS) and Mid Day Meal scheme, as also the grains provided through the PDS.

A few state governments are also slowly moving forward in this direction. The Odisha Millets Mission initiated in 2017–18

works on four verticals—production, processing, marketing and consumption—through a unique institutional architecture of partnerships with academia and civil society. By 2020–21, the programme has spread across 76 blocks in 14 districts with a target of reaching 1,00,000 farmers to cultivate millets. The *mandia* laddoos prepared by women's self-help groups (SHGs) under Mission Shakti and introduced under the ICDS have proved extremely popular among preschool children (Jena and Mishra 2021). Reports from the ground in 2020 speak of the overwhelming enthusiasm, especially among hitherto typically excluded tribal farmers, who rode horses and mules, to wade through rivers and cross multiple hills to reach government procurement centres (personal interview, Dinesh Balam 2020).

A similar noteworthy example is that of the tribal-dominated Dindori district in Madhya Pradesh, a malnutrition hotspot in recent decades. Here, a state-civil society partnership has led to a revival in the cultivation of Kodo (Dutch millet) and Kutki (little millet), which are renowned for their anti-diabetic and nutritional properties. The Government of Madhya Pradesh's Tejaswini Rural Women's Empowerment Programme helped women's SHG federations develop a business plan for establishing a supply chain of Kodo bars and burfis, which were included in the ICDS. The products were clinically tested for their nutrient content at certified labs in Hyderabad, to ensure appropriate standards of taste and quality (Mathur and Ranjan 2021). These are the kinds of reforms and outreach all states need to pursue, with support from the centre.

Done at scale, this would enable a steady demand for these nutritious crops and help sustain a shift in cropping patterns, which would provide a corrective to the currently, highly skewed distribution of irrigation to only a few crops and farmers. It would also be a significant contribution to improved nutrition, especially for children, and a powerful weapon in the battle against the twinned curse of malnutrition and diabetes. It is quite evident that a major contributor to this "syndemic" is the displacement of whole foods in the average Indian diet by energy-dense and nutrient-poor, ultra-processed food products.¹⁸ Recent medical research has found that some millets contain significant anti-diabetic properties. According to the Indian Council of Medical Research, foxtail millet (*kangani/kakun*) has 81% more protein than rice. Millets have higher fibre and iron content, and a low glycemic index. Millets also are climate-resilient crops suited for the drylands of India. If children were to eat these nutri-cereals, India would be better placed to solve the problems of malnutrition and obesity.

To clarify, this is not a proposal for open-ended public procurement. That would be neither feasible nor desirable. The argument is for the diversification of the procurement basket to include crops suited to local agroecologies. A useful benchmark could be 25% of the actual production of the commodity for that particular year/season (to be expanded up to 40%, if the commodity is part of the PDS), as proposed under the 2018 Pradhan Mantri Annadata Aay Sanrakshan Abhiyan. Without such an initiative, the announcement of MSPs for

23 crops every year is reduced to a token ritual, with little benefit to most farmers.

Proposed Shift in Cropping Patterns

If such a switch in cropping patterns, to reflect the agroecological diversity of India, were to be effected, what volume of water would India save by 2030? We have made an attempt to quantify the water that could be saved each year in 11 major agricultural states: Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Telangana, and Tamil Nadu.¹⁹ These states together accounted for about 66% of the total irrigated area of the country in 2015–16. We quantify the baseline water used in the production of crops using the average (mean) yields and areas for each crop in each state in the most recent 10-year period for which data is available. We compare the baseline water use to two exploratory scenarios of crop replacements:

Scenario 1 (small change): Replacement of high water-demanding crops with low water-using ones to the extent of 10%–25% of the crop area in the kharif season and 25% in the rabi season; and Scenario 2 (higher change): Replacement of high water-demanding crops with low water-using ones to the extent of 25%–50% of the crop area in the kharif season and 50% in the rabi season.

Rice is the major irrigated crop in the southern states of Andhra Pradesh, Karnataka, Telangana, and Tamil Nadu, while wheat is the major irrigated crop in Bihar, Gujarat, Madhya Pradesh, and Rajasthan. Both rice and wheat are heavily irrigated in Punjab and Haryana. We explore possible crop switches in both kharif and rabi seasons. In each state, we have taken one high water-footprint crop in each season and estimated water saving by switching area under this crop to two lower water-footprint crops (Table 8).

