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Water and Agricultural Transformation in India
A Symbiotic Relationship -- I[1]

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This is the first part of a paper (in two parts) in which we present the argument for twin propositions: (a) that solving India's water problem requires a paradigm shift in agriculture (Part I) and (b) 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 percent of India's water and just three water-intensive crops continue to use 80 percent of agricultural water, basic water needs of millions of people, for drinking water or protective irrigation, cannot be met. The paper outlines the constituent elements of each of the existing paradigms of water and agriculture, explains why they need to be transformed and then describes the nature of the paradigm shift required in both areas.

The first part of the paper argues that the paradigm shift in agriculture requires shifting cropping patterns towards crops suited to each agro-ecological region, a movement from monoculture to poly-cultural crop bio-diversity, a decisive move towards agro-ecological farming and greater emphasis on soil rejuvenation. The second part of the paper will outline the paradigm shift needed in water.

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 on-going 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.

I. Green Revolution: context and achievements

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[1] This is the first part of the revised version of a paper originally commissioned by the Food and Agriculture Organisation and presented at the National Dialogue *Indian Agriculture Towards 2030* organised by the NITI Aayog in January 2021. We are extremely thankful to Jean Dreze for taking out time to give us detailed comments on the paper.

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Recent revisionist scholarship[5] 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.[6] At the same time, there is also no denying that the Indian political leadership was deeply troubled by excessive dependence on wheat shipments under the PL-480 Food Aid Program of the United States.[7] We cannot overlook the fact that 90 percent 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 percent even during the period from 1961 to 1965. In 1965-66, the United States of America 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 percent 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.[8]

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 3 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 (Dreze, 2021). The single most important fact worth noting here is that in the early 1970s 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

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[5] See especially Subramanian (2015). Stone (2019) provides a good summary of the emerging work.

[6] 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.

[7] 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).

[8] How politically invested the United States of America 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 United States of America 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).

risen steadily with the cropping intensity growing from 119 percent to 140 percent (Table 2).

Table 1: Food grain 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: DAC. 2020. https://eands.dacnet.nic.in

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.[9]

Table 2: All-India net sown area and gross cropped area, 1950-2015

Period	Net Sown Area (‘000 ha)	Gross Cropped Area (‘000 ha)	NSA/TGA (%)	GCA/TGA (%)	GCA/NSA (cropping intensity) (%)
1950-51 to 1954-55	123 248	137 874	37	42	112
1955-56 to 1959-60	130 770	149 418	40	45	114
1960-61 to 1964-65	135 908	156 387	41	48	115
1965-66 to 1969-70	137 863	159 632	42	49	116
1970-71 to 1974-75	139 587	165 438	42	50	119
1975-76 to 1979-80	140 993	171 051	43	52	121
1980-81 to 1984-85	141 467	175 604	43	53	124
1985-86 to 1989-90	139 759	178 031	43	54	127
1990-91 to 1994-95	142 505	185 650	43	56	130
1995-96 to 1999-00	142 178	189 401	43	58	133
2000-01 to 2004-05	139 073	185 602	42	56	133
2005-06 to 2009-10	140 614	192 971	43	59	137
2010-11 to 2014-15	140 806	197 405	43	60	140

Source: DAC. 2020. https://eands.dacnet.nic.in

Note: TGA: total geographical area

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[9] 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.

II. Constituent elements of the Green Revolution paradigm

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:

i. **Higher-yielding seeds and concomitant use of chemical fertilizers and pesticides:** The consumption of fertilizers rose dramatically from 2 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).

