

Assessment of Productivity and Monetary Losses Due to Water Erosion in Rainfed Crops Across Different States of India for Prioritization and Conservation Planning

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Abstract Estimated annual production losses from rainfed cereal, oilseed and pulse crops at state, zonal and national levels do not provide a comparative picture of the severity of losses in different areas and crops leading to decline in production on per-unit area basis. In this paper, productivity or per-unit area production losses have been estimated for the considered rainfed crops to identify the states/regions in the country where intensive conservation measures need to be adopted to bring erosion within permissible limits and to restore the productivity of these crops to their potential capacity. Further, productivity losses were valued at government minimum support prices of the study crops to compute the monetary losses in the major cereal, oilseed and pulse crops in the country. It was observed that productivity loss in rainfed cereals at state level ranges from 0.2–10.9 q/ha, for oilseeds 0.1–6.3 q/ha and for pulses 0.04–4.4 q/ha. These losses in the states having relatively smaller areas under these crops and are low ranked in terms of total production loss, such as northeastern states, Goa, Kerala and Uttarakhand, are 2–5 times higher than the national average and are placed in top 8–10 ranks of affected states, thus justifying the need to estimate productivity losses rather than the production losses. The northeastern states, though account for only 4 % of rainfed area under considered crops, are the leading states in terms of productivity losses. India as a whole suffers a loss of 1.63 q/ha in productivity of rainfed crops, which is valued at Rs. 2,484/ha. In absolute terms, the annual production losses are 13.4 Mt valued at Rs. 205.32 billion considering minimum support price of 2011/12. About 53 % of total monetary loss is accounted for by paddy, groundnut, soybean and maize crops due to water erosion.

Keywords Conservation planning · Crop productivity · Erosion · Monetary loss · Rainfed

Introduction

Mankind is utilizing ecological services at a significantly higher rate than the mother earth can provide, thereby

putting enormous pressure on the natural resources. Land, which includes soil, biological and water resources, is one of the principal natural resources providing ecoservices for the sustenance of life. As per the first global assessment of human-induced soil degradation (GLASOD), out of the world's total land area of 13.5 billion ha, about 2 billion ha (15 %) is degraded, mainly resulting from water erosion [10]. In contrast to GLASOD estimate, as per the latest scientifically based approach, global assessment of land degradation and improvement (GLADA), 24 % of global land is degraded [3, 4]. Though the global estimates of degraded area vary due to the lack of credible data based on groundtruthing [7], the areas highlighted by the two analyses hardly overlap, clearly showing that land degradation is a global issue. It is estimated that if this trend

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continues, 1.4–2.8 % of the total agricultural, pasture and forestland would be lost by 2020, and declining yields (or increasing input requirements to maintain yields) can be expected over a much larger area [11].

In India, as per harmonized database on land degradation, 120.72 million ha area is subjected to various forms of land degradation, with maximum (68.4 %) contribution by water erosion (82.57 million ha) [8]. Potential erosion rates estimated for different states indicate that 39 % area (126 million ha) has erosion rate of >10 t/ha/year while 11 % area falls in very severe category (>40 t/ha/year). However, the permissible soil loss rate, depending upon soil quality and depth, is estimated to vary from 2.5 to 12.5 t/ha/year. About 69.5 % area of India has soil loss tolerance limit of <10 t/ha/year, while about 13.3 % area has a soil loss tolerance limit of only up to 2.5 t/ha/year [9]. Further, soil erosion risk estimates prioritized for various states indicate that major part of the total geographical areas of Nagaland (69 %), Arunachal Pradesh (42 %), Meghalaya (35 %) and Uttarakhand (34 %) falls under erosion risk priority classes 1 and 2 [15].

Among the soil groups, red soils (mostly alfisols, inceptisols and ultisols) and black soils (vertisols and vertic subgroups) acutely suffer due to water erosion. Black soils (73 million ha), mainly supporting rainfed agriculture, are subject to severe sheet and rill erosion with an annual soil loss of 20 to over 100 t/ha/year. Red soils (71 million ha), having a shallow depth of 20 cm in some parts of India, are even more prone to water erosion due to physical deterioration caused by surface sealing and crusting problems under rain drop impact, resulting in low intake capacity and rapid surface runoff and erosion [12]. Alluvial soils (mostly alluvium-derived deep inceptisols and entisols) occupy the largest area and are relatively less affected by water erosion due to greater soil depth formed through transportation of fine soil by natural agents such as water onto the parent material.

Among the negative impacts of soil erosion by water, loss in crop productivity by removal of topmost fertile part containing organic matter and plant nutrients has a strong bearing on national food security, especially under the scenario of declining per capita net sown area, which is well below the prescribed threshold limit of 2.0 ha of rainfed land or 1.0 ha of irrigated land required for a family of five to six members [1]. Further, agricultural productivity has remained stagnant, and rainfed areas, which constitute about 60 % of the gross cultivated area, contribute only 40 % to the national food basket [18]. To ensure food security, the average productivity of all food grains needs to be doubled from the current 1.75 [6] to 3.3 t/ha to produce the estimated 310 Mt of food grains from net sown area of 150 million ha by 2050 [2].

Attempts were made in the past to assess macrolevel production losses due to soil degradation. Annual loss in production was estimated to vary from 7.2 to 13.5 Mt [5]. The annual production losses of considered 11 major crops varied from 1.7 to 4.1 % of total production valued at Rs. 52–84 billion. TERI [17] reported annual loss due to all forms of soil degradation ranging from Rs. 89–232 billion, out of which erosion by water and wind alone accounted for Rs. 61 billion (69 %) to 216 billion (94 %). However, these estimations were poorly based either on limited number of studies or on gross assumptions regarding the effect of soil degradation on crop productivity. Further, prevailing erosion rates in different types of soil were not considered. Recently, annual production and monetary losses due to water erosion were estimated by Sharda et al. [12] by evolving and adopting a systematic approach that integrates data on erosion category-wise potentially eroded areas under major soil groups (alluvial, black or red) in each state with productivity loss factors (PLF) of 27 major rainfed crops, including cereals (8), oilseeds (10) and pulses (9), evolved through experimental studies in rainfed areas of different agroclimatic regions of the country. Following this approach, the total annual production loss was estimated as 13.4 Mt at 16 %, valued at Rs. 111.7 billion considering the minimum support price during 2005/06 and at Rs. 162.8 billion during 2008/09 [13].

