Main Micronutrients Available and their Method of Use

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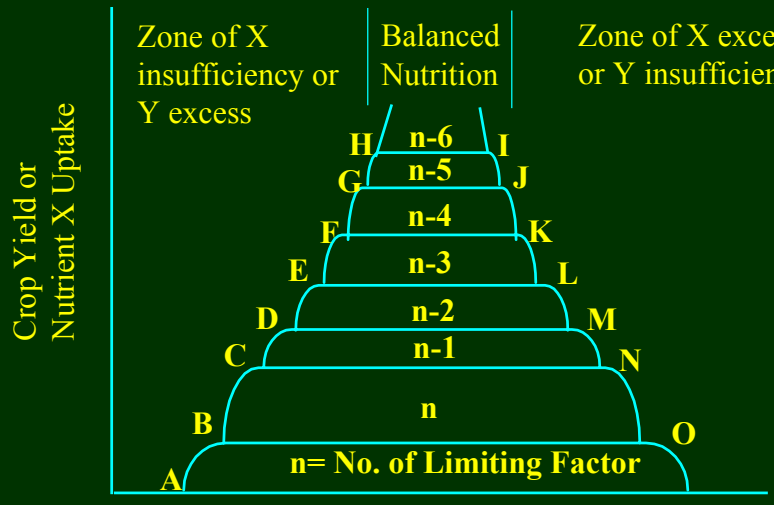
Diagrammatic representation of the response of a crop to a number of limiting factors



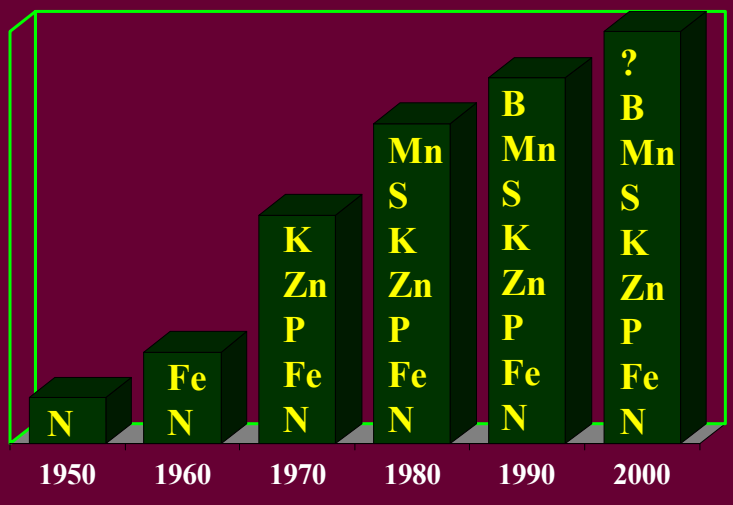
Sumner and Farina (1986)

Yield levels determinant of limiting nutrients

Productivity (made tea), kg/ha	Limiting factor
Below 800	Nil
800 - 1000	N and K
1000 - 2000	N, P, K, Zn + liming
2000 - 3000	N, P, K, Zn + liming with material containing $MgCO_3$
3000 - 4000	N, P, K, Zn, Mg, Si, B + liming, transport process within the soil
Above 4500	N, P, K, Zn, Mg, Si, Mo,B liming, transport process within the soil

Tandon and Kimmo (1993)

Progressive expansion in the occurrence of nutrient deficiencies



Status of micronutrient deficiencies on global scale and in India

Zinc and boron deficiencies suspected in almost every country (Sillanpaa, 1982)

Indian scenario

- **Zinc deficiency most widespread (47%)**
- **Boron deficiency (35%) – From limited data**
- **Iron deficiency (13%)**
- **Molybdenum deficiency (7%) – Limited data**
- **Manganese deficiency (4%)**
- **Copper deficiency (2%)**