First, we quantify baseline crop production based on recent yield and area data.²⁰ Our purpose is to build different scenarios to demonstrate the potential of water savings through crop replacements. For estimating the irrigation water use in these scenarios, we have calculated blue water footprints (BWF), which represent the volume of water consumed during crop production in cubic metre per tonne. Season and state-specific water footprints for cereal crops were drawn from Kayatz et al (2019) and for other crops from Mekonnen and Hoekstra (2011).²¹ In this method, the total evapotranspiration (ET) requirement of the crops is estimated using FAO's CROPWAT model. National- and state-specific ET for each of the crops studied is generated, which is modified by the crop factor (k) to get estimated consumptive use of water or total water footprint (TWF) by each crop in each state. The proportion of the green water footprint (GWF) is estimated by modelling effective rainfall during the season. The difference between TWF and GWF is attributed to the irrigation component or the BWF of crops.²² The BWF is multiplied by crop production, to get estimated blue water use by crops in each state in each season.²³

In these 11 states, we take the area under three most water-intensive crops, namely rice, wheat and sugar cane, and

Table 8: Crop Replacements Scenarios by State and Seasons²⁴

State	Scenario I (% Replacement)		Scenario II (% Replacement)	
	Kharif	Rabi	Kharif	Rabi
Andhra Pradesh	10	25	25	50
Bihar	10	25	25	50
Gujarat	25	25	50	50
Haryana	25	25	50	50
Karnataka	25	25	50	50
Madhya Pradesh	10	25	25	50
Maharashtra	25	25	50	50
Punjab	25	25	50	50
Rajasthan	0	25	0	50
Tamil Nadu	10	0	25	0
Telangana	10	25	25	50

redistribute the area to the replacement crops.²⁵ The replacement crops are largely pulses and nutri-cereals. The choice of the replacement crops is governed by an analysis of the cropping pattern of the concerned state in the period before the monoculture of the green revolution took firm roots there. Thus, these are crops suited to the agroecology of each region, and therefore, their revival has a solid basis in both agricultural science and farmer experience. The water savings were calculated based on the change in irrigation water required for each state in each season. Irrigation water savings are given as the difference between the water use at baseline as compared to the crop replacement scenarios. In order to make suitable and realistic proposals for crop replacements, we consider several factors.

Seasons: Crop production is strongly determined by seasons, which need to be taken into account while proposing replacements. For example, since most of the nutri-cereals are grown in the kharif season, we cannot propose a replacement of wheat (a predominantly winter crop) with nutri-cereals like jowar. Crop growing seasons for rice in Tamil Nadu are such that the proposals for replacement have to consider if the sowing and harvesting time of the replacement crops match those of rice. Similarly, for the replacement of an annual crop like sugar cane in Maharashtra, we have identified a crop sequence covering both the kharif and rabi seasons, so that the replacement of one crop is with a group of two or more crops.

Source of irrigation and extent of control over water: Crops grown in command areas of large dams are largely irrigated by the field flooding method. It is, therefore, difficult to replace rice grown in the canal commands and floodplains of rivers, like the Godavari and Krishna in Andhra Pradesh, with any other crop. However, in the non-command areas of Andhra Pradesh and Telangana, mainly the undulating and upland regions, it is possible to replace rice because the major source of irrigation here is groundwater. The situation in Punjab and Haryana is similar, since groundwater accessed through tube wells is the major source of irrigation.

Soil conditions and agronomy: Once certain crops, like rice, are continuously grown in an area, the soil conditions change

considerably so that any crop replacement may become difficult. This particularly applies to the low-lying regions of West Bengal, Odisha, and Chhattisgarh. Similarly, when intercropping is practised, there are certain crop combinations involved. So, when we propose replacement of one crop (such as soya bean in Madhya Pradesh), we need to also propose replacement of other crops in the crop mix when the intercrop does not match with the replacement crop (Table 9).

Table 9: State- and Season-specific Crop Replacements

State	Water-intensive Crop		Replacement Crop	
	Kharif	Rabi	Kharif	Rabi
Andhra Pradesh	Rice	Rice	Tur, groundnut	Gram, sesame
Telangana	Rice	Rice	Tur, jowar	Gram, sesame
Bihar	Rice	Wheat	Tur, urad	Gram, lentils
Gujarat	Cotton	Wheat	Tur, bajra	Gram, rapeseed
Haryana	Rice	Wheat	Tur, bajra	Gram, rapeseed
Karnataka	Rice	Wheat	Tur, groundnut	Gram, moong
Madhya Pradesh	Soya bean	Wheat	Maize, jowar	Gram, rapeseed
Maharashtra*	Sugar cane	Wheat	Jowar, tur	Gram, rapeseed
Punjab	Rice	Wheat	Tur, moong	Gram, rapeseed
Rajasthan**	Miscellaneous crops	Wheat	No change	Gram, rapeseed
Tamil Nadu***		Rice	Tur, Urad	

*Sugara cane is an annual crop. **We make no change in kharif in Rajasthan, as the crops are mostly already low water-consuming ones. ***In Tamil Nadu, agricultural seasons do not exactly correspond to the kharif–rabi distinction applied in the rest of the country.

