Soil Nutrient Balance Sheets in India: Importance, Status, Issues, and Concerns

By H.L.S. Tandon

Negative nutrient balances in most Indian soils not only mirror poor soil health, they also represent severe on-going depletion of the soil's nutrient capital, degradation of the environment, and vulnerability of the crop production system in terms of its ability to sustain high yields. In the prevailing regime of widespread negative nutrient balances, it is difficult to foresee positive nutrient balances in most parts of India, even when all available sources of plant nutrients are deployed, unless their quantity and efficiency is raised substantially. Depleted soils cannot be expected to support bumper crops or high growth rates.

Many readers will recall the grave situation which India faced in the early 1990s when the country's foreign exchange reserves were depleted to alarmingly low levels. The concern for negative monetary balances triggered major economic reforms, the benefits of which are being witnessed today not only in India but the world over. The state of depletion of soil nutrient reserves reflected in negative nutrient balances is very similar to the macro-economic crisis of the early 1990s. The only difference being that while the economic reforms were put into place rapidly, the concern for deteriorating negative soil nutrient balances is largely limited to the scientific community and have not yet rung the alarm bell in the corridors of planning and policy-making.

It should be absolutely clear to those in the Government and its Planning Commission who are emphasising the need to step up the growth rate of agricultural production that poor quality and nutrient depleted soils cannot support any moderate to high agricultural production targets unless the soil nutrient reserves are improved substantially. A key factor in enabling the country to achieve future agricultural production targets will be how well and fast the depletion of soils is reduced and the nutrient balance sheet is moved from red towards green. This will not, and cannot, happen overnight or in a few years, but serious efforts to reverse the process must start right away.

Soil Nutrient Balance Sheets

An assessment of nutrient additions, removals, and balances in the agricultural production system generates useful, practical information on whether the nutrient status of a soil (or area) is being maintained, built up, or depleted. A simplified depiction of nutrient additions and removals is given in **Figure 1**.

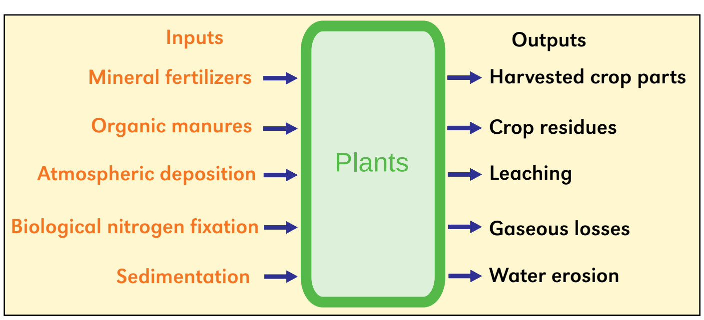

Figure 1. A simplified presentation of nutrient additions and removals in agricultural soils (Smaling, 1993)

Estimates of nutrient input and output allow the calculation of nutrient balance sheets both for individual fields and for geographical regions. It is a book-keeping exercise, similar in many ways to keeping a bank account. A considerable amount of information on nutrient uptake and removal by crops and cropping system is now available. In most cases, different balance sheets are not comparable due to vastly different assumptions and computation methodologies. Several aspects of nutrient uptake, removal, and balances have been dealt with in detail elsewhere (Kanwar and Katyal, 1997; Tandon, 2004).

Nutrient balance sheets in most soils of India have been deficient and continue to be so. This is primarily because nutrient removals by crops far exceed the nutrient additions through manures and fertilisers. For the past 50 years the gap between removals and additions has been estimated at 8 to 10 M t $N+P_2O_5+K_2O$ per year (Tandon, 2004). This has been the case in the past, at present, and this will likely continue into the future. To this extent, the soils are becoming depleted – the situation is akin to mining soils of their nutrient capital, leading to a steady reduction in soil nutrient supplying capacity. On top of this deficit are the nutrient losses through various other means. For example, nutrient losses through soil erosion are alarmingly large, but are rarely taken into account.