The estimated annual total production and monetary losses, however, are not truly comparable across different crops and states as they were based on total area under each crop in a state. Difference in losses was thus largely a function of acreage of area under a given crop in a state rather than indicating the impact of severity of erosion on production losses. For realistic comparison of estimated losses across states/regions and to adopt appropriate conservation measures in a given area [16], it is imperative to estimate production and monetary losses on per-unit area basis for the considered rainfed crops in the country. The main objective of the present study was to estimate productivity losses due to water erosion of rainfed cereal, oilseed and pulse crops, so that comparative picture may emerge for each type of crop among the states as well as zones and each individual crop at national level for prioritizing the implementation of conservation programs to check erosion and contain the losses in a given state/zone.

Materials and Methods

Based on the available estimated data [12, 13] of annual production loss and potential eroded rainfed area under each cereal crop cultivated in a state, average productivity loss, i.e., per-unit area production loss in a year in terms of quintal per hectare, was estimated of the rainfed cereals

together in the state by dividing the figure of summated production loss from all the cereals cultivated in the state by the corresponding summated rainfed area figure of these crops. Similarly, these losses were estimated for cultivated rainfed oilseeds and pulses in the state. These estimates were done for all the 29 states as well as for the six zones in which these states fall, namely northern (Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, Uttarakhand, Uttar Pradesh and Delhi), central (Chhattisgarh and Madhya Pradesh), southern (Andhra Pradesh, Karnataka, Kerala and Tamil Nadu), western (Goa, Gujarat, Maharashtra and Rajasthan), eastern (Bihar, Jharkhand, Odisha and West Bengal) and northeastern (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura). Further, similar estimations were done by adopting the same method for all the crops (cereals, oilseeds and pulses) together at state as well as zonal level. In total, 27 rainfed crops including eight cereals (paddy, maize, wheat, pearl millet, sorghum, finger millet, barley, and other cereals and millets), ten oilseeds (rapeseed, sesamum, groundnut, linseed, soybean, castor, niger, sunflower, safflower and other oilseeds) and nine pulses (gram, pigeon pea, black gram, green gram, lentil, horse gram, pea, red gram and other pulses) that are cultivated under rainfed conditions in different states of the country were covered in the study.

At national level, estimation of the per-hectare average production loss, however, was done for each of the above-listed crops, for which the available national-level eroded rainfed area data of a crop [12, 13] were utilized to divide the corresponding production loss data of the crop. Estimation of the monetary losses at national level was done based on the available estimated production loss data of each crop at national level, by using the minimum support/procurement price of the crop for the year 2011/12. In case of crops that do not have such prices, actual wholesale prices were used for the estimation.

Results

Productivity Losses of Rainfed Crops in States

Cereals

Analysis of productivity losses of all rainfed cereal crops together in each state indicated that the state of Goa experiences highest loss of 10.9 q/ha (Table 1) followed by Nagaland (6.5 q/ha), Manipur (5.8 q/ha) and Andhra Pradesh (5.6 q/ha). Kerala suffers a loss of 5.1 q/ha and is closely followed by Meghalaya, which suffers a loss of 5.0 q/ha. Mizoram and Arunachal Pradesh suffer from 4.4 and 4.1 q/ha losses, respectively. Karnataka and Sikkim

experience a loss of 3.9 and 3.5 q/ha, respectively. These are the leading states in terms of productivity losses of all rainfed cereal crops together. India as a whole experiences a loss of 2.0 q/ha from rainfed cereals. Therefore, loss experienced by Goa is approximately 5 times of country's average. Nagaland, Manipur and Andhra Pradesh suffer from 3 times higher loss, and the remaining states discussed above suffer from 2 times higher loss. The states of Chhattisgarh, Uttarakhand, Odisha, Assam, Himachal Pradesh and Madhya Pradesh also suffer from higher losses than the national average (2.1–2.9 q/ha). Remaining states experience a loss of <2.0 q/ha ranging from 0.2 (Haryana) to 1.9 (Jharkhand) q/ha.

Oilseeds

In case of oilseeds, Nagaland suffers from highest loss (6.3 q/ha) followed by Goa (6.0 q/ha) (Table 1). Arunachal Pradesh and Kerala follow with 4.1 and 3.7 q/ha losses, respectively. Tamil Nadu experiences a loss of 3.3 q/ha followed by northeastern states of Sikkim (2.9 q/ha), Meghalaya (2.6 q/ha) and Mizoram (2.2 q/ha). The country, on an average, experiences a productivity loss of 1.4 q/ha in rainfed oilseeds. Thus, Nagaland has 5 times higher loss than all-India average followed by 4 times in case of Goa, 3 times in case of Arunachal Pradesh and Kerala and 2 times in the remaining four out of top eight states. The other states with significant losses are Rajasthan (1.9 q/ha), Karnataka (1.7 q/ha), Madhya Pradesh and Maharashtra (1.4 q/ha). Remaining states experience a loss of <1.4 q/ha ranging from 0.1 (Haryana) to 1.2 (Chhattisgarh) q/ha.

Pulses

The analysis of per-hectare production losses of all rainfed pulse crops together in each state indicated that Meghalaya has highest loss of 4.4 q/ha, which is followed by its four neighboring states—Mizoram (3.3 q/ha), Nagaland (3.1 q/ha), Arunachal Pradesh (3.0 q/ha) and Sikkim (2.6 q/ha). Sikkim and Goa (2.1 q/ha) are followed by Kerala (1.7 q/ha), Uttarakhand (1.5 q/ha), Assam (1.4 q/ha) and Delhi (1.4 q/ha). India as a whole experiences a loss of 0.9 q/ha from rainfed pulse crops. Thus, Meghalaya and Mizoram experience 5 and 4 times higher loss than the national average, respectively, and Nagaland, Arunachal Pradesh and Sikkim 3 times, while the rest of the top ten states experience 2 times higher loss than the national average. The other states that follow include Karnataka (1.3 q/ha), Andhra Pradesh (1.2 q/ha), Madhya Pradesh (1.1 q/ha), Jharkhand (1.0 q/ha), Odisha (1.0 q/ha), Manipur (1.0 q/ha) and Gujarat (1.0 q/ha). Remaining states experience a loss of <1.0 q/ha ranging from 0.0 q/ha in Haryana to 0.9 q/ha in Uttar Pradesh.