Table 10: Comparison of Annual Irrigation Water under Different Crop Scenarios

State	Blue Water Use (BCM ² /Year)			Blue Water Saving (%)	
	Baseline	Scenario I	Scenario II	Scenario I	Scenario II
Andhra Pradesh	10.06	8.15	6.08	19	40
Telangana	5.46	4.33	3.12	21	43
Bihar	7.80	6.35	4.74	19	39
Gujarat	13.22	10.35	7.48	22	44
Haryana	8.39	7.42	6.38	12	24
Karnataka	1.17	0.97	0.82	17	30
Madhya Pradesh	14.92	12.16	9.40	19	37
Maharashtra	13.93	10.58	7.24	24	48
Punjab	14.26	11.58	8.26	19	42
Rajasthan	15.71	13.97	13.13	11	16
Tamil Nadu	5.45	4.95	4.20	9	23
	110.35	90.81	70.83	18	36

* BCM (billion cubic metres).

Table 10 provides a comparison of the total blue water saved in 11 states after crop replacements in Scenarios I and II, as compared to the irrigation water required to produce the water-intensive crops in the baseline scenario.

Given that water-intensive crops currently occupy over 30% of the gross irrigated area in these states, the amount of water saved annually is considerable. This water could be diverted to critical and supplementary irrigation for millions of small and marginal farmers, while also reducing the pressure on rural drinking water sources.

It can be argued that these crop replacements will result in some reduction in the total output because of differentials in yields across crops.²⁶ However, it must be borne in mind that the rapidly deteriorating water situation increasingly poses a very serious constraint to maintaining the productivity levels of water-intensive crops, especially in states like

Punjab and Haryana. An extremely important recent study has concluded that,

[G]iven current depletion trends, cropping intensity may decrease by 20% nationwide and by 68% in groundwater-depleted regions. Even if surface irrigation delivery is increased as a supply-side adaptation strategy, cropping intensity will decrease, become more vulnerable to inter-annual rainfall variability, and become more spatially uneven. We find that groundwater and canal irrigation are not substitutable and that additional adaptation strategies will be necessary to maintain current levels of production in the face of groundwater depletion. (Jain et al 2021: 1)

Hence, it would be fallacious to assume that output levels of water-intensive crops could be sustained indefinitely in heavily groundwater-dependent states, like Punjab and Haryana. At the same time, our proposal is for aligning cropping patterns with regional agroecology and that includes raising the share of eastern India in the national output of water-intensive crops, like rice. Ironically, even though this region has abundant water resources, it depends on groundwater-scarce regions for its supply of foodgrains. It has been correctly pointed out that “eastern states which are safe in their groundwater reserves and net importers, also have the highest yield gaps and therefore the greatest unmet potential to increase production” (Harris et al 2020: 9). Raising the share of rice procured from eastern India would greatly help a move in this direction, as would tweaking electricity tariffs there (Sidhu et al 2020). We must also clearly recognise that food stocks over the last decade have greatly exceeded the “buffer norm,” which is around 31 million tonnes for wheat and rice. Indeed, even after all the additional drawals following the COVID-19 pandemic, the central pool still had 63 million tonnes in stock in October 2020 (Husain 2020).²⁷

Moreover, the nutritional content of the crop mix we are proposing is definitely superior. Increasing the consumption of nutri-cereals over rice and wheat could reduce iron-deficiency anaemia, while the increased consumption of pulses could reduce protein–energy malnutrition (DeFries et al 2018). The

Table 11: All-India Weighted Average Wholesale Prices, October 2018

Crops	Weighted Average Annual Wholesale Price (₹/quintal)	
	Water-intensive crops	Replacement crops
Sugar	3,563	
Rice	2,030	
Wheat	1,889	
Cotton	5,394	
Soya bean	2,979	
Moong		4,774
Gram		3,862
Urad		3,740
Masoor		3,723
Arhar		3,687
Ragi		2,256
Jowar		1,993
Bajra		1,478
Maize		1,315
Sesamum		10,961
Groundnut		4,249
Rapeseed		3,817

Source: Ministry of Agriculture and Farmers Welfare, published as Answers Data of Session 246, 247 and 248 of Rajya Sabha, Parliament of India.