Nutrient loss through soil erosion is second only to nutrient removal as a result of crop production. An annual loss of 8 M t plant nutrients has been mentioned through 5.3 billion t of soil lost by water erosion (Prasad and Biswas, 2000). Estimates of removals through leaching and gaseous losses are not available.

Cropping system based scenario: In many cases, even the well managed cropping systems raised on currently recommended rates of nutrient application end up depleting soil fertility. The rice-wheat annual cropping system, the most intensive annual system practiced in India, is cited as one example (Tiwari et al., 2006). Productivity of the rice-wheat system was tested at 10 locations across India for 2 years. Crops received recommended rates of nutrients through fertilisers as per the site specific nutrient management (SSNM) plan. Average annual grain productivity was 13.3 t/ha. In many cases, even when the nutrients were applied based on the requirement of individual fields, nutrient uptake exceeded nutrient input resulting in negative balances. The N and P balances were

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; M t = million metric tons; S = sulphur; BNF = biological N fixation.

Table 1. Summary of nutrient balance sheet in dryland agriculture.	
	$N+P_2O_5+K_2O$, M t
Estimated additions (fertilisers)	1.0
Estimated removals (crops)	7.4
Balance	-6.4

Source: Tandon (2004).

Table 2. Summarised nutrient balance sheet of the plantation sector.		
Nutrient	Gross balance, '000 t	Net balance, '000 t
N	-179	-272 to -284
P_2O_5	-52	-91 to -97
K_2O	-186	-283 to -298
Total	-417	-643 to -680

Source: Tandon (2004).

positive at 5 sites and negative in the other 5. The K and S balances were negative at all 10 sites; the K balances were the most negative.

The dryland scenario: In addition to the intensively cropped irrigated lands, it is noteworthy that even in the vast non-irrigated dry lands, overall nutrient balances are negative as removals exceed additions by 7 to 1 (**Table 1**). These lands are estimated to receive 10% of the fertiliser used in India, but account for 30% of the total nutrient removal. Expectation for high levels of crop productivity would be unrealistic in such a scenario unless the nutrient depletion process is drastically reduced if not halted.

Plantation sector scenario: The fate of the supposedly well-managed plantation sector is not much different as the depletion of nutrients is rampant and increasing in intensity. Gross nutrient balances sum to -417,000 t $N+P_2O_5+K_2O$ and are much worse on a net basis after accounting for fertiliser use efficiency (**Table 2**).

Some segments where nutrient balances are expected to be positive are vineyards, intensively cultivated field under potato/vegetables, bananas, sugarcane, and cotton (N only).

State level scenario: A state-wise picture of nutrient additions, removals, and balances is provided in **Table 3**. The computations in many cases are based primarily on fertiliser input alone. In most cases, the nutrient balances are negative indicating that nutrient removals exceed nutrient additions.

The national scenario: By adding up recent state-level nutrient balance sheets computed earlier (Tandon, 2004), an illustrative balance sheet of NPK in Indian agriculture is summarised in **Table 4** and **Figure 2**. The present scenario is based mostly on nutrient input through fertilisers for which data are available. The net figures have been arrived at by adjusting fertiliser input for use efficiencies of 50% for N, 35% for P_2O_5 (including residual effects), and 70% for K. On the removals side, 80% of crop uptake for N and P was considered along with 60% of crop K uptake.

On a gross basis, the balance is positive for N and P, but is negative for K. On a net basis, which is more realistic and useful for planning nutrient management, the balance is negative

Table 3. Nutrient addition through fertilisers, nutrient removal by crops, and apparent balance in major states of India ('000 t).