Classes of micronutrient fertilizers

- **Inorganic products**
  - Sulfate salts
  - Boron salts
  - Molybdenum salts
  - Sparingly soluble compounds
- **Synthetic chelates**
  - Mostly EDTA salts
- **Natural complexes of plant origin**
  - Lignosulfonates
  - Polyflavonoids
  - Phenols
- **Formulations**

Micronutrient containing fertilizers included in the FCO of India

Nutrient	Fertilizer	Chemical formula	Minimum nutrient content(%)
Zinc	Zinc sulfate heptahydrate	$ZnSO_4.7H_2O$	21
	Zinc sulfate monohydrate	$ZnSO_4.H_2O$	33
	Chelated zinc	Zn-EDTA	12
	Zincated urea(43% N)		2
	Zincated phosphate (Suspension, 12.9% P_2O_5)		19.4

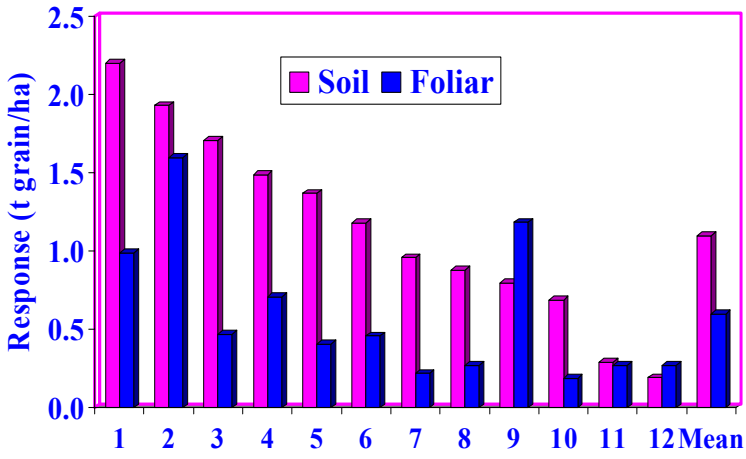
Micronutrient containing fertilizers included in the FCO of India

Nutrient	Fertilizer	Chemical formula	Minimum nutrient content(%)
Boron	Borax	$Na_2B_4O_7.10H_2O$	10.5
	Boric acid	H_3BO_3	17
	Di-sodium octa borate tetrahydrate	$Na_2B_8O_{13}.4H_2O$	20
	Boronated single super-phosphate(16% P_2O_5 powdered)		0.18

Micronutrient containing fertilizers included in the FCO of India

Nutrient	Fertilizer	Chemical formula	Minimum nutrient content(%)
Iron	Ferrous sulfate	$FeSO_4.7H_2O$	19
	Chelated iron	Fe-EDTA	12
Manganese	Manganese sulfate	$MnSO_4.H_2O$	30.5
Copper	Copper sulfate	$CuSO_4.5H_2O$	24
Molybdenum	Ammonium molybdate	$(NH_4)_6Mo_7O_{24}.4H_2O$	52

Response of wheat to soil (10 kg Zn/ha) and foliar (1.5 kg Zn/ha) applied Zn



Source: Katyal and Randhawa (1983)

Effect of different rates of Zn application on yield (q ha^{-1}) of oilseed crops

Crop	No. of experiments	Rates of Zn (kg/ha)			
		0	2.8	5.6	11.2
Groundnut	10	16.5	17.7	17.6	17.6
Raya	9	12.3	14.5	14.3	13.9
Soybean	5	6.3	7.4	8.2	9.5
Sesamum	2	2.1	2.3	3.0	3.2

Nayyar *et al.* (1990)

Response of wheat to the rates and methods of Zn application

Methods of application	Rates of Zn (kg ha^{-1})		
	2.8	5.6	11.2
Broadcast & mix	7.0	9.8	11.7
Drill	8.0	5.7	6.2
Band placement	3.7	4.7	5.3
Top dressing*	1.3	4.2	4.5
Control	39.6		
CD (P=0.05)	6.0		