impact on farmers' incomes is also likely to be positive both because of lower input requirements and costs of production associated with our crop mix, as also higher wholesale prices for the replacement crops. The average wholesale price in 2018 for the water-intensive crops was ₹3,171/quintal, compared to ₹3,821/quintal for the replacement crops (Table 11, p 49). Further analysis is required to understand the impact of these changes at the state level, but these data indicate that if steady demand for the replacement crops can be ensured, farmer incomes would not be impacted negatively, even as national nutritional and water security are both advanced through this change. What would help significantly is more emphasis on research and development (R&D) in the replacement crops, stronger farmer extension support for them, as also expanded procurement, and higher price support in order to create the right macroeconomic environment for crop replacement.²⁸

Return to Polycultural Biodiversity

Farming faces twin uncertainties, stemming from the market and the weather. For such a risky enterprise to adopt monoculture is patently suicidal.²⁹ But that is what the green revolution has moved Indian farming towards: more and more land under one crop at a time and year-on-year production of the same crop on the same land. This reduces the resilience of farm systems to weather and market risks, with even more grave consequences in this era of rapid climate change and unpredictable patterns of rainfall. Climate models project an increase in the frequency, intensity, and area under drought conditions in India by the end of the 21st century (Krishnan et al 2019). The persistence of monoculture makes India even more vulnerable to disruptions from climate change and extreme weather events, for it has by now been conclusively established that

[C]rops grown under "modern monoculture systems" are particularly vulnerable to climate change as well as biotic stresses ... what is needed is an agroecological transformation of monocultures by favoring field diversity and landscape heterogeneity, to increase the productivity, sustainability, and resilience of agricultural production ... Observations of agricultural performance after extreme climatic events in the last two decades have revealed that resiliency to climate disasters is closely linked to farms with increased levels of biodiversity. (Altieri et al 2015: 3)

The vast monocultures that dominate 80% of the 1.5 billion hectares of arable land are one of the largest causes of global environmental changes, leading to soil degradation, deforestation, depletion of freshwater resources, and chemical contamination. (Altieri and Nicholls 2020: 2)

It has also been shown that plants grown in genetically homogeneous monocultures lack the necessary ecological defence mechanisms to withstand the impact of pest outbreaks. Francis (1986) summarises the vast body of literature documenting lower insect pest incidence and the slowing down of the rate of disease development in diverse cropping systems compared to corresponding monocultures. Vandermeer (1989) provides innumerable instances of how intercropping enables farmers to minimise risk by raising various crops simultaneously. Natarajan and Willey (1986) show how polycultures (intercrops of sorghum [jowar] and peanut, millet and peanut, and sorghum and millet) had greater yield stability

and showed lower declines in productivity during a drought than monocultures.

Most recently, the largest ever attempt in this direction (Tamburini et al 2020) has included a review of 98 meta-analyses and a second-order meta-analysis based on 5,160 original studies comprising 41,946 comparisons between diversified and simplified practices. They conclude:

Enhancing biodiversity in cropping systems is suggested to promote ecosystem services, thereby reducing dependency on agronomic inputs while maintaining high crop yields. Overall, diversification enhances biodiversity, pollination, pest control, nutrient cycling, soil fertility, and water regulation without compromising crop yields. (Tamburini et al 2020: 1)

A recent report of the FAO's Commission on Genetic Resources for Food and Agriculture also brings out the key role of biodiversity in sustaining crop production:

The world is becoming less biodiverse and there is good evidence that biodiversity losses at genetic, species and ecosystem levels reduce ecosystem functions that directly or indirectly affect food production, through effects such as the lower cycling of biologically essential resources, reductions in compensatory dynamics and lower niche occupation. (Dawson et al 2019: 6)

Moreover, as a recent study of agrobiodiversity in India argues, "when we lose agricultural biodiversity, we also lose the option to make our diets healthier and our food systems more resilient and sustainable" (Thomson et al 2020: 611). It is, thus, clear how a move away from monoculture towards more diverse cropping patterns would increase resilience against climate and market risks, while also reducing water consumption, without compromising productivity.

Rejecting the Originative Flaw

The fundamental question that needs to be raised about the green revolution is its overall strategy, its conception of the agricultural production system in general, and of soils in particular. The overarching strategy was one of "betting on the strong," which meant focusing investment and support on farmers, regions, and crops that were seen as most likely to lead to an increase in output (Tomlinson 2013). It was a "commodity-centric" vision, where the idea was to deploy such seeds as it would maximise output per unit area, given the right doses of fertilisers and pesticides. The amount of chemical nutrients applied demanded correspondingly larger inputs of water, which, in turn, made the resultant ecosystem extremely favourable to the profusion of pests, which threatened output unless pesticides were utilised to kill them.