Table 1 Estimated annual productivity loss due to water erosion from rainfed cereal, oilseed and pulse crops in states of India

S. no.	State	Cereals		Oilseeds		Pulses	
		Rainfed area ('000 ha)	Annual productivity loss (q ha ⁻¹)	Rainfed area ('000 ha)	Annual productivity loss (q ha ⁻¹)	Rainfed area ('000 ha)	Annual productivity loss (q ha ⁻¹)
1.	Delhi	7.3	0.7	3.9	0.3	0.0	1.4
2.	Haryana	454.5	0.2	172.6	0.1	122.6	0.0
3.	Himachal Pradesh	622.0	2.2	19.0	0.2	28.0	0.7
4.	Jammu and Kashmir	526.4	1.3	20.1	0.1	26.1	0.4
5.	Punjab	150.0	0.3	12.2	0.1	5.0	0.1
6.	Uttarakhand	545.5	2.9	23.8	0.3	54.7	1.5
7.	Uttar Pradesh	3,370.0	1.7	577.3	0.6	2,150.4	0.9
8.	Chhattisgarh	3,114.3	2.9	285.3	1.2	884.6	0.9
9.	Madhya Pradesh	4,394.7	2.1	5,464.6	1.4	3,095.3	1.1
10.	Andhra Pradesh	1,181.9	5.6	2,495.1	1.2	1,777.6	1.2
11.	Karnataka	3,721.5	3.9	2,171.3	1.7	1,989.3	1.3
12.	Kerala	112.3	5.1	4.1	3.7	8.4	1.7
13.	Tamil Nadu	854.5	1.8	479.9	3.3	558.4	0.6
14.	Goa	35.7	10.9	0.4	6.0	7.8	2.1
15.	Gujarat	1,762.8	1.2	2,755.8	0.8	739.8	1.0
16.	Maharashtra	7,573.0	1.3	3,006.9	1.4	3,097.1	0.7
17.	Rajasthan	2,464.5	0.6	1,538.5	1.9	1,259.1	0.5
18.	Bihar	2,039.0	0.5	83.0	0.2	579.3	0.3
19.	Jharkhand	1,462.0	1.9	62.0	0.9	266.0	1.0
20.	Odisha	2,954.9	2.8	716.7	1.0	1,513.9	1.0
21.	West Bengal	3,077.7	1.0	291.0	0.6	219.2	0.5
22.	Arunachal Pradesh	141.0	4.1	27.0	4.1	7.0	3.0
23.	Assam	2,359.0	2.5	275.0	1.1	101.0	1.4
24.	Manipur	125.3	5.8	–	–	8.0	1.0
25.	Meghalaya	83.0	5.0	8.0	2.6	4.0	4.4
26.	Mizoram	52.0	4.4	5.7	2.2	7.0	3.3
27.	Nagaland	152.0	6.5	35.5	6.3	31.0	3.1
28.	Sikkim	67.1	3.5	10.0	2.9	7.0	2.6
29.	Tripura	145.0	1.7	6.0	0.9	8.0	0.5
	India	43,548.9	2.0	20,550.7	1.4	18,555.6	0.9

Cumulative Productivity Losses of Rainfed Crops in States

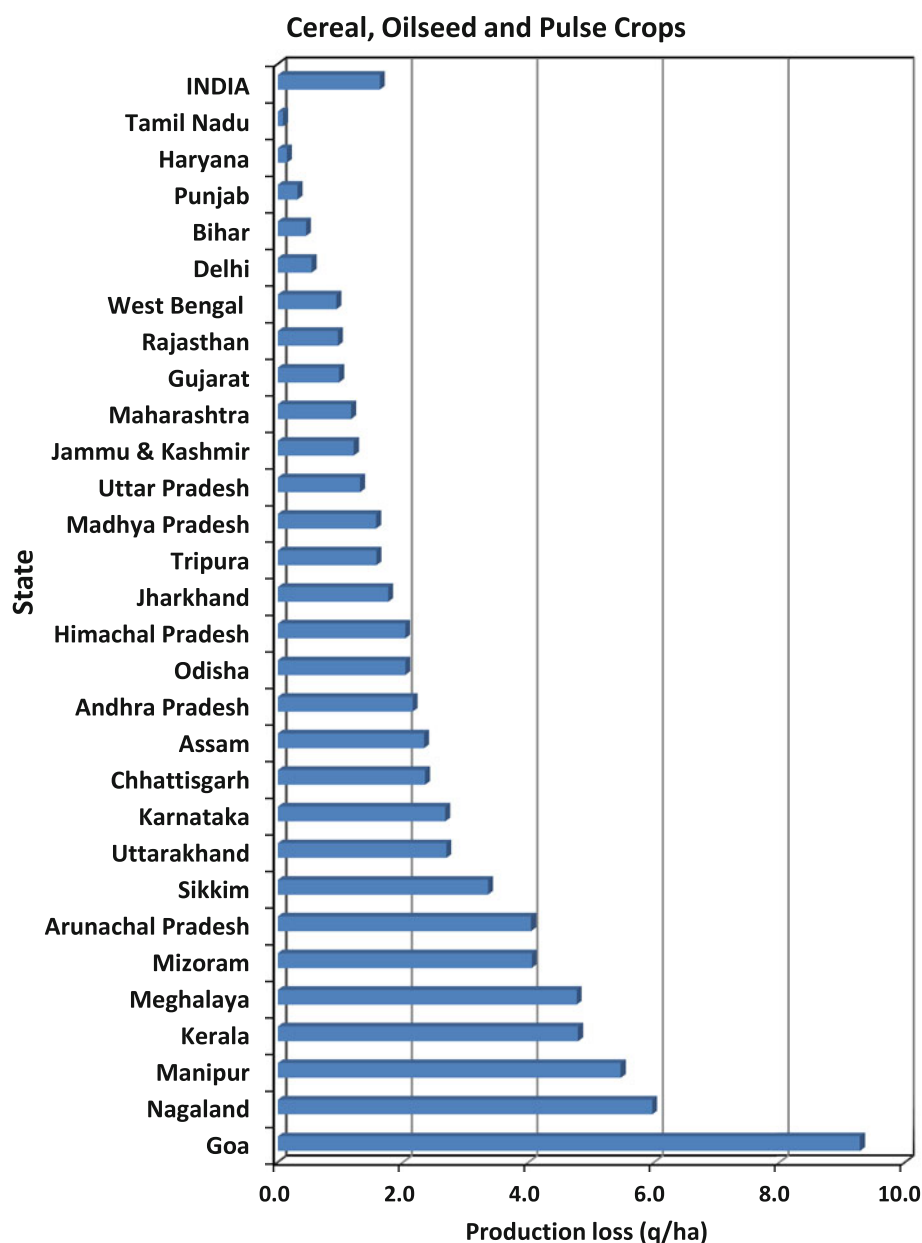
The cumulative productivity losses occurring from all rainfed cereal, oilseed and pulse crops cultivated in each state were analyzed to understand the overall impact of the losses from these crops. It was observed that Goa is suffering the most (9.3 q/ha) (Fig. 1). With India's average loss of 1.6 q/ha, the state experiences about 6 times higher loss than the national average. Goa is followed by Nagaland (6.0 q/ha) having 4 times higher loss, while Manipur (5.5 q/ha), Kerala (4.8 q/ha) and Meghalaya (4.8 q/ha) have 3 times higher loss. States having 2 times higher loss are Mizoram (4.1 q/ha), Arunachal Pradesh (4.0 q/ha), Sikkim (3.4 q/ha), Karnataka (2.7 q/ha) and Uttarakhand