Table 3: Fertilizer consumption in India, 1950-2019

Year	Fertilizer 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. www.faidelhi.org/general/con-npk.pdf

Table 4: Synthetic Pesticide Consumption in India, 2001-2020

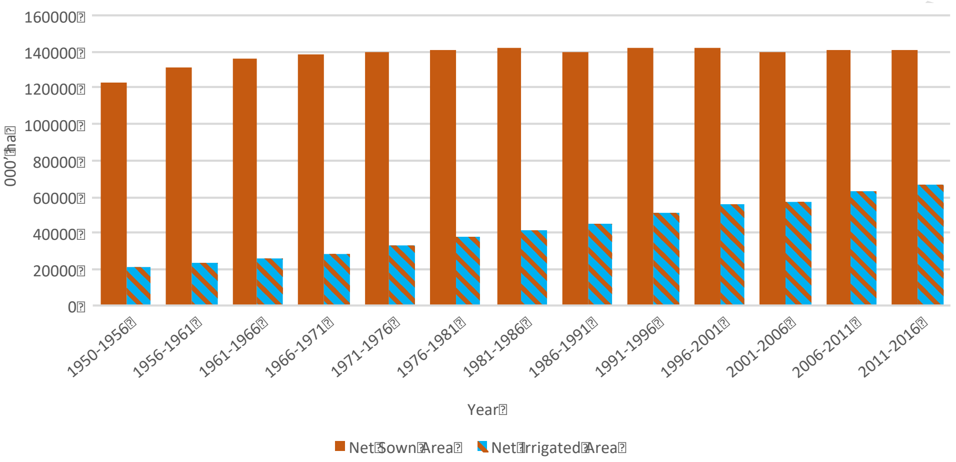
Period	Consumption (‘000 tonnes)
2001-04	45.46
2004-07	41.28
2007-10	42.44
2010-13	51.38
2013-16	56.84
2016-19	60.46
2019-20	60.56

Source: Agricultural Statistics at a Glance, 2019 for 2001-19; Directorate of Plant Protection, Quarantine and Storage, Department of Agriculture and Co-operation for 2019-20

ii. **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 her 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 tubewells, 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 that the crops require it.

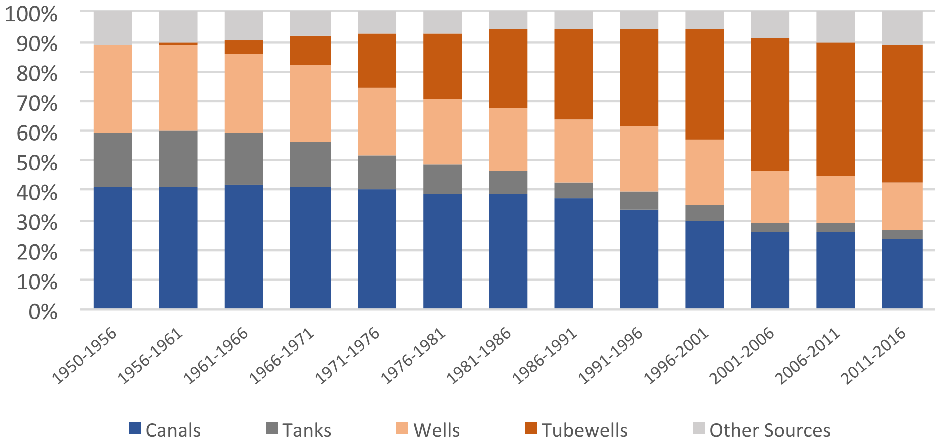
Over the last four decades, around 84 percent of total addition to the net irrigated area has come from groundwater. At 250 billion cubic metres (BCM), India draws more groundwater every year than any other country in the world. India’s annual consumption is more than that of China and the United States of America (the second and third largest groundwater using countries) put together (Vijayshankar, Kulkarni and Krishnan, 2011).

Figure 1: All-India net sown and net irrigated area, 1950-2016



Source: DAC, 2020. https://eands.dacnet.nic.in

Figure 2: All-India percentage of irrigation from different sources, 1950-2016



Source: DAC, 2020. https://eands.dacnet.nic.in

Note: “Other Sources” largely include groundwater sources, such as dug-cum-borewells. Hence, groundwater could well be said to account for nearly 70 percent of irrigation today

iii. **Easier availability of credit:** The access to seeds, fertilizers, 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 re-privatisation overlook the fact that before nationalisation not even 1 percent of India's villages were served by commercial banks. Furthermore, the share of banks in rural credit was no more than 2.4 percent, with most of these loans being made to plantations, not farmers. It is the easier availability of credit that fuelled the investments that drove India's Green Revolution (Shah *et al.*, 2007).[10]

iv. **Role of the 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, the paradigm of agricultural extension during the Green Revolution 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 today, great effort will be needed to re-energise and re-orient 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'.

v. **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.[11] 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.[12]

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[10] 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.