This is a perspective that exclusively focuses on productivity (output/area) of a given crop by specifically targeting soil nutrients or pest outbreaks (Hecht 1995). Such a view is atomistic, and assumes that "parts can be understood apart from the systems in which they are embedded and that systems are simply the sum of their parts" (Norgaard and Sikor 1995: 22). It is also mechanistic, in that relationships among parts are seen as fixed, changes as reversible, and systems are presumed to move smoothly from one equilibrium to another. Such a view ignores the fact that, often, parts

cannot be understood separately from their wholes and that the whole is different (greater or lesser) than the sum of its parts. It also overlooks the possibility that parts could evolve new characteristics or that completely new parts could arise (what is termed as “emergence” in soil science literature) (Addiscott 2010; Falconer et al 2012; Baveye et al 2018). As Lent (2017: 370) argues,

Because of the way a living system continually regenerates itself, the parts that constitute it are in fact perpetually being changed. It is the organism's dynamic patterns that maintain its coherence ... This new understanding of nature as a self-organized, self-regenerating system extends, like a fractal, from a single cell to the global system of life on Earth.

On the other hand, in the green revolution vision, soil was seen essentially as a stockpile of minerals and salts, and crop production was constrained as per Liebig's Law of the Minimum—by the nutrient least present in the soil. The solution was to enrich the soil with chemical fertilisers, where the soil was just a base with physical attributes necessary to hold roots: “Crops and soil were brute physical matter, collections of molecules to be optimized by chemical recipes, rather than flowing, energy-charged wholes” (Mann 2018: 2578).

Thus, the essential questions to be posed to a continued blind adherence to the green revolution approach, in the face of India's growing farm and water crises, are: (i) Is the soil an input–output machine, a passive reservoir of chemical nutrients, to be endlessly flogged to deliver, even as it shows clear signs of fatigue? (ii) Or is it a complex, interacting, living ecosystem to be cherished and maintained so that it can become a vibrant, circulatory network, which nourishes the plants and animals that feed it? (iii) Will a toxic, enervated ecosystem with very poor soil quality and structure, as also gravely fallen water tables, be able to continue to support the agricultural production system?

In the words of Rattan Lal, the Indian–American soil scientist, winner of the 2020 World Food Prize:

The weight of living organisms in a healthy soil is about 5 tonne per hectare. The activity and species diversity of soil biota are responsible for numerous essential ecosystem services. Soil organic matter content is an indicator of soil health, and should be about 2.5% to 3.0% by weight in the root zone (top 20 cm). But soil in Punjab, Haryana, Rajasthan, Delhi, Central India and southern parts contains maybe 0.5% or maybe 0.2%. (Bera 2020)

According to FAO, generating 3 cm of top soil takes 1,000 years, and if current rates of degradation continue, all of the world's top soil could be gone within 60 years (Arsenault 2014). Lal favours compensation for farmers through payments (around ₹1,200 per acre per year) for soil protection, which he regards as a vital ecosystem service (Grewal Sharma 2020).

It is important to understand the key relationship between soil quality and water productivity and recognise that every land-use decision is also a water-use decision (Bossio et al 2008). Lal (2012) explains how soil organic matter (SOM) affects the physical, chemical, biological, and ecological qualities of the soil. In physical terms, higher SOM improves the water infiltration rate and the soil's available water-holding capacity.

Chemically, it has a bearing on soil's capacity to buffer against pH, as also its ion-exchange and cation-exchange capacities, nutrient storage and availability, and nutrient-use efficiency. Biologically, SOM is a habitat and reservoir for the gene pool, for gaseous exchange between the soil and the atmosphere, and for carbon sequestration. Ecologically, SOM is important in terms of elemental cycling, ecosystem carbon budget, filtering of pollutants, and ecosystem productivity.³⁰

A recent overview of global food systems rightly points to the “paradox of productivity:”

[A]s the efficiency of production has increased, the efficiency of the food system as a whole—in terms of delivering nutritious food, sustainably and with little waste—has declined. Yield growth and falling food prices have been accompanied by increasing food waste, a growing malnutrition burden and unsustainable environmental degradation. (Benton and Bailey 2019: 3)

Benton and Bailey (2019: 7) urge policymakers to move from the traditional preoccupation with total factor productivity towards total system productivity (TSP):

A food system with high TSP would be sufficiently productive (to meet human nutritional needs) whilst imposing few costs on the environment and society (so being sustainable), and highly efficient at all stages of the food chain so as to minimise waste. It would optimise total resource inputs (direct inputs and indirect inputs from natural capital and healthcare) relative to the outputs (food utilisation). Maximising TSP would maximize the number of people fed healthily and sustainably per unit input (direct and indirect). In other words, it would increase overall systemic efficiency.