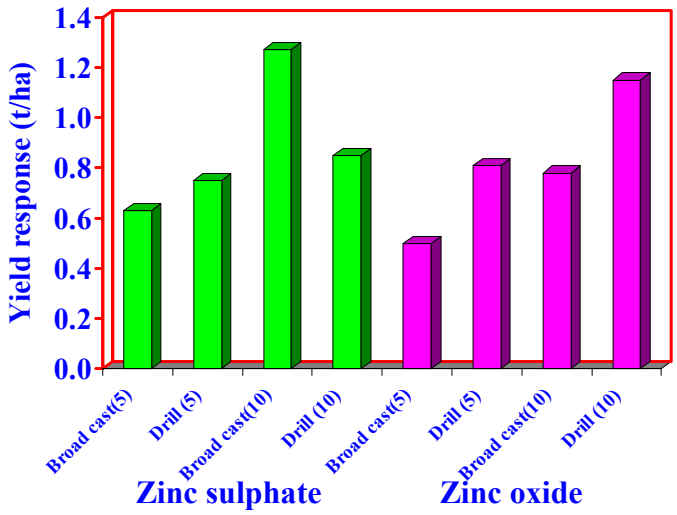
*60 days after seeding

Nayyar *et al.* (1990)

Effect of Zn sources on the yield and Zn uptake by rice (Source: Nayyar *et al.*, 1990)

Source	Zn rate (kg ha^{-1})	Grain yield (q ha^{-1})	Zn uptake (g ha^{-1})
Control	0	19.8	36
$ZnSO_4$	11	41.0	104
	22	52.0	143
ZnO	11	36.7	81
	22	41.6	97
Zn-frits	11	37.4	85
	22	40.3	95
MMCM	11	37.4	90
	22	50.8	126
CD(P=0.05)	Source	4.8	13
	Zn rate	7.1	14

Effect of Zn application on grain yield response of wheat



Source: Sharma and Katyal (1986)

Effect of sources, methods and doses of Zn on yield of wheat (Source: Rathore *et al.*, 1995)

Particulars	Grain yield (q ha^{-1})	CD (0.05)
Control	33.1	
Zn treated	38.0	
Sources		
Zinc sulfate	39.6	1.5
Zinc oxide	37.1	
Zinc phosphate	37.4	
Methods		
Broadcast	37.2	1.2
Band placement	38.8	
Rate (kg Zn ha^{-1})		
5.0	35.5	1.2
10.0	40.3	

Influence of various sources of Zn on dry matter yield and micronutrient composition of rice

Treatment	Dry matter (g pot^{-1})	Zn content (mg kg^{-1})	Ratios in rice			DTPA Zn (mg kg^{-1})
			Cu/Zn	Mn/Zn	Fe/Zn	
Control	5.46	21	1.8	9.1	11.0	0.4
EDTA	9.22	25	3.5	8.7	18.4	0.3
DTPA	7.46	25	3.0	7.3	13.5	0.4
Zn-EDTA	7.55	83	0.6	2.1	3.8	1.9
Zn-DTPA	8.71	80	0.5	2.0	5.3	1.9
$ZnSO_4.7H_2O$	9.26	53	0.5	2.9	4.7	1.8
CD (P=0.05)	3.30	15				0.3

Source: Rattan and Shukla (1991)

Grain yield (t ha^{-1}) of corn with Zn sources band applied with 10-15-0 starter fertilizer

Zn sources	Zn applied (kg ha^{-1})				
	0	0.11	0.33	1.12	3.36
Control	3.9				
Zn-EDTA		8.6	8.7	9.5	8.8
ZnO		8.2	8.2	8.6	9.1
$ZnSO_4$		8.3	8.9	8.7	9.1
Zn-NH_3 complex		7.8	8.6	8.5	8.8
$ZnSO_4$-UAN		8.2	8.2	8.9	8.8

Source: Hergert *et al.* (1984)