[11] The Foodgrains Prices Committee (1964) recommended the setting up of the Food Corporation of India "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).

[12] 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.

III. Wheels come off the Green Revolution

While it is undeniable that the Green Revolution paradigm represents a powerful break from the past that provided India with comfortable food security,[13] 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 300,000 farmers have committed suicide in the last 30 years, a phenomenon completely unprecedented in Indian history.[14] There is growing evidence of steady decline in water tables and water quality. At least 60 percent of India's districts are either facing a problem of over-exploitation or severe contamination of groundwater (Vijayshankar, Kulkarni and Krishnan, 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 methemoglobinemia 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 immune system and other intergenerational effects (Margni *et al.*, 2002).[15] 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. 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

> "evidence demonstrates the negative health and environmental effects of pesticides, and there is widespread understanding that intensive pesticide application can increase the

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[13] 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.

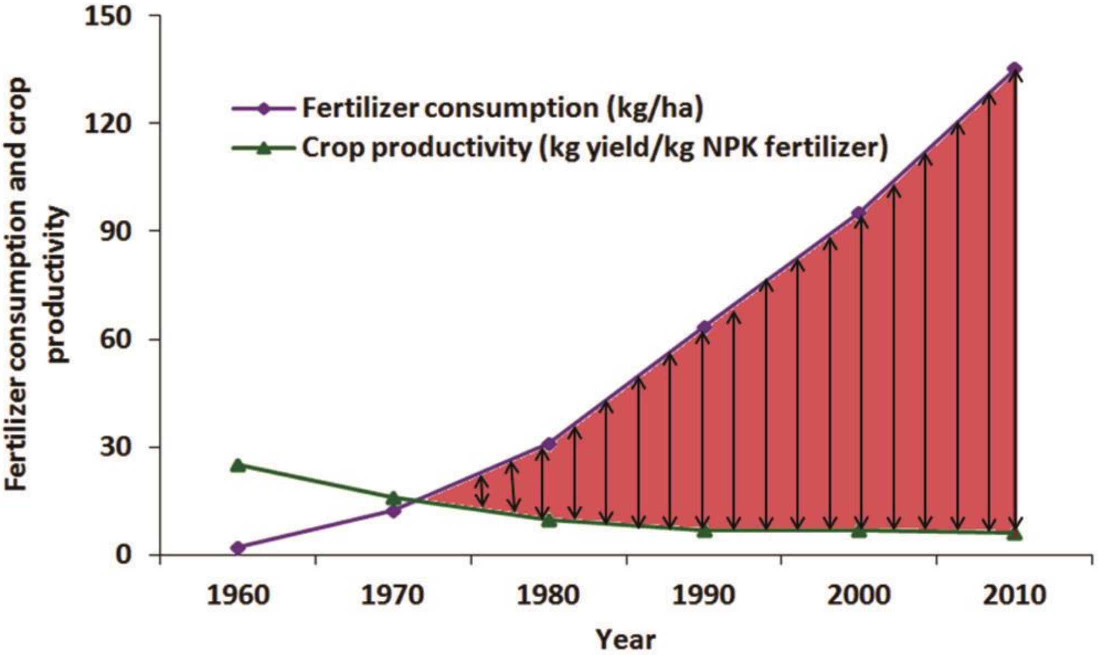
[14] This data comes from the National Crime Records Bureau, as committing suicide still remains a crime under Indian law.

[15] 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.

> vulnerability of agricultural systems to pest outbreaks and lock in continued reliance on their use.” (Jepson *et al.*, 2020)

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 fertilizer use has fallen from around 25 kg grain/kg of nitrogen, phosphorus and potassium (NPK) fertilizer 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.