In light of this understanding, attempts are being made all over the world to foster an ecosystem approach, with higher sustainability and resilience, lower costs of production, as also economy in water use, along with higher moisture retention by the soil. Broadly, these alternatives to the green revolution paradigm come under the rubric of agroecology. In the latest quadrennial review of its Strategic Framework and Preparation of the Organization's Medium-term Plan, 2018–21, the FAO states:

High-input, resource-intensive farming systems, which have caused massive deforestation, water scarcities, soil depletion and high levels of greenhouse gas emissions, cannot deliver sustainable food and agricultural production. Needed are innovative systems that protect and enhance the natural resource base, while increasing productivity. Needed is a transformative process towards “holistic” approaches, such as agro-ecology and conservation agriculture, which also build upon indigenous and traditional knowledge.

Hecht (1995: 4) provides an excellent summary of the philosophy underlying agroecology:

At the heart of agro-ecology is the idea that a crop field is an ecosystem in which ecological processes found in other vegetation formations such as nutrient cycling, predator/prey interactions, competition, commensalism, and successional changes also occur. Agro-ecology focuses on ecological relations in the field, and its purpose is to illuminate the form, dynamics, and function of these relations (so that ... agro-eco-systems can be manipulated to produce better, with fewer negative environmental or social impacts, more sustainably, and with fewer external inputs.

Anderson et al (2021: 2) sum up key features of the approach embodied by agroecology:

Over the past five years, the theory and practice of agroecology have crystallized as an alternative paradigm and vision for food systems.

Agroecology is an approach to agriculture and food systems that mimics nature, stresses the importance of local knowledge and participatory processes and prioritizes the agency and voice of food producers. As a traditional practice, its history stretches back millennia, whereas a more contemporary agroecology has been developed and articulated in scientific and social movement circles over the last century. Most recently, agroecology—practised by hundreds of millions of farmers around the globe—has become increasingly viewed as viable, necessary and possible as the limitations and destructiveness of “business as usual” in agriculture have been laid bare.

In India, a large number of such alternatives have emerged over the past two decades. These include natural farming, non-pesticide-managed agriculture, organic farming, conservation agriculture, low external input sustainable agriculture, etc. But they all share a common base of agroecological principles, rooted in the local context. Recently, some state governments have given a big push to this movement. The biggest example is that of the Community Managed Natural Farming programme of the Government of Andhra Pradesh (GoAP), beginning 2016.³¹ Crop-cutting experiments by the state agriculture department claim higher than average yields, reduced costs and higher net incomes for “natural” farmers compared to “non-natural” farmers, in all districts and for all crops. Encouraged by the results, the GoAP has now resolved to cover the entire cultivable area of 80 lakh hectares in the state by 2027 (Kumar 2020). These agroecological alternatives embody a paradigm shift in farming and have a crucial role to play in redressing both farmer distress and India’s worsening water crisis.

State Support for the Shift

Clearly, there is robust scientific support for exploring alternatives to green revolution farming, which needs to be an essential part of the response to both the crises of water and agriculture

in India. However, there is also a need to make a strong argument against any kind of fundamentalism on both sides. Those who insist on business-as-usual are being fundamentalist and irresponsible because they are turning a blind eye to the distress of India’s farmers and the grave water crisis in the country. On the other hand, it is also important that those working for alternatives adopt procedures for transparent verification and evaluation of their efforts. What is more, these efforts will need multiple forms of support from the government, similar to the multipronged approach adopted at the time of the green revolution.

First, the soil testing capacities of the entire country need to be urgently and comprehensively ramped up. This means not only establishing more soil-testing laboratories, but also testing on a much wider range of parameters, based on the “living soils” vision, where testing is extended to the 3 ms (moisture, organic matter and microbes). This will make it possible to assess over time whether the claims of different farming approaches can be validated as being truly “regenerative” and for an assessment to be made about the kinds of interventions that may or may not be required in each specific context.

Second, widespread and affordable facilities must be made available for testing the maximum residue level of chemicals in farm produce, in line with government food safety regulations, without which there will be no guarantee that the produce meets required health safety standards.