Relative availability coefficients (RAC) of Zn-fertilizers in corn

Fertilizer	Water solubility (%)	RAC (%)		
		Yield	Zn uptake	
			A	B
Zn-EDTA	100	70	100	---
$ZnSO_4$	100	77	23	100
Zn lignosulfonate	100	100	22	94
Zinc oxide (55)	55	60	12	48
Zinc oxide (26)	26	37	0.5	1
Zinc sucrate	1	14	5	21

A: Computed with EDTA as 100; B: Computed with $ZnSO_4$ as 100

Source: Gangloff *et al.* (2002)

Fertilizer zinc efficiency (%) in Inceptisol and Vertisol

Crop	Zn (Mixed)	Zn+compost (Mixed)	Zn as zincated urea	Zn for surface transpl.	CD(5%)
Inceptisol					
Rice (D)	1.32	1.32	2.41	1.73	0.37
Wheat (R)	0.45	0.45	1.19	0.47	0.13
Rice (R)	0.82	0.54	1.72	0.52	0.30
Vertisol					
Rice (D)	1.37	1.49	2.70	1.42	0.34
Rice (R)	0.48	0.48	0.28	0.53	0.06

D: direct; R: residual

Source: Deb *et al.* (1986)

Effect of Zn supply on shoot dry weight of the bread wheat

Species		Leaf deficiency symptoms[a]	Shoot dry weight (g/plant) -Zn	Shoot dry weight (g/plant) +Zn	Zn efficiency (%)
T. aestivum	Fakon	2	0.74±0.08	1.15±0.08	64
S. cereale	Pluto	5	1.18±0.07	1.34±0.07	88
Triticale	pluto x Fakon	4	1.10±0.20	1.51±0.02	73
LSD (P=0.05)			0.26	0.12	

a: Nacrotic patches on leaves): 1: very severe to 5: absent or very slight

Source: Cakmak *et al.* (1997)

Effect of Zn-sources on grain yield of corn

Source	Mode	Zn rate (kg ha^{-1})	Grain yield (t ha^{-1}) A	B
Teprosyn (300 g Zn+ 200 g P_2O_5/L)	Seed coating	0.06	5.04	3.40
ZnO (80% Zn)	Seed coating	0.13	5.19	3.09
$ZnSO_4.7H_2O$ (21% Zn)	Basal (soil)	5.00	5.74	3.69
CD (P=0.05)			0.07	0.25

A: Haplustert (DTPA-Zn 0.55 mg kg^{-1}), B: Calciorthent (DTPA-Zn 0.46 mg kg^{-1})

Source: Singh (2002)

Conclusions from multi-locational experiments

- Seed treatment with concentrated micronutrient formulations beneficial in bold size seed crops on marginal Zn soils
- On highly Zn-deficient soils, basal soil application is superior
- Seed treatment with low Zn accretions environmentally attractive
- Seed treatment adds less Zn and is cost effective

Source: Singh (2002)

Interaction harvest of soybean seed with FYM X Zn

FYM (t ha^{-1})	Zn (kg ha^{-1})	Interaction yield (kg ha^{-1})
4	3	26
4	6	133
4	12	62
8	3	187
8	6	240
8	12	125
16	3	260
16	6	134
16	12	-35

Singh (1998)

Influence of rate of B application on seed yield (t ha^{-1}) of oilseed crops

Crop	Rate of B application (kg ha^{-1})		
	0	1.5	2.5
Groundnut	18.9	21.3	23.1
Mustard	12.5	15.6	14.6
Sunflower	17.5	20.7	16.7

Sinha *et al.* (1991)

Effect of doses and methods of boron application on yield of wheat

Treatments	Grain yield (q ha^{-1})
Borax (kg ha^{-1})	
0	7.58
10	23.08
20	26.48
30	23.28
CD (P=0.05)	
Methods	
Full soil	19.82
Half soil + half foliar (2)	21.12
Full foliar (3)	19.41
CD (P=0.05)	0.56

( ) indicates number of foliar spray

Source: Mitra and Jana (1991)

Effect of rate and frequency of B application on cumulative grain yield response (t ha^{-1}) and total B uptake (g ha^{-1}) in calcareous soils