State	N			P_2O_5			K_2O			$N+P_2O_5+K_2O$		
	Add	Rem	Bal	Add	Rem	Bal	Add	Rem	Bal	Add	Rem	Bal
A.P.	1,256	477	779	576	497	79	191	817	-625	2,024	1,791	233
Assam	38	257	-219	15	74	-59	18	294	-277	71	625	-554
Bihar	618	481	137	101	102	-1	54	492	-438	774	1,075	-301
Chhattisgarh	67	156	-89	68	68	-0	13	137	-124	148	360	-212
Gujarat	691	340	351	268	121	147	61	426	-365	1,020	887	123
Haryana	597	362	235	201	145	56	5	490	-485	803	998	-195
H.P.	29	43	-14	5	8	-3	4	25	-21	39	76	-37
Jharkhand	40	165	-125	15	60	-45	5	20	-15	60	245	-185
Karnataka	681	473	209	374	239	135	216	604	-388	1,272	1,315	-43
Kerala	87	149	-62	44	53	-9	87	176	-89	219	377	-158
M.P.	519	696	-177	344	431	-87	24	849	-825	888	1,976	-1,088
Maharashtra	923	1,559	-636	450	608	-158	197	2,096	-1899	1,571	4,262	-2,692
NE States	19	96	-77	5	17	-12	3	84	-81	41	198	-157
Orissa	196	227	-31	56	104	-48	40	282	-242	291	614	-323
Punjab	1,081	589	492	275	279	-4	19	764	-745	3,276	3,580	-304
Rajasthan	547	835	-288	147	235	-88	7	1,068	-1061	1,375	1,631	-256
Tamil Nadu	484	405	79	145	111	34	162	398	-236	791	914	-123
U.P.	2,387	1,497	889	776	305	471	114	1,777	-1664	3,276	3,580	-304
W.Bengal	562	764	-202	297	241	56	226	801	-575	1,085	1,806	-721
All India	10,923	9,613	1,310	4,188	3702	486	1,454	11,657	-10,203	16,564	24,971	-8,406

Add = Additions, Rem = Crop uptake, Bal = Balances.
Summarised by Tandon (2004) from various Indian published sources from Fertiliser News.

Table 4. Soil nutrient balance sheet in India

Nutrient	Gross balance sheet, '000 t			Net balance sheet, '000 t		
	Addition	Removal	Balance	Addition	Removal	Balance
N	10,923	9,613	1,310	5,461	7,690	-2,229
P_2O_5	4,188	3,702	486	1,466	2,961	-1,496
K_2O	1,454	11,657	-10,202	1,018	6,994	-5,976
NPK Total	16,565	24,971	-8,406	7,945	17,645	-9,701

for N, P, K, and S (not shown). The net negative NPK balance or annual depletion of 9.7 M t is 19% N, 12% P, and 69% K. The current estimated average net depletion per ha from India's 143 M ha of net sown area comes to 16 kg N, 11 kg P_2O_5, and 42 kg K_2O (69 kg $N+P_2O_5+K_2O$). The large proportion for K is partly because crops remove an average of 1.5 times more K than N, and K application through fertiliser is much lower than that of N or P.

Thus the nutrient needs of crops and associated nutrient losses of Indian agriculture are so large (and growing each year) that no single source, be it fertiliser, organic manures, or crop residues can meet them by itself. The nutrient deficit can be reduced by putting all available sources of plant nutrients to use. However, Indian soils are still estimated to be losing close to 9 M t $N+P_2O_5+K_2O$ annually even after harnessing currently utilisable organic resources plus input through BNF on a gross basis (**Table 5**).

Some Issues and Concerns

Construction of nutrient balance sheets is tempting, but very challenging because of the many sources of nutrients involved and the range of efficiencies possible from a suite of nutrient sources. Thus nutrient balance sheets will stand modified (upwards or downwards) depending upon the assumptions made, the reliability of the data available, the inclusion of inputs other than fertilisers (organics, BNF) and their efficiency, and the inclusion of nutrient removals through various channels of loss in addition to crop uptake.

A major source of confusion and possible error while dealing with published literature is the question of whether presented nutrient removal figures actually refer to net removals or total nutrient uptake. The other, rather commonly encountered problem concerns the units employed. Often it is not clearly stated whether data are presented on an elemental (P and K) or oxide (P_2O_5, K_2O) basis. Data presented as P or K can in fact turn out to be on an oxide basis when cross checked with the authors.