Third, this also requires large-scale and separate processing, storage and transport facilities for the produce of “natural farmers” so that it does not get contaminated by the produce of conventional chemical farmers. Storage of pulses needs careful attention to moisture and temperature. Dry and cool pulses can be stored for longer periods. This demands major investments

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in new technologies that are now easily available. For crops like millets, processing remains an unaddressed challenge. Therefore, millet-processing infrastructure needs to become a priority, to incentivise farmers to move to water-saving crops and also to move them up the value chain.

Fourth, the present farm input subsidy regime that incentivises production with a high intensity of chemical inputs must shift to one that supports the production of organic inputs and provides payment for farm ecosystem services, like sustainable agriculture practices, improving soil health, etc. This can, in fact, become a way to generate rural livelihoods, especially if the production of organic inputs could be taken up at a large scale by federations of women SHGs and farmer producer organisations.

Fifth, the SHG-bank linkage would also be crucial in order to ensure that credit actually reaches those who need it the most and whose dependence on usurious rural moneylenders grew after strict profitability norms were applied to public sector banks in 1991 (Shah 2007). Shah (2007) explains how SHGs, led by women, enable these banks to undertake sound lending, rather than the botched-up, target-driven lending of the Integrated Rural Development Programme in the years following bank nationalisation. The SHG-Bank Linkages Programme has not only benefited borrowers, but has also improved the profitability of many bank branches in rural and remote areas,

thus mitigating the inclusion-profitability dilemma that afflicted public sector banks in the first three decades after nationalisation. As a result, formal rural credit has, once again, made a comeback during the last decade, after a period of decline in the 1990s and early 21st century. Such credit support will be crucial if the paradigm shift in farming proposed in this paper is to be scaled up on the ground.

Finally, the entire agricultural extension system needs to be rejuvenated and revamped, to make it align with this new paradigm. Special focus must be placed on building a whole army of community resource persons, farmers trained in all aspects of agroecology to be ambassadors of this fresh perspective and understanding, working in a truly “rhizomatic” manner, allowing for multiple, non-hierarchical points of knowledge representation, interpretation and sharing.³²

Thus, to carry forward the agroecological revolution in India, there is a need for an overarching architecture very similar to the one that propelled the green revolution in its heyday, even though each of its constitutive elements would be radically different. It is only if the pattern of subsidies is changed and these reforms are put in place by the government that the paradigm shift in farming proposed in this paper will be able to take off in real earnest. Otherwise, doubts about its authenticity and power could remain.