Treatment (kg borax ha^{-1})	Rice-wheat		Maize-mustard	
	Grain	Uptake	Grain	Uptake
8 kg to 1st crop only	2.34	261	0.82	127
8 kg to alternate crop	5.26	722	2.24	466
8 kg to each crop	6.80	1311	3.85	954
16 kg to 1st crop only	4.19	584	1.44	391
16 kg at two crops interval	6.85	1288	3.61	973
16 kg to alternate crop	9.28	1696	4.61	1099
16 kg to each crop	5.45	2622	3.49	2063
32 kg to 1st crop only	3.95	925	2.21	880
32 kg at two crops interval	6.82	2709	3.60	1657
0.25% boric acid solution spray thrice to each crop	2.81	851	2.03	694

(Source: Sakal *et al.*, 2002)

Effect of Fe application on yield and Fe uptake by rice

Treatment	Grain yield (q ha^{-1})		Fe-uptake (kg ha^{-1})	
	UP	P	UP	P
Foliar application ($FeSO_4.7H_2O$%)				
0.5 (6)	37.8	---	1.76	---
1.0 (3)	38.5	---	1.83	---
2.0 (3)	44.7	84.6	2.22	3.98
3.0 (3)	55.1	87.0	2.50	---
Soil application ($FeSO_4.7H_2O$ kg ha^{-1})				
100	15.7	65.4	1.18	2.04
200	26.6	---	1.13	---
Control	15.0	56.3	1.01	1.87
CD (P=0.05)	3.3	6.0	0.84	0.73

P: Puddled; UP: unpuddled; ( ) indicates the number of days;

Source: Nayyar and Takkar (1989)

Issues in Iron

Globally, over three billion people are iron-deficient (Fourth Report on the World Nutrition Situation - 2000)

Anemia – iron deficiency a problem in India.

Cost of iron fortification in India - $88 million per year

Only 10^{-13} of total soil iron in the soluble form for absorption by plants.

Rather than depletion, ability of the plant to mobilize sufficient iron is the issue (Han *et al.*, 1994).

Iron content in some tissues of a transgenic rice line expressing soybean ferritin cDNA

	Seed	Leaf	Stem	Root
	(µg Fe/ g dry weight)			
Transformants				
(Fk 1)	38.1±4.5[a]	104.8±7.9[b]	162.8±8.1[b]	962.1± 65.6[b]
(Fk 11)	35.9±7.7[a]	98.8±25.8[b]	175.5±17.2[b]	966.8± 105.7[b]
Nontransformants				
(N 4)	14.3±3.0[a]	119.3±8.9[b]	170.0±5.3[b]	956.0±37.4[b]

a: Significant or b: nonsignificant differences between the mean values were calculated by F test ($P<0.05$)

Source: Goto *et al.* (1999)

Effect of mode, source and rate of Mn application on yield, Mn concentration and Mn uptake by wheat (Source: Nayyar & Bansal, 2000)