Figure 3: Relationship between fertilizer consumption and crop productivity



Source: Indoria et al (2018, Figure 2)

Moreover, despite overflowing granaries, the 2020 *Global Hunger Index Report* by the International Food and Policy Research Institute (IFPRI) ranked India 94th out of 107 countries.[16] 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 such people in the world. In 2019, India had 28 percent (40.3 million) of the world’s stunted

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[16] 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)

children (low height-for-age) and 43 percent (20.1 million) of the world's wasted children (low weight-for-height) under-five years of age.[17] 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).

IV. Not quite a Green Revolution

To outline precisely how we can institute a paradigm shift in farming, we must first understand why this multi-fold 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.[18]

Table 5: All-India and region-wise cropped area

('000 ha)

Region	Period	Rice	Wheat	Nutri-Cereals[19]	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

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[17] 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)

[18] 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 350,000 known plant species on our planet are edible (Miller, 2021).

[19] The Government of India 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. In a notification, the agriculture ministry said, "the central government hereby declares millets comprising sorghum (jowar), pearl millet (bajra), finger millet (ragi/mandua), minor millets – foxtail millet (kangani/kakun), proso millet (cheena), kodo millet (kodo), barnyard millet (sawa/sanwa/ jhangora), little millet (kutki) and two pseudo millets (black-wheat (kuttu) and ameranthus (chaulai) which have high nutritive value as "Nutri Cereals"." (https://www.financialexpress.com/ market/commodities/ government-renames-millets-as-nutri-cereals/1140338)

	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	2 3151	14 829	2 270	21 184	151 315
	1980-83	37 779	21 541	39 602	21 872	17 233	2 983	24 855	165 698
	1990-93	38 828	2 1946	31 400	24 310	22 453	3 376	27 011	168 817
	2003-06	38 913	24 147	26 926	20 846	23 973	3 648	34 744	173 718
	2012-14	39 616	27 965	23 304	20 973	26 530	5 019	35 852	179 260

Notes: 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

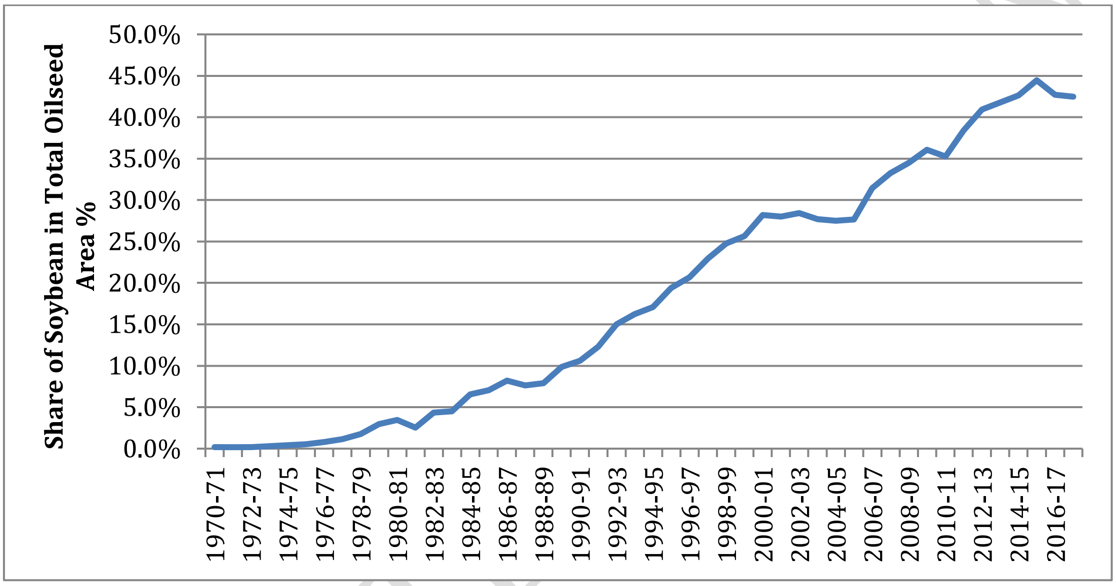
Table 6: All India and region-wise distribution of cropped area