(2.7 q/ha). Other states having high losses are Chhattisgarh (2.3 q/ha), Assam (2.3 q/ha), Andhra Pradesh (2.2 q/ha), Odisha (2.0 q/ha), Himachal Pradesh (2.0 q/ha) and Jharkhand (1.8 q/ha), while remaining states have losses ranging from 0.1 q/ha (Tamil Nadu) to 1.6 q/ha (Madhya Pradesh and Tripura).

Productivity Losses of Rainfed Crops in Zones

A comparison across six zones of India in terms of per-hectare production losses from rainfed cereal crops cultivated in the zones indicated that southern zone (4.0 q/ha) suffers from highest loss (Fig. 2) followed by northeastern zone with 3.0 q/ha loss, though the difference in the loss between the top two zones is significant (1.0 q/ha). The

Fig. 1 Annual aggregate production loss per hectare due to water erosion from rainfed cereal, oilseed and pulse crops in states of India



central zone stands third (2.4 q/ha). The eastern zone follows with a loss of 1.9 q/ha. The northern zone loses about 1.7 q/ha of rainfed cereal crops. The western zone has the lowest per-unit area loss in rainfed cereals. In case of rainfed oilseed crops, a somewhat similar trend was observed for the top three zones, with only difference of exchange in rankings of southern (1.6 q/ha) and northeastern zones (1.9 q/ha) followed by central zone (1.4 q/ha). The western zone closely follows (1.3 q/ha). The western zone is followed by eastern (0.9 q/ha) and northern (0.5 q/ha) zones. Rankings of top three zones for productivity losses in rainfed pulses are similar to that of oilseeds. Northeastern zone suffers highest loss of 1.9 q/ha followed

by southern zone (1.2 q/ha) and central zone (1.0 q/ha). The rest of the three zones, namely northern, eastern and western, follow closely with 0.9, 0.8 and 0.7 q/ha losses, respectively.

Analysis of productivity losses in rainfed cereal, oilseed and pulse crops together in each zone indicated that northeastern zone suffers from highest loss of 2.8 q/ha (Fig. 3) followed by southern (2.2 q/ha), central (1.8 q/ha), eastern (1.6 q/ha), northern (1.3 q/ha) and western (1.1 q/ha) zones.

Background information pertaining to the productivity losses in rainfed cereal, pulse and oilseed crops in different states and zones is presented in Supplementary Tables 1 to 29.

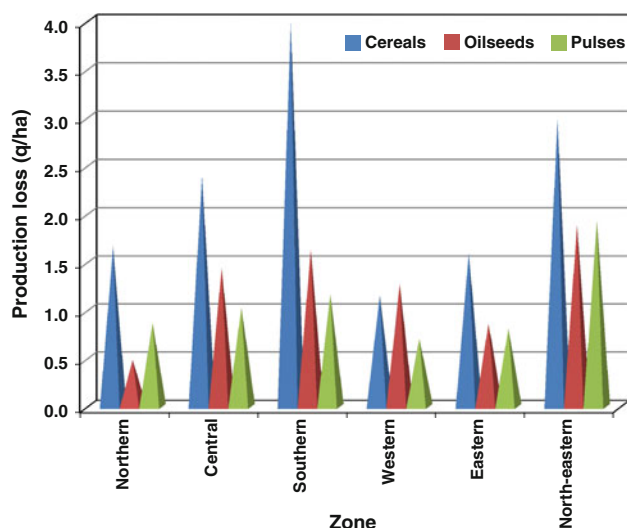


Fig. 2 Annual production loss per hectare due to water erosion from rainfed cereal, oilseed and pulse crops in different zones of India

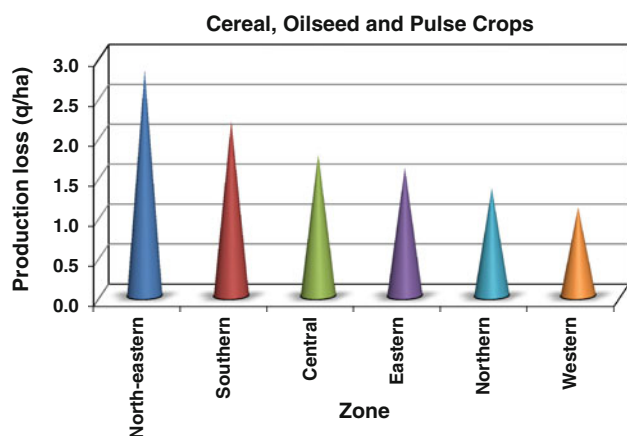


Fig. 3 Annual aggregate production loss per hectare due to water erosion from rainfed cereal, oilseed and pulse crops in different zones of India