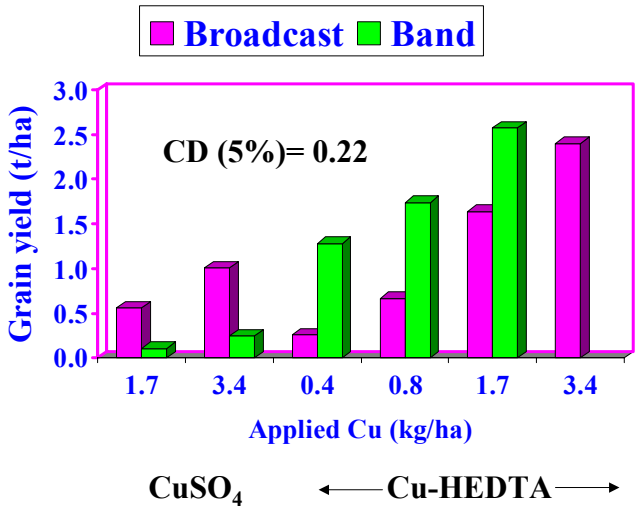
Source	Rate	Grain yield (t ha^{-1})	Mn conc. (mg kg^{-1}) Grain	Mn conc. (mg kg^{-1}) Straw	Mn uptake (g ha^{-1})
	Soil application				
$MnSO_4.H_2O$	20 kg Mn ha^{-1}	2.58	13.0	7.0	65
	40 kg Mn ha^{-1}	2.70	14.5	7.5	74
	Seed treatment				
$MnSO_4.H_2O$	75 g kg^{-1}	2.90	14.8	13.5	114
Teprosyn-Mn	5 mL kg^{-1}	2.50	17.3	14.0	102
	Foliar Spray				
$MnSO_4.H_2O$	0.50%	3.85	16.5	12.3	150
	1.00%	4.00	17.8	14.0	173
Mn-EDTA	0.10%	3.73	16.0	11.3	137
	0.25%	4.05	18.0	13.0	166
Control yield (t ha^{-1})		2.25	11.8	6.3	52
LSD (P=0.05)		0.69	4.2	3.1	32

Copper fertilization

- Regular use of Bordeaux mixture supplements Cu
- Soil application of Cu preferred under continuous monitoring
- 5-15 kg Cu ha^{-1} under Broadcast
- 1-4.5 kg Cu ha^{-1} under Band placement
- 100-200 g Cu ha^{-1} for Foliar spray

Source: Katyal and Rattan (1990)

Effect of Cu carrier, rate and method of application on yield of wheat (Source: Varvel, 1984)



Effect of mode of application of Cu on the tuber yield of potato

Treatment	Yield ($q\ ha^{-1}$)
Soil application (10 kg $CuSO_4$ ha^{-1})	136 (105)
Foliar spray (0.2% $CuSO_4$ at 60 & 90 DAT)	148 (100)
Seed soaking (0.05% $CuSO_4$ solution for 3 h)	155 (108)

( ) indicates yield at control

Source: Dwivedi and Dwivedi (1992)

Effect of modes of molybdenum application on yield of soybean

Mode of application	Yield at control ($q\ ha^{-1}$)	Grain yield response ($q\ ha^{-1}$)
Soil (0.5 kg Mo ha^{-1})	8.45	6.5
Foliar (0.05% Mo sol.)*	8.65	4.4

* At 60 and 90 days after sowing (DAS) for soybean; 120 and 150 DAS for wheat;( ) indicates yield at control;

Dwivedi *et al.* (1990)

Effect of molybdenum on yield of oilseed crops in red loam soils of Bihar plateau

Mo levels (kg/ha)	Yield (q ha^{-1})		Yield responses (q ha^{-1})	
	Groundnut (pod)	Soybean (grain)	Groundnut	Soybean
0	15.4	18.2	---	---
0.2	15.9	20.9	0.5	2.7
0.4	21.6	22.2	6.2	4.0
0.6	18.4	22.1	3.0	3.9
0.8	14.2	22.9	-1.2	4.7

Sinha (1983-87)

Effect of molybdenum application on the grain yield and Mo uptake by soybean grains

Sharma and Minhas (1986)

Treatment	Yield (q ha^{-1})	Mo uptake (g ha^{-1})
Soil application (g ha^{-1})		
Mo_0	18.6	0.21
Mo_{35}	17.7	0.23
Mo_{70}	21.8	0.29
Mo_{105}	26.7	0.29
Mo_{140}	24.1	0.31
Seed treatment		
Mo_o	15.5	0.15
Mo_{35}	19.5	0.27
Mo_{70}	18.4	0.48
Mo_{105}	19.3	0.61
Mo_{140}	19.5	0.71
CD at 5%	3.22	0.19

Philosophy of micronutrient fertilization

- Shotgun or insurance application
  - Hazardous particularly for B and Mo
- Prescription application
  - Widely followed
- Product research essentially centers around single micronutrient carrier