(%)

Region	**Period**	**Rice**	**Wheat**	**Nutri-Cereals**	**Pulses**	**Oilseeds**	**Sugarcane**	**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

Figure 4: Share of soyabean in total area under oilseeds



Source: DAC, 2018. *Agricultural Statistics at a Glance*

As can be seen from Tables 5 and 6, over the past 50 years, the share of nutri-cereals in cropped area has gone down 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 the states of 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.[20] Figure 5 shows that the share of soyabean in oilseeds acreage rose from less than 1 percent in the early 1970s to over 40 percent in 2016/17, even as the share of the other eight oilseeds has stagnated. Other than soyabean, the only other crops showing a rise in acreage during the period of the Green Revolution are wheat, rice and sugarcane.

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[20] See Vijayshankar (2016) for an account of how state support played a crucial role in pushing the "soya-wheat revolution" in Madhya Pradesh

The rise in acreage of wheat and rice is a direct consequence of the procurement and price support offered by the state. In the case of sugarcane and soyabean, 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). 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.*[21] 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.

Table 7: Share of crops in public procurement, 2007-2019
(%)

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.

V. The paradigm shift required in agriculture

V.1 Towards crop diversification reflecting agro-ecology of diverse regions

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[21] 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).

A recent study supported by the National Bank for Agriculture and Rural Development (NABARD) and the Indian Council for Research in International Economic Relations (ICRIER) estimated that about 78 percent of India's water is consumed in agriculture (Sharma *et al.*, 2018). FAO's AQUASTAT database puts this figure closer to 90 percent (FAO, 2019). The NABARD-ICRIER study identified three "water guzzler" crops – rice, wheat and sugarcane – which occupy about 41 percent of the gross cropped area and consume more than 80 percent of irrigation water. Shah (2019) suggests that sugarcane, which occupies just 4 percent of cropped area, uses up 65 percent of irrigation water in Maharashtra. In Karnataka, rice and sugarcane, which cover 20 percent of cropped area, consume as much as 70 percent 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.

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 very carefully calibrated, location-specific manner, to align with local agro-ecologies. The best way of doing this is to start procurement of crops that match the agro-ecology of each region.

India's cropping pattern before the Green Revolution included a much higher share of millets, pulses and oilseeds. These agro-ecologically 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 (MDMS), as also the grains provided through the PDS. A few state governments are also slowly moving forward in this direction. The Odisha Millets Mission (OMM) 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 100,000 farmers to cultivate millets. The *mandia laddoos* prepared by women SHGs under Mission Shakti and introduced under the ICDS have proved extremely popular among the pre-school 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 (Dinesh Balam, personal communication). 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 program helped women's SHG Federations develop a business plan for establishing a supply-chain of Kodo bars and *barfis,* which were included in the ICDS supplementary nutrition program. The products were clinically tested for their nutrient content at National Accreditation Board for Testing and Calibration Laboratories (NABL) 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.[22] Recent medical research has found that some millets contain significant anti-diabetic properties. According to the Indian Council of Medical Research, foxtail millet has 81 percent 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 – which provide a higher content of dietary fibre, vitamins, minerals, protein and antioxidants and a significantly lower glycemic index – India would be better placed to solve the problems of malnutrition and obesity.

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[22] 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)

To clarify, this is not a proposal for open-ended public procurement. That would be neither feasible nor desirable. The argument is for diversification of the procurement basket to include crops suited to local agro-ecologies. 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 PM-AASHA scheme. Without such an initiative, the announcement of Minimum Support Prices for 23 crops every year is reduced to a token ritual, with little benefit to most farmers.

If such a switch in cropping patterns, to reflect the agro-ecological diversity of India, were to be effected, what volume of water would India save by the year 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.[23] These states together accounted for about 66 percent 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 ten-year period for which data are 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 percent of the crop area in the *kharif* season and 25 percent 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 percent of the crop area in the *kharif* season and 50 percent 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 gives the list of states and seasons analysed.