Productivity and Monetary Losses of Rainfed Crops in India

Productivity and per-unit area monetary losses were estimated for each of the 27 rainfed cereal, oilseed and pulse crops at national level. Among the cereals, finger millet suffers the highest loss of 3.72 q/ha equivalent to Rs. 3,904/ha (Table 2). Maize, an erosion-permitting crop due to its morphology and drainage needs follows with a loss of 3.11 q/ha valued at Rs. 3,050/ha. Maize is followed by paddy (2.26 q/ha and Rs. 2,443/ha). Wheat, mostly (about 90 %) cultivated under irrigated conditions all over India, suffers from 2.10 q/ha loss (Rs. 2,347/ha) under rainfed conditions. Wheat is followed by ‘other cereals and millets’

(comprising minor cereals and millets) (1.80 q/ha worth Rs. 1,804/ha), barley (1.54 q/ha worth Rs. 1,200/ha), pearl millet (1.12 q/ha worth Rs. 1,101/ha) and sorghum (1.05 q/ha worth Rs. 1,026/ha). The rainfed cereal crops, on an average, suffer a productivity loss of 2.05 q/ha equivalent to Rs. 2,131/ha. In total monetary loss terms, it ranges from Rs. 232 million (barley) to Rs. 46,535 million (paddy) among the cereal crops considering 2011/12 minimum support prices, which for all rainfed cereals works out to Rs. 92,783 million.

Among the rainfed oilseeds, groundnut suffers from highest loss of 1.66 q/ha (Rs. 4,472/ha) (Table 3) followed by castor with a loss of 1.60 q/ha and highest monetary loss of Rs. 7,577/ha. Soybean suffers from third highest loss of 1.54 q/ha (Rs. 2,603/ha). Rapeseed occupies third place in terms of its share (10 %) in total rainfed area under oilseeds; however, it loses at 1.48 q/ha equivalent to Rs. 2,735/ha. ‘Other oilseed crops’ occupying only 3 % of total rainfed area lose productivity at 1.01 q/ha, while the remaining oilseeds suffer a production loss of <1.0 q/ha ranging from 0.59 (linseed) to 0.96 q/ha (safflower). The rainfed oilseed crops suffer from production loss of 1.37 q/ha equivalent to Rs. 3,144/ha at national level. The total monetary loss ranges from Rs. 638 million (safflower) to Rs. 24,360 million (groundnut) among the oilseed crops at 2011/12 prices, which is equivalent to Rs. 64,607 million.

The analysis of losses of rainfed pulses indicated that pea having an insignificant share in total rainfed area under pulses suffers from highest productivity loss (1.30 q/ha) equivalent to Rs. 4,149/ha (Table 4), followed by gram with 21 % area and a loss of 1.27 q/ha (Rs. 2,666/ha). Though redgram suffers from third highest productivity loss (1.24 q/ha), it has highest monetary loss of Rs. 4,327/ha among the pulses. Pigeon pea, accounting for 12 % of rainfed area under pulses, is the fourth pulse crop suffering from a loss of >1.0 q/ha equivalent to Rs. 3,255/ha, while the remaining pulses suffer from productivity loss ranging from 0.47 (greengram) to 0.91 q/ha (other pulses). The country as a whole suffers from a productivity loss of 0.93 q/ha equivalent to Rs. 2,583/ha from the rainfed pulse crops. In absolute terms, the monetary loss ranges from Rs. 153 million (pea) to Rs. 16,937 million (other pulses) among the pulse crops at 2011/12 prices, which is equivalent to Rs. 47,934 million.

The country as a whole suffers from a productivity loss of 1.63 q/ha in rainfed cereal, oilseed and pulse crops together due to water erosion, which is equivalent to Rs. 2,484/ha. Out of total production loss of 13.4 Mt, the share of cereals, oilseeds and pulses is 66, 21 and 13 %, respectively (Fig. 4). In monetary terms, the total loss amounts to about Rs. 205.3 billion considering minimum support price during 2011/12 with share of cereals,

Table 2 Estimated annual per-unit area production and monetary losses due to water erosion from major rainfed cereal crops in India

Crop	Potential eroded rainfed area ('000 ha)	Production loss (t)	Unit area production loss (q/ha)	Monetary loss (Rs. million)	Unit area monetary loss (Rs/ha)
Barley	193.6	29,781	1.54	232	1,200
Finger millet	1,502.8	558,788	3.72	5,867	3,904
Maize	5,968.9	1,857,442	3.11	18,203	3,050
Paddy	19,052.2	4,308,786	2.26	46,535	2,443
Pearl millet	5,137.6	577,100	1.12	5,656	1,101
Sorghum	8,061.3	844,256	1.05	8,274	1,026
Wheat	2,694.6	564,640	2.10	6,324	2,347
Other cereals and millets	937.9	168,690	1.80	1,692	1,804
Total	43,548.9	8,909,483	2.05	92,783	2,131

Table 3 Estimated annual per-unit area production and monetary losses due to water erosion from major rainfed oilseed crops in India

Crop	Potential eroded rainfed area ('000 ha)	Production loss (t)	Unit area production loss (q/ha)	Monetary loss (Rs. million)	Unit area monetary loss (Rs/ha)
Castor	672.3	107,462	1.60	5,094	7,577
Groundnut	5,447.0	902,233	1.66	24,360	4,472
Linseed	369.3	21,911	0.59	684	1,852
Niger	357.9	22,246	0.62	645	1,802
Rapeseed	2,015.0	297,936	1.48	5,512	2,735
Safflower	368.1	35,449	0.96	638	1,734
Sesamum	1,648.7	104,070	0.63	3,538	2,146
Soybean	7,490.6	1,153,886	1.54	19,501	2,603
Sunflower	1,594.0	106,510	0.67	2,982	1,871
Other oilseeds	587.8	59,489	1.01	1,653	2,812
Total	20,550.7	2,811,192	1.37	64,607	3,144