NOTES

- 1 See especially Subramanian (2015). Stone (2019) provides a good summary of the emerging work.
- 2 Cullather (2010, Chapter 8) brilliantly teases out how the view that “only chemical fertiliser and birth control could keep mankind off a treadmill to starvation” became dominant in the 1960s, pushing for support to the green revolution as the only way to save India from self-destructing through famine.
- 3 Especially distressing was the introduction of the “short-tether” policy in 1965–66 by the Lyndon Johnson administration, which refused to commit PL-480 wheat shipments to India more than one month in advance (Tomlinson 2013).
- 4 How politically invested the US was in the green revolution is quite evident from this articulation by the person who coined the term: “These developments in the field of agriculture contain the makings of a new revolution. It is not a violent Red Revolution like that of the Soviets, nor is it a White Revolution like that of the Shah of Iran. I call it the Green Revolution.” From *The Green Revolution: Accomplishments and Apprehensions*, address by William S Gaud, Administrator, US Agency for International Development, 8 March 1968. How a broad-based political consensus cutting across ideological divisions emerged in the US in the 1960s around the view that “economic development represented the primary defense against an evolving communist strategy of subversion and economic penetration” (p 154), has been well documented in Cullather (2010).
- 5 This proposition is debatable because it is based on deeply problematic assumptions: that alternatives to the green revolution necessarily require more land to produce the same output and that the implications of green revolution farming for ecology, resilience, income stability, and health, are small enough to be ignored.
- 6 There were, undoubtedly, many problems in the manner in which rural credit was handled, which will be dealt with when we describe the paradigm shift required in the architecture of the green revolution.
- 7 The Foodgrains Prices Committee (1964) recommended the setting up of the FCI “to enable the government to undertake trading operations through which it can influence the market prices.” Minimum support prices were to be recommended by the Agricultural Prices Commission, also set up in 1965. With this, another objective was added to the food security system: “to guarantee reasonable prices to the farmers and thereby increase production” (Mooij 1998).
- 8 There were, of course, many limitations in the nature and scope of the procurement operations, which we will describe in the elaboration of the new paradigm.
- 9 This is food security defined narrowly as having sufficient buffer stocks to ward off any unexpected price surge following shortfalls in production. This food security is very different from nutritional security, which does not exist even today, which is also why we are advocating a paradigm shift in agriculture.
- 10 This data comes from the National Crime Records Bureau, as dying by suicide still remains a crime under Indian law.
- 11 Even at low concentration, pesticides exert several adverse effects that may manifest at biochemical, molecular or behavioural levels. The actual transport, presence and impact are, of course, influenced by drainage, rainfall, microbial activity, soil temperature, treatment surface, application rate, as well as the solubility, mobility and half-life of individual pesticides.
- 12 It has also been correctly pointed out that in tackling hunger what matters is not just the size of the buffer stock but its distribution among those who remain in need of it. In July 2020, the buffer stock reached 100 million tonnes but cereal distribution under the PDS and other welfare schemes has been only around 60 million tonnes in 2020–21 (Dreze 2021).
- 13 A new joint study by the Oxford and Lancaster universities, BITS Pilani and Bocconi University, Italy, shows that “there was no evidence that receipt of PDS rice and sugar was associated with improvements in child nutrition” (Bartell et al 2020).
- 14 Even globally, around 60% of all the plant calories and proteins come from just three grass crops—rice, maize and wheat—even though the FAO claims that at least 30,000 of the 3,50,000 known plant species on our planet are edible (Miller 2021).
- 15 The Government of India (GoI) took a historic decision in 2018 of renaming traditional cereals as “nutri-cereals,” dispensing with the long-standing nomenclature, which described them as “coarse cereals,” with an implicit inferior status (*Financial Express* 2018).
- 16 See Vijayshankar (2016) for an account of how state support played a crucial role in pushing the “soya-wheat revolution” in Madhya Pradesh.
- 17 The experience of the Pradhan Mantri Garib Kalyan Anna Yojana in 2020 has demonstrated the possibilities and power of expanding pulses in the PDS (Dreze 2021).
- 18 A 2019 report by the Lancet Commission, “The Global Syndemic of Obesity, Undernutrition, and Climate Change,” draws attention to this phenomenon. See also Gulati and Misra (2014).
- 19 The basic data on yield, area under cropping, and production is derived from the database of the DAC, GoI.
- 20 We use time-series data for 2008–17, the latest 10-year period for which data from the DAC (2020) is available for each selected crop in each season. Area multiplied by yield gives estimates of crop production.
- 21 Their data is for the period 1996–2005, which is the most recent available estimate for

non-cereal crops at the state level. These figures have not been updated as this would require a substantial analysis, beyond the scope of this paper. Nevertheless, our analysis provides a meaningful order of magnitude of the change in water use that can be achieved through this shift in cropping pattern.

- 22 It is assumed that crops are irrigated only to meet the ET requirement and there is no over-irrigation. To the extent that the farmer has no direct way of measuring ET or predict rainfall, this would lead to an underestimation of the actual water use by farmers.
- 23 Not all water footprints are seasonal—only those from cereals are. ET/yield changes and their effect on crop water requirements have not been modelled. Baseline for water savings assumes no change in the adoption of water-saving technology.
- 24 The percentage shift in crop area in kharif and rabi varies between different states. Here, we have considered the difficulty of replacing a major irrigated crop like rice in the southern Indian states, where it also happens to be the main staple crop of the area. We have also considered the possibility that in the waterlogged areas of north Bihar, nothing else except rice can grow, and hence, replacing it would be difficult. In such situations, we have reduced the area shift from 25% and 50% in Scenarios I and II to 10% and 25% respectively.
- 25 We keep the sum of the water-intensive and replacement crops area constant.
- 26 What is encouraging, however, is that in recent times, the productivity of nutri-cereals has been going up because of which despite a sharp reduction in the acreage under nutri-cereals, their production has not declined. This is a positive sign leading us to believe that with greater R&D investments in nutri-cereals, their productivity can be further improved.
- 27 So much so that India has been a major exporter of rice in recent years and may now be also expanding its wheat exports substantially (Damodaran 2021).
- 28 It is encouraging to note that recent increases in MSPs have tended to favour our replacement crops and not so much rice and wheat.
- 29 In complex organic systems, there is always a trade-off between efficiency and robustness (Csete and Doyle 2002).
- 30 Several studies have documented the depletion of soil organic matter and organic carbon in the soils of north-west India after the adoption of the green revolution (Pal et al 2009; Chauhan et al 2012; Ghosh et al 2017).
- 31 Initially called Zero Budget Natural Farming, this label, suggestive of a certain kind of fundamentalism and exaggeration, has now been dropped.
- 32 A “rhizome has no beginning or end; it is always in the middle, between things, interbeing, *intermezzo*” (Deleuze and Guattari 1987).

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