First, we quantify baseline crop production based on recent yield and area data.[24] Our purpose is to build different scenarios to demonstrate the potential of water savings

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[23] The basic data on yield, area under cropping and production is derived from the database of Directorate of Agriculture and Co-operation (DAC), Government of India.

[24] We use time-series data for the period 2008-17, the latest ten-year period for which data from the DAC is available for each selected crop in each season (DAC, 2020). Area multiplied by yield gives estimates of crop production.

through crop replacements. For estimating the irrigation water use in these crop replacement scenarios, we have calculated blue water footprints, which represent the volume of water consumed during crop production in m^3 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).[25] In this method, the total evapo-transpiration (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 blue water footprint (BWF) of crops.[26] The BWF is multiplied by crop production, to get estimated blue water use by crops in each state in each season.[27]

To estimate the potential for annual water savings, we propose crop switches in both *kharif* and *rabi* crops in different states, through the scenarios in Table 8.[28]

Table 8: Crop replacements scenarios by state and seasons

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

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[25] 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

[26] 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.

[27] 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

[28] 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 water-logged 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 percent and 50 percent in Scenarios I and II to 10 percent and 25 percent respectively.

In these 11 states, we take the area under three most water-intensive crops, namely rice, wheat and sugarcane, and re-distribute the area to the replacement crops.[29] 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 agro-ecology 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:

i. 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 replacement of an annual crop like sugarcane 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.

ii. 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 tubewells is the major source of irrigation.

iii. 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 inter-cropping is practised, there are certain crop combinations involved. So, when we propose replacement of one crop (such as soyabean in Madhya Pradesh), we need to also propose replacement of other crops in the crop mix when the inter-crop does not match with the replacement crop.

Based on these considerations and limiting factors, Table 9 brings together the state-specific and season-specific crop replacements proposed.

Table 9: State-specific and season-specific crop replacements

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[29] We keep the sum of the water-intensive and replacement crops area constant

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	Soybean	Wheat	Maize, Jowar	Gram, Rapeseed
Maharashtra*	Sugarcane	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	

Note: *Sugaracane 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 provides a comparison of the total blue water saved (cubic kilometres or billion cubic metres) 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.

Table 10: Comparison of annual irrigation water under different crop scenarios

State	Blue Water Use (BCM/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**

Given that water-intensive crops currently occupy over 30 percent 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 total output because of differentials in yields across crops.[30] 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

> "given 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).

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 agro-ecology and that includes raising the share of Eastern India in 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 food grains. 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, p.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).[31]

Moreover, the nutritional content of the crop mix we are proposing is definitely superior. Increasing 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 impact on farmers' incomes is also likely to be positive both because of lower input requirements and costs of production associated

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[30] 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.

[31] 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)

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 INR 3 171/quintal, compared to INR 3 821/quintal for the replacement crops (see Table 11). 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 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 macro-economic environment for crop replacement.[32]

Table 11: All-India weighted average wholesale prices, October 2018

	Crops	**Weighted average annual wholesale price (INR/quintal)**
Water intensive crops	**Sugar**	3 563
	Rice	2 030
	Wheat	1 889
	Cotton	5 394
	Soyabean	2 979
Replacement crops	**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 Famers Welfare, published as Answers Data of Session 246, 247 and 248 of Rajya Sabha, Parliament of India, available from data.gov.in

V.2 Monoculture Impairs Resilience: Return to Polycultural Bio-diversity

Farming faces twin uncertainties, stemming from the market and the weather. For such a risky enterprise to adopt monoculture is patently suicidal.[33] But that is what the Green Revolution has moved Indian farming towards: more and more land under one crop

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[32] It is encouraging to note that recent increases in MSPs have tended to favour our replacement crops and not so much rice and wheat

[33] In complex organic systems, there is always a trade-off between efficiency and robustness (Csete and Doyle, 2002).