Divergent assumptions made by various workers regarding nutrient use efficiency are another major problem while working out net nutrient balances (Tandon, 2004). Nutrient use efficiency for both organic and mineral sources have been equated, and is a questionable practice. Unrealistically high and rarely cited efficiency figures (i.e., 100% for P and 100% for K) have been used in the calculation of nutrient balance sheets (Katyal, 2001). These have been justified by stating that whatever P and K are not taken up by a crop remain in the soil and are eventually used. However, even in case of P and K, there can be irreversible conversion into unavailable forms (reductant-soluble P) and also leaching of K in coarse textured soils under flood irrigation or heavy rainfall. Most workers use efficiency figures of 30 to 50% for N, 20 to 30% for P, and 70 to 80% for K.

Table 5. Total nutrient additions, removals and balance in Indian agriculture.

	$N + P_2O_5 + K_2O$, M t
Additions (fertilisers, organics, BNF)	24
Removals (harvested crops, erosion)	33
Balance	9

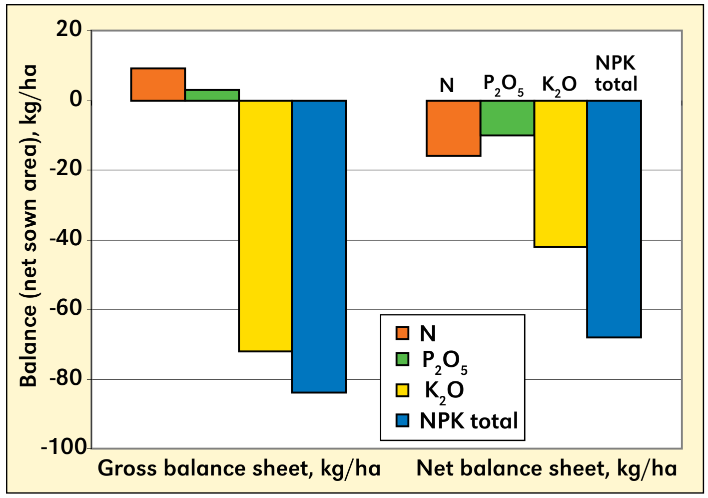

Figure 2. The overall nutrient (NPK) balance in Indian agriculture. Source: Tandon (2004).

The contribution of BNF can be either oversimplified or overlooked in many balance sheets for N. This is unjustified for a country like India in view of its 22 M ha under pulses and another 13 M ha under groundnut and soybean. At an assumed average BNF of 25 kg N/ha, a sizeable input of 875,000 t N is contained in these legumes (550,000 t N in pulses alone). When this N input is integrated into balance sheets and it is assumed that much of what is fixed stays in the plant, the net removal of N is reduced accordingly. In the process, the overall nutrient balance for N is positively altered. Indian researchers have employed figures varying from 50% to 90% as the proportion of BNF-derived N in legumes. But there are cases where researchers have completely ignored BNF while working out the nutrient balances in pulse production systems. In a recent analysis by ICAR scientists, it was concluded that the negative nutrient balances under pulses resulted in a net mining of 395,000 t N, 50,000 t P_2O_5 and 352,000 t K_2O (Ganeshamurthy et al. 2003). In this study, there was no mention of BNF or its contribution to N removal by pulses – as if the entire N removal came from the soil-fertiliser sector.

Nutrient Balances – More Complex Than Input and Output

Nutrient balance sheets are not just mathematical computations, but will continue to be very important for gaining insight into the dynamics of soil fertility, nutrient budgeting, and practical nutrient management planning. However, a meaningful balance sheet requires comprehensive data, realistic assumptions, clear distinction between nutrient removal and nutrient uptake, the inclusion of various sources of nutrients, and their estimated efficiency factors, and accounting of nutrient losses through other routes including erosion. However, in the case of erosion, real losses need to be differentiated from inter-site transfers.