Table 4 Estimated annual per-unit area production and monetary losses due to water erosion from major rainfed pulse crops in India

Crop	Potential eroded rainfed area ('000 ha)	Production loss (t)	Unit area production loss (q/ha)	Monetary loss (Rs. million)	Unit area monetary loss (Rs/ha)
Blackgram	1,902.2	117,115	0.62	3,865	2,032
Gram	3,892.4	494,108	1.27	10,376	2,666
Greengram	1,454.2	68,400	0.47	2,394	1,646
Horsegram	243.9	15,030	0.62	496	2,033
Lentil	1,202.2	72,796	0.61	1,638	1,362
Pea	36.8	4,766	1.30	153	4,149
Pigeon pea	2,294.2	233,348	1.02	7,467	3,255
Redgram	1,064.9	131,668	1.24	4,608	4,327
Other pulses	6,464.8	590,136	0.91	16,937	2,620
Total	18,555.6	1,727,367	0.93	47,934	2,583

oilseeds and pulses as 45, 32 and 23 %, respectively. About 53 % of the total monetary loss is accounted for by paddy (22 %), groundnut (12 %), soybean (9 %) and maize (9 %) crops.

Background information pertaining to the productivity losses in individual rainfed cereal, pulse and oilseed crops in the country at national level is presented in Supplementary Table 30.

Discussion

Productivity Losses of Rainfed Crops in States

Cereals

Highest productivity loss in a small state of Goa (10.9 q/ha) is attributed to 39 % production loss occurring from

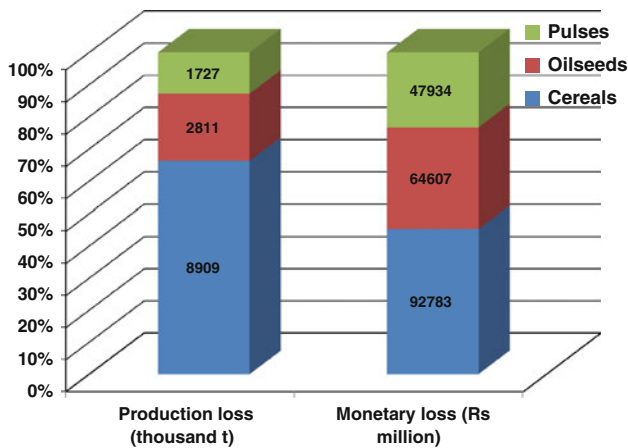


Fig. 4 Estimated annual production and monetary losses of rainfed cereal, oilseed and pulse crops due to water erosion in India

paddy crop alone, which is cultivated in 99 % of its rainfed area under cereals [14]. The crop is mostly cultivated in red soils, which are relatively more prone to water erosion than black and alluvial soils. In case of hilly state of Nagaland, the high loss (6.5 q/ha) is due to 40 % production loss in paddy cultivated in 57 % of rainfed area under cereal crops as well as other crops experiencing significant production loss ranging from 34 % (finger millet) to 45 % (pearl millet) from cultivation on steep slopes in red soils leading to high erosion rates in the state. In case of Manipur, paddy (97 % of rainfed area under cereal crops) and maize suffering from 23 and 21 % production loss, respectively, contribute to high losses. In Andhra Pradesh, a large number of rainfed cereals are cultivated, such as maize (31 %), sorghum (28 %), paddy (29 %), finger millet (33 %) and pearl millet (26 %), that cause the high productivity loss. Except sorghum, all these crops are cultivated in red soils. Sorghum is cultivated in red as well as in black soils. Black soils, though less prone to erosion than red soils, are, however, highly erosive as they are subject to severe sheet and rill erosion. Kerala suffers mainly from production losses in paddy (23 %) cultivated in red soils. Meghalaya suffers mainly from paddy (31 % production loss from 75 % of rainfed land under cereals) and maize (28 %) production loss. Meghalaya's sister states of Mizoram and Arunachal Pradesh suffer from losses in paddy, maize and 'other cereals and millets' (comprising minor cereals and millets) cultivated in red soils. In case of Jharkhand (1.9 q/ha), cereal crops are cultivated mostly in red soils and partially in alluvial soils. Alluvial soils are relatively less affected by water erosion, and hence, the state has a lower rate of productivity loss from rainfed cereals. For the same reason, states located in alluvial plains—Haryana, Punjab, Bihar and West Bengal—suffer from negligible productivity loss.

Considering total production losses in rainfed cereal crops, Karnataka experiences the highest loss (1.47 Mt) followed by Maharashtra, Madhya Pradesh, Chhattisgarh, Odisha, Andhra Pradesh, Assam, Uttar Pradesh, West Bengal and Jharkhand [14], which is not the trend in terms of productivity losses discussed above. A comparison of states, following two different approaches, indicated that except Karnataka and Andhra Pradesh, none of the states ranked high according to productivity losses criteria are ranked in top ten states based entirely upon total production losses in cereal crops. In fact, the eight states are ranked 12–22 places higher in terms of productivity losses. It thus justifies the need for the estimation of losses on per-unit area basis rather than considering the losses only in totality.

Oilseeds

The hilly state of Nagaland (6.3 q/ha) suffers from the highest productivity loss in case of rainfed oilseeds mainly due to soybean, which loses 54 % of its production while accounting for 84.5 % of the state's rainfed cultivated area under oilseeds. Groundnut also suffers a production loss of 54 % in this state, as well as in the small state of Goa (6.0 q/ha), where it is the main cause of high productivity loss. Arunachal Pradesh and Kerala follow due to >40 % production loss from oilseeds, while Tamil Nadu suffers 26–27 % production loss from oilseeds cultivated in red soils. In Sikkim, Meghalaya and Mizoram, rapeseed and sesamum suffer from >30 % of production losses. Rest of the states experiencing higher productivity loss than the national average include Maharashtra (17 %), Madhya Pradesh (20 %), Karnataka (25 %) and Rajasthan (28 %). In Rajasthan, oilseeds are cultivated in black and alluvial soils, while in Madhya Pradesh and Maharashtra, they are grown in all the three major types of soil. On the basis of total production losses in rainfed oilseed crops, the top eight states are Madhya Pradesh (0.8 Mt) followed by Maharashtra, Karnataka, Andhra Pradesh, Rajasthan, Gujarat, Tamil Nadu and Odisha. Except Tamil Nadu, none of these states are ranked in the top eight states suffering from the losses on per-hectare basis. The other seven states rank at 11–23 places higher on the basis of productivity losses.