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 risk, 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 twenty-first 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

> "crops grown under 'modern monoculture systems' are particularly vulnerable to climate change as well as biotic stresses . . . what is needed is an agro-ecological 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).

> "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)

It has also been shown that plants grown in genetically homogenous 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 the corresponding monocultures. In his classic work on inter-cropping, Vandermeer (1989) provides innumerable instances of how inter-cropping enables farmers to minimise risk by raising various crops simultaneously. Natarajan and Willey (1996) show how polycultures (intercrops of sorghum 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 5160 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).

A recent report of the FAO's Commission on Genetic Resources for Food and Agriculture also brings out the key role of bio-diversity 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)

Moreover, as a recent study of agro-biodiversity 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 Jacob *et al.*, 2020). 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.

V.3 Rejecting the originative flaw (soil as an input-output machine)

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 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 eco-system 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). 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).[34] As Lent (2017) 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, the 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 the 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).

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:

1. 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?
2. Or is it a complex, interacting, living eco-system to be cherished and maintained so that it can become a vibrant, circulatory network, which nourishes the plants and animals that feed it?
3. Will a toxic, enervated eco-system 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, who is also the winner of the 2020 World Food Prize:

> "The weight of living organisms in a healthy soil is about 5 ton 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 percent or maybe 0.2 percent."[35]

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[34] Addiscott (2010); Baveye *et al* (2018); Falconer *et al* (2012)

[35] Interviews to Indian Express (22 June 2020) and Mint (12 June 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.[36] Lal favours compensation for farmers through payments (around INR.1 200 per acre per year) for soil protection, which he regards as a vital eco-system service.

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). Rattan 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, eco-system carbon budget, filtering of pollutants and eco-system productivity.[37]

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

> "as 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)

Benton and Bailey urge policy-makers to move from the traditional preoccupation with Total Factor Productivity (TFP) 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 minimize waste. It would optimize total resource inputs (direct inputs and indirect inputs from natural capital and healthcare) relative to the outputs (food utilization). Maximizing 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." (ibid.)

In the light of this understanding, attempts are being made all over the world to foster an eco-system 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

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[36] https://www.scientificamerican.com/article/only-60-years-of-farming-left-if-soil-degradation-continues, 5 December 2014

[37] 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 (Chouhan, *et al.,* 2012; Ghosh *et al.*, 2017; Pal *et al.*, 2009).

agro-ecology. 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) provides an excellent summary of the philosophy underlying agro-ecology:

> "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."

A recent overview sums up key features of the approach embodied by agro-ecology:

> "Over the past five years, the theory and practice of agroecology have crystalized 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" (Anderson *et al.*, 2021).

In India, a large number of such alternatives to the Green Revolution paradigm 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 agro-ecological 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 Based Natural Farming programme of the Government of Andhra Pradesh (GoAP), which started in 2016.[38] Crop-cutting experiments by the State Agriculture Department claim higher 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

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[38] Initially called Zero Budget Natural Farming, this label, suggestive of a certain kind of fundamentalism and exaggeration, has now been dropped

by 2027 (Vijay Kumar, 2020). These agro-ecological 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.

VI. Conclusion

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 multi-pronged approach adopted at the time of the Green Revolution. These include:

1. 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 3Ms (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.
2. Widespread and affordable facilities must be made available for testing the maximum residue level of chemicals in farm produce, in line with regulations of the Food Safety and Standards Authority of India (FSSAI), without which there will be no guarantee that the produce meets required health safety standards.
3. 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 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.

4. 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 eco-system 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 self-help groups (SHGs) and farmer producer organisations (FPOs).
5. 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 *et al.* (2007) explain 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 (IRDP) in the years following bank nationalisation. The SHG-Bank Linkages Programme has not only benefitted 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 twenty-first 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.
6. 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 (CRPs), farmers trained in all aspects of agro-ecology, who would be the best 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.[39]

Thus, to carry forward the agro-ecological 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

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[39] A "rhizome has no beginning or end; it is always in the middle, between things, interbeing, *intermezzo*." (Deleuze and Guattari, 1987)

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.

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