Nutrient recycling should also be taken into account. For example, on the input side, part of mineral fertilisers, particularly N, S, and K, can be leached down the soil profile but get recycled through the pumping of ground waters for irrigation. Over a toposequence, one field's nutrient loss can also become another field's (and farmer's) gain. Nutrients from organic manures can enter the plant after mineralisation. Atmospheric deposits (N, S) originate from N in the air, gaseous losses, or pollution. Similarly, inputs through inter-site transfer of sediments have often been the result of erosion in other areas (i.e., 30% of the soil and nutrients moved by water erosion end up in the sea, the remaining 70% stay on the land).

Table 6. An illustrative example of the information required for computation of detailed nutrient balance sheets.

No	Component	N	P_2O_5	K_2O	Remarks
1.	**Additions**				
1a	**Fertiliser**				
1b	Efficiency	35-60	25-35	65-80	typical values
1c	Net				
2a	**Organic manures/composts**				
2b	Efficiency	10-20	10-25	80-90	
2c	Net				
3a	**Crop residues**				
3b	Efficiency	C:N	C:N	80-90	C:N ratio deciding factor
3c	Net				
4a	**Biological nitrogen fixation**				
4b	Bacterial inoculation	25 kg/ha	–	–	typical
4c	Blue Green Algae	25-30 '			typical
4d	Azolla	30-60 "			see text
5a	Green manure/Green leaf manure				
5b	Efficiency	varies	–	–	
5c	Net				
6a	Soil erosion/runoff				?
7a	Irrigation Waters				?
7b	Gross				?
7c	Net				?
8a	Precipitation				?
8b	Gross				?
8c	Net				?
	Total Additions				
	Gross				
	Net				
	Removals				
9	Crop Uptake				
9a	% retained on the field				
9b	% removed				to be used
10	Nutrients removed by weeds				to be used
11	Nutrients removed by other routes				
11a	Soil erosion				?
11b	Leaching losses				?
11c	Volatilisation/gaseous losses				?
	Total Removals				
12	Nutrient Balance				
12a	Gross				
12b	Net				Ideal

On the output side, harvested crop parts and crop residues both yield valuable organic manures. Most estimates of nutrient removal by crops (from the soil) are overestimates because in many cases nutrient removal is equated with nutrient uptake, and this is not the case in many situations, as discussed in detail elsewhere (Tandon, 2004). The proportion of nutrients taken up which constitute nutrient removal can vary from less than 10% (as in cardamom) to about 30% (as in coffee) to around 90% as in several field crops when only stubbles and roots are left behind.

Towards Detailed Nutrient Balance Sheets

Only detailed nutrient balance sheets provide a correct picture that can be used for designing nutrient management strategies. An illustrative example of such a balance sheet is provided in **Table 6**. A balance sheet on a net basis also requires data on the use efficiency and residual effect of various nutrients. For nutrients which leave a significant residual effect (P, S, nutrients from organic sources), computation of annual balance sheets is not of much value as it only provides a part of the picture.

Actual nutrient removals by crops, and not the amounts absorbed, need to be taken into account. In many cases, such as jute, a substantial proportion of nutrients absorbed are returned to the fields through leaf-fall well before harvest. Likewise, nutrients removed by weeds and not only the main crop are also important. In the case of hand-weeding, where the plants are uprooted and removed from the field, removals equal uptake. However, in the case of chemical weeding, where plants die but stay in the fields, the absorbed nutrients get recycled and do not contribute to removals.

Where significant amounts of crop residues are returned to the field, these contribute significant quantities of K. Likewise, legume residues also contribute to the N input as does BNF through various systems such as N fixing bacteria, blue green algae, and Azolla. In the case of Azolla, the N input depends on the times Azolla is harvested when grown as a dual crop or whether its biomass is brought in from outside and ploughed in as a green manure. Traditional green manures bring in a significant amount of N (30 to 120 kg N/ha), but the other nutrients added by them are simply soil derived nutrients which have been taken up during growth. Green leaf manuring is another route of nutrient additions, which they have in all probability absorbed from another field or field bunds. The nutrients added through organic manures/composts generally last for more than a crop season.