Pulses

Meghalaya has highest loss of 4.4 q/ha in rainfed pulse crops due to 33 % total production loss in pulse crops. Its four neighboring hill states—Mizoram, Nagaland, Arunachal Pradesh and Sikkim—also suffer from high productivity losses due to 27, 40, 38 and 26 % total production losses, respectively. Similarly, Kerala, Uttarakhand, Assam and Delhi experience 23, 22, 23 and 7 % production losses from rainfed pulses, respectively. Uttarakhand experiences

this loss due to high erosion rates [14] from steep topography and faulty management practices. Madhya Pradesh (0.3 Mt) followed by Karnataka, Maharashtra, Andhra Pradesh, Uttar Pradesh, Odisha, Chhattisgarh, Gujarat, Rajasthan and Tamil Nadu are the leading ten states in terms of total losses from pulse crops, but none of these states rank in the top ten on the basis of per-hectare production losses. It fully justifies the need for the estimation of losses on per-unit area or productivity basis rather than by considering only the total losses to set priority for adoption of conservation measures to check soil erosion.

Cumulative Productivity Losses of Rainfed Crops in States

High cumulative productivity losses in rainfed cereal, oilseed and pulse crops in Goa (9.3 q/ha) are mainly due to high losses in the order of cereals and pulses while Nagaland's high losses are attributed to losses in pulses and cereals. Manipur suffers because of losses in cereals, whereas Kerala, Meghalaya, Mizoram, Arunachal Pradesh, Sikkim and Karnataka experience high losses in all the three types of crops. Uttarakhand has high losses only in cereals and pulses. The ranking of states according to per-hectare cumulative losses occurring from all the rainfed cereal, oilseed and pulse crops is different from the ranking as per the total production losses. Out of the top ten states listed above, only Karnataka is ranked among the top ten states as per the total losses. The state is ranked first as per the total losses [14] but ranked tenth as per losses on per-hectare basis. The rest of the nine states are ranked at 5 (Uttarakhand) to 22 (Goa) places higher than their rank as per total losses. It clearly indicates the need to assess the production losses on per-unit area basis, to identify the states suffering from high production losses due to water erosion.

Productivity Losses of Rainfed Crops in Zones

The southern zone suffers from highest productivity losses from rainfed cereals among the zones as it comprises Andhra Pradesh, Karnataka and Kerala, which are among top ten states that suffer from highest per-hectare production losses in rainfed cereal crops. For the same reason, the northeastern zone is the second highest loser as it comprises six out of the top ten losing states. In case of central zone, both the constituent states suffer from higher productivity loss than the national average. In case of eastern zone, only Odisha suffers from higher productivity loss compared to the national average, but in case of northern zone, two states, namely Uttarakhand and Himachal Pradesh, suffer from higher productivity losses than the national average due to water erosion. The western zone

has the lowest losses. Though Goa has the highest loss among all the states, the losses incurred by other three states are below the national average. The above rankings of six zones on the basis of productivity loss in rainfed cereals are different from total production loss rankings, i.e., southern followed by central, eastern, western, northern and northeastern zones [14]. Only similarity is that southern zone is ranked on the top as per both the criteria, which indicates its importance for adopting appropriate conservation measures. Noteworthy difference is in the ranking of northeastern zone that ranks lowest on production loss basis but second on productivity loss basis. Since this zone has the smallest rainfed area under cereals, it is ranked last in terms of total losses, but on per-unit area basis, its losses are significant.

Northeastern zone suffers the most in case of oilseeds as five out of eight states suffering from highest productivity loss are in this zone. Southern zone follows as it has only two states ranked among the top eight losing states. The central zone is ranked after the southern zone because its two states experience a loss approximately equal to the national average. The western zone closely follows as Goa is ranked second among all the states, and two states (Rajasthan and Madhya Pradesh) are having a higher loss than the national average loss. The eastern and northern zones comprise states that have lowest productivity losses among all the states. These rankings are significantly different from the total production loss rankings of the six zones, i.e., western followed by southern, central, eastern, northeastern and northern zones. Northern zone is ranked last in both the rankings, which indicates that the zone is having least problem of production loss of rainfed oilseed crops. Significantly, northeastern zone, which is ranked fifth in total loss terms with smallest area under rainfed oilseed crops, is ranked highest on productivity loss basis. On the other hand, the western zone ranked highest in terms of total loss is ranked fourth on per-unit area loss basis for oilseed crops.

Similar to oilseeds, the northeastern zone suffers from highest loss of productivity in rainfed pulses due to its five states ranked topmost among the top ten states suffering from such losses. The rankings in terms of total losses from rainfed pulses, i.e., southern zone followed by central, western, eastern, northern and northeastern zones, are entirely different from the above rankings on per-unit area basis. The most significant difference is in the ranking of the northeastern zone, which is ranked last as per total losses with smallest area under rainfed pulses, but ranks first on the basis of productivity losses.

The productivity loss rankings considering all the cultivated rainfed cereals, oilseeds and pulses are different from those based on total production loss, i.e., southern zone followed by central, western, eastern, northern and

northeastern zones [14]. A significant difference between the two rankings is in case of northeastern zone, which has smallest rainfed area under these crops and, therefore, has lowest total production loss. However, in terms of productivity loss, it is contrastingly ranked the highest. It clearly indicates that even zones having smaller total production loss need to be given high priority for tackling national problem of production loss due to water erosion.