Source: Mortvedt (1991)

Projected product requirement in 2025 AD

Products	Reference
Zinc sulfate 3-5 lakh tons	Rattan *et al.* (1997)
Zinc sulphate 15 lakh tons Copper sulfate 11,363 tons Iron sulfate 1,71,426 tons Manganese sulphate 18,331 tons	Takkar *et al.* (1997)

Some facts about micronutrient fertilizers in India

Fertilizers	Installed capacity (t)	Production (t)	Use (%)	Price-range (Rs/t)
Zinc sulfate (132)	157,050	58,440	83+11	8,000-12,000
Ferrous sulfate (27)	47,605	33,530	12+14	700-3,000
Copper sulfate (43)	22,685	12,470	14	31,000-50,000
Manganese sulfate (8)	7,270	4,100	22	6,500-13,250
Borax (12)	30,400	21,950	7	24,000-30,000
Solubor (1)	5,000	3	100	69,000
Ammonium molybdate (6)	80	35	20	2,60,000-4,75,000
Chelated zinc (21)	1,785	360	100	1,10,000-2,00,000
Chelated iron (13)	1,100	274	100	1,10,000-1,50,000
Mixtures				
Soil application material (88)	19,852	10,051	100	8,000-30,000
Powder for spray (70)	8,953	4,107	100	3000-12,500
Liquid for spray (000L) 46	1,480	908	100	40-110 (Rs/L)

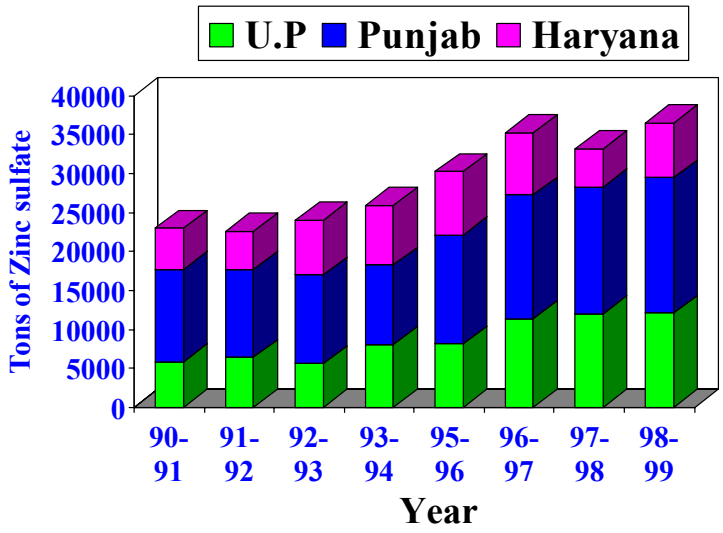
Source: PDIL (1996)

Production of zinc sulfate in India

Year	Production (tons)
1985-86	27,178
1986-87	35,564
1987-88	41,708
1988-89	37,660
1989-90	42,445
1990-91	55,390
1991-92	58,440
2001-02	51,121
2002-03	48,978

Compiled from different sources

Consumption of zinc sulfate in three states of India (Source: Fertiliser Statistics, NR)



Problems encountered in fluctuating zinc sulphate production

- Non-synchronization of time of availability of zinc ash with need-based seasonal manufacturing of zinc sulfate
- Inadequate storage facilities
- Poor finances
- Unfair trade practices by few

  (Diversion of quality zinc ash to extraction of zinc metal)

Conclusions

- Carriers with single micronutrient are agronomically most effective
- Soil application for Zn, Cu, B and Mo under continuous monitoring for whole cropping sequence is a sustainable practice
- Foliar sprays superior for Fe and Mn
- Biotechnological options for Fe, Zn and Cu fortification
- System based integrated micronutrient management is an effective strategy
- Product modification needed for specific soil and crop situations
- Need for change in GOI policy to assign at least zinc sulfate production to the major fertilizer industry

Micronutrient fertilizers

need

Macro attention

for

Sustainable crop production