Plant nutrients lost through erosion are important and should be taken into account. However, these constitute either net removals or inter-site transfers which need to be appreciated as all eroded material does not end up in rivers or the sea. It will also make a difference whether nutrient balances are computed for an individual field or for a larger landmass/region. In several cases, net nutrient removals from the soil can be substantial, along with the valuable topsoil.

In the case of nutrient input through irrigation waters, a significant amount of several nutrients can be brought in, but the net addition will depend upon the composition of water, volume and frequency of irrigation, quantities of nutrients retained in the root zone, and those removed from the soil with percolating waters. The same applies to precipitation where nutrient removals through leaching can exceed the nutrients brought in, which also depends on soil physical properties and the rainfall intensity.

For computing N balance sheets, inclusion of BNF is a must. The amounts of N added would depend on the population and effectiveness of the N fixing micro-organisms. Typically, inoculation with N fixing microbes is associated with an N input of 25 to 30 kg/ha. Azolla can contribute 30 to 60 kg N/ha depending on whether one or two harvests are taken during rice growth. Some N fixation takes place even without inoculation where the native bacterial population is sizable and effective.

Finally, the amount of background research required to compute detailed nutrient balance sheets is large and expensive. As the volume of such data increases, the number and dependence on assumptions will decrease, thus providing dependable and realistic nutrient balance sheets which correctly mirror the state of soil health and can be put to use for improving it on a medium to long-term basis. An illustrative example of the information required for computation of detailed nutrient balance sheets is provided in **Table 6**.

Conclusions

Finally, in the absence of any quantum jump in fertiliser use, large-scale nutrient recycling and adoption of IPNS, it is very likely that the nutrient balance sheet of Indian agriculture will continue to be negative and its soils will continue to get depleted for years to come. Poor people and poor soils co-exist.

The time has come to put a stop to further nutrient depletion of agricultural soils and take the severity of negative nutrient balances with the same urgency as the negative balance of payments and foreign exchange depletion was taken in the early 1990s for the country's economic health. This calls for direct and serious intervention at the highest levels. Affirmative action is needed for improving soil fertility and hence soil nutrient balances on a very large scale. Sufficient scientific information is now available to undertake such measures and scientists can play a limited role by focusing on the problem and furnishing area specific guidelines. Major initiatives must come from the political leadership, planners, policy-makers, financial institutions, and the providers of plant nutrients.

We must be very clear that no amount of planning for higher agricultural production targets will bear fruit on impoverished, nutrient depleted soils whose nutrient balance sheets have been in the red for decades. Depleted soils will refuse to deliver the goods if not handled properly. **The custodian of national wealth and well being is as much the soil bank of India as is the Reserve Bank of India.** BC-INDIA

Dr. Tandon is the Director of Fertiliser Development and Consultation Organisation, New Delhi, India, e-mail: fdco@vsnl.net, fdco@airtelbroadband.in.

References

Ganeshamurthy, A.N. et al. 2003. Fert. News, 48 (5) 23-24, 27-34, 37-41.

Kanwar, J.S. and J.C. Katyal (eds). 1997. Plant nutrients needs, supply, efficiency and policy issues. 2000-2025, NAAS, New Delhi, pp329.

Katyal, J.C. 2001. J. Indian Society Soil Sci., 49, 570-592.

Prasad, R.N. and P.P. Biswas. 2000. *In* Singh, G.B. and Sharma, B.R. (eds). 50 years of natural resource management research, ICAR. New Delhi, pp 644.

Smaling, E.M.A. 1993. *In* The role of plant nutrients for sustainable food production in Sub – Saharan Africa, H. Van Reulen and W.H.Prins (Eds.) Leidschendan, The Netherlands: VKP.

Tandon, H.L.S. 2004. Fertilizers in Indian Agriculture – from 20th to 21st century. FDCO, New Delhi, India. pp. 240.

Tiwari, K.N., et al. 2006. Site-specific nutrient management for sustainable high yield agriculture: Results of Rice–Wheat and Rice–Rice Systems. Potash & Phosphate Institute of Canada–India Programme and Project Directorate of Cropping Systems Research (ICAR). pp. 110.