Productivity and Monetary Losses of Rainfed Crops in India

Finger millet suffers the highest loss of 3.72 q/ha due to significant losses in Karnataka (5.2 q/ha), Andhra Pradesh (3.4 q/ha) and Uttarakhand (3.0 q/ha), which are important states in terms of rainfed area under the crop at national level. About 65 % of total rainfed area under the crop lies in southern zone, having red soils, which are most susceptible to fertility loss due to water erosion. It is followed by maize because Karnataka (10.0 q/ha) and Andhra Pradesh (8.9 q/ha) are important states having some of largest rainfed areas under the crop, which occupies 14 % of total rainfed area under cereals. Paddy accounts for 44 % of total rainfed area under cereals, about 80 % of which lies in eastern (alluvial and red soils), central (red and black soils) and northeastern (alluvial soils) zones. The important states are Andhra Pradesh (7.2 q/ha), Karnataka (6.6 q/ha), Chhattisgarh (3.0 q/ha) and Odisha (2.8 q/ha). Paddy is cultivated as rainfed crop in many states, such as northeastern zone, that have relatively lesser cultivated area under the crop but suffer from >3.0 q/ha of productivity losses. These states need to implement conservation measures [16] intensively for mitigating these losses and improve the rural economy. In case of wheat, Madhya Pradesh (2.9 q/ha), Uttarakhand (2.8 q/ha) and Maharashtra (2.6 q/ha) are important states in terms of productivity losses. Though other cereals and millets have only 2 % share in total rainfed area under cereals, 64 % of it lies in black soils of central zone and these soils are prone to erosion losses leading to productivity loss. Barley suffers losses mainly in Uttarakhand (2.5 q/ha), Madhya Pradesh (1.7 q/ha) and Uttar Pradesh (1.2 q/ha). Pearl millet occupies 12 % of total rainfed area under cereals, out of which about 96 % lies in red and alluvial soils of southern, western and northern zones. Red soils are highly prone to such losses. Sorghum accounts for 19 % of total rainfed area under cereals, 89 % of which lies in the southern (Karnataka and Andhra Pradesh black soils) and western (Maharashtra black soil) zones.

Groundnut accounts for 27 % of the total rainfed area under oilseeds, mainly in red soils of southern zone and black soils of western zone, resulting in high productivity

losses. Tamil Nadu (3.6 q/ha), Karnataka (3.5 q/ha) and Madhya Pradesh (2.3 q/ha) are important states under the crop at national level. Though castor follows groundnut in terms of oilseed losses, however, the crop has only 3 % share in total rainfed area under oilseeds. Nonetheless, it is an important crop for mitigating the total production losses of rainfed oilseeds. Soybean is an important oilseed crop accounting for 36 % of the total rainfed area under oilseeds (mainly in central and western zones). Chhattisgarh (3.3 q/ha) and Andhra Pradesh (3.2 q/ha) are important states for mitigating the losses at national level. About 54 % of the rainfed area under rapeseed is located in western (Rajasthan, black soils) and central (Madhya Pradesh, all three major soil groups) zones. The other important states are Gujarat (2.8 q/ha), Rajasthan (2.2 q/ha) and Madhya Pradesh (1.5 q/ha).

The high loss of gram is because the crop is cultivated in black and red soils of central and southern zones, and black and alluvial soils of western zone. Uttar Pradesh (1.8 q/ha) and Madhya Pradesh (1.4 q/ha) are important states for this crop. Though share of redgram is only 6 % in total area under rainfed pulses, Karnataka (1.4 q/ha) is the most important state for mitigating this national loss. For pigeon pea, suffering from a loss >1.0 q/ha, Madhya Pradesh is the most important state suffering from a loss of 1.8 q/ha.

Conclusions

The total production losses estimated earlier by following a systematic approach only identified the states and crops that are suffering from maximum losses on the basis of extent of total rainfed area. A more pragmatic approach was adopted in the present study where the effect of total area was neutralized by considering the losses among crops, states or zones on per-hectare or productivity basis. The analysis indicated that productivity losses of the leading states in case of each crop group were 5 times of the respective national average, mainly due to cultivation of crops in red or black soils. These states need to implement the conservation measures intensively under suitable policy interventions for mitigating these production losses and improving their individual rural economies. The large states of Andhra Pradesh, Karnataka and Tamil Nadu that were ranked high on the basis of total production losses were observed to also suffer from high productivity losses, which indicated that losses from these states definitely need to be mitigated on priority. This is more so, as mitigation of losses in these states having large rainfed areas under these crops will significantly reduce the losses at national level. Among the six zones, the hilly northeastern zone and red and black soils southern zone are most affected followed by central zone. The northeastern zone, though accounts

for only 4 % of rainfed area under these crops, needs to be given high priority for tackling the problem of soil erosion as productivity losses are highest in this zone. India as a whole loses 1.63 q/ha of productivity in rainfed crops, which is valued at Rs. 2,484/ha. In absolute terms, the production and monetary losses are 13.34 Mt and Rs. 205.32 billion, respectively. Out of these production and monetary losses, cereals are the major contributors (66 and 45 %, respectively), followed by oilseeds (21 and 32 %, respectively) and pulses (13 and 23 %, respectively). About 53 % of the total monetary loss is accounted for by paddy, groundnut, soybean and maize crops. Over time, the economic loss, if remained unchecked, will continue to rise due to increase in prices of various crops, thus affecting agricultural economy of the country. The findings of the study will help the central and state governments, policy makers, soil conservationists and environmentalists to prioritize the states and the crops being cultivated in a given state, for planning and implementation of conservation programs effectively following watershed approach to bring the prevailing erosion rates within permissible limits and prevent the gigantic recurring losses in productivity of rainfed crops in the country.

The Way Forward

Analysis of the productivity losses of the 27 rainfed cereal, oilseed and pulse crops due to water erosion on cumulative basis in different states and zones and on individual crop basis at the national level has provided a comparative picture of losses being incurred among the crops, states and zones. It clearly identifies the states and crops that need to be prioritized for the implementation of conservation programs on watershed basis to check soil erosion and contain the national production losses. Mitigation of losses in the prioritized states at the first level and the prioritized crop within the priority state at the second level will minimize the losses in the shortest possible period. Mitigation of losses in the priority states having large rainfed areas under these crops will significantly reduce the losses at national level and boost productivity of rainfed areas, which are having potential to achieve future agricultural production targets of the country. For this, appropriate policy interventions need to be devised and adopted at national and state levels for effective implementation by the concerned ministries and funding agencies. Channelizing the limited development funds and scarce resources as per the identified priorities would go a long way in achieving production prosperity in the country and ensure environmental security.

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