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Mapping Current Micronutrients Deficiencies in Soils of Uttarakhand for Precise Micronutrient Management

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Content of micronutrients and their ability to supply to crop vary widely depending upon soil types, nature of crops grown, ecology and agro climatic variability. Total levels of micronutrients are rarely indicative of plant availability, hence, rational management of micronutrient fertility and toxicity requires an understanding of how plant-available soil micronutrients vary across the soils. Soils deficient in their ability to supply micronutrients to crops are alarmingly widespread across the Uttarakhand State, and this problem is aggravated by the fact that many modern cultivars of major crops are highly sensitive to low micronutrient levels. Although micronutrient deficiencies (Zn-9.6, Mn-4.7, Fe-1.4, Cu-1.4, B-7.0 and Mo-0.9%) in Uttarakhand are much lower than the national average due to low pH, high organic carbon and favorable climate. However, frequency distribution of micronutrients into various category showed that large area in the state has potential to be deficient in future, which may respond to micronutrient applications. In order to understand the geographic distribution of available micronutrient content in soil of the state, soil micronutrient maps have been developed using GPS and GIS to improve our understanding regarding nature and extent of micronutrient deficiencies and their response to crop growth and development. The maps revealed that soils deficient in zinc, boron and manganese also exhibited crop response from 3.0 to 36%. However, deficiency of Fe, Cu and Mo is negligible. These maps and frequency distribution of available micronutrient content in soils will be highly useful in assessing fields' scale variability for developing site-specific precision micronutrients management for better human and livestock health of Uttarakhand.

INTRODUCTION

Uttarakhand- a hilly state of the country and majority of area in state is covered with forests (64%). About 14% area is under cultivation with various food and horticultural crops (26). Major soil zones of the state are Hill Soils, Bhabhar Soils and Tarai Soils. However, agricultural land is confined particularly in Udham Singh Nagar and southern part of Dehradun and Nainital and Haridwar districts at foothills of Himalayas, is particularly known as Bhabhar and Tarai region. Hill soils are brown to grayish brown and dark grey in colour and moderately acidic to neutral in reaction. The major soil limitations of hill soils are highly porous with low moisture retention capacity, moderate to severe erosion prone and terrace cultivation at steep slopes. The Bhabhar (which means coarse stony and porous material) soils are shallow with loamy sand to loam textures containing abundant quantities of gravel and stones in sub surface (26). Water percolation through profile is very rapid; nutrient and moisture retention capacity is low. Tarai soils are thick and very fertile with medium to heavy texture, imperfect to moderate drainage, dark colored and high in organic matter, cation exchange capacity and nutrient holding capacity. Taxonomically these soils belong to great groups of Mollisols, Inceptisols, Entisols and Alfisols soil orders. Cultivation is mainly confined to Kharif season but on availability of irrigation Rabi crops are also grown.

Wheat, rice, barley, minor millet, sugarcane, potato and lentil are the major crops of the hills. The main crops grown in Bhabhar and *Tarai* region are rice, wheat, sugarcane, maize and pulses. Soybean cultivation has also picked up in these regions especially, in the Bhabar soils. Gram and lentil are the major pulse crops while *toria* is the major oilseed crop of the regions. *Tarai* soils need improvement in drainage for successful production of crops like maize, soybean, arhar, etc. The fertiliser application in the state is very poor hence it has been declared as 'Organic state' by Government of Uttarakhand. However, intensification of agriculture without replenishment of nutrients to soil causes production fatigue in these areas.

Although in the field scale Zn deficiency in Indian agriculture was first reported by Y.L. Nene in 1966 from Pantnagar soils (15)**.** But in recent years, acreage under micronutrients' deficiency has increased due to imbalanced use of fertilisers, low use of organic manure and poor replenishment as compared to crop demand (24). Now the deficiency of zinc (Zn), iron (Fe) and manganese (Mn) have been emerging and posing threats to sustain food productivity, particularly in areas where high yielding rice, maize and wheat cultivars are grown. Micronutrient deficiencies are now frequently observed in oilseed, pulse and vegetable crops also (18).

In order to manage soil micronutrient deficiencies and toxicity there is need to understand level of micronutrients in soil and its distribution for developing micronutrients management options, which in turn result in to sustainable agriculture and better livestock production (27). Maps showing different levels of available micronutrient content would be useful for assessing micronutrient deficiencies in soil-plants-animal/humans continuum (28). Maps depicting micronutrient deficiencies status may be used for understanding, in generalized terms, how regional micronutrient deficiencies may affect crop production, livestock and human health. Such maps can also be useful in examining how soil micronutrient content and availability relate to climate, soil properties, or soil genetic characteristics. These maps will also be useful in distribution of micronutrients fertiliser as per farmers' need. Thus, in this paper efforts have been made to develop the micronutrients status maps, their deficiencies and influence on crop yield and nutrient uptake. Frequency distribution of micronutrients has been also attempted in order to develop site specific micronutrients fertiliser recommendation for different deficiency levels.

Soil Sampling, Analysis and Preparation of Deficiency Maps

A total of 2575 surface soil samples (0-15 cm depth) were collected covering all the *talukas* and districts of the state using multi stratified random sampling technique during the year 2010-2014. The sampling size varied with the size of the district, cropped area and cropping intensity from all 13 districts of the state, viz., Almora (177), Bageshwar (125), Chamoli (200), Champawat (200), Dehradun (200), Haridwar (200), Nainital (147), Pauri Garhwal (200), Pithoragarh (202), Rudraprayag (200), Tehri Garhwal (200), U.S. Nagar (324) and Uttarakashi (200).

The soil samples were duly processed and analysed for micronutrients (Zn, Fe, Mn, Cu, B and Mo) by adopting standard protocols for soil analysis. Analysis of Zn, Fe, Mn and Cu, was performed using Diethylene Triamine Penta Acetic Acid (0.005 DTPA+0.1 M Triethanolamine and 0.01M $CaCl_2$ solution buffer) as outlined by Lindsay and Norwell (1978) while hot water soluble B was analysed utilizing methods suggested by Berger and Truog (1939) and Mo was analysed by ammonium oxalate pH 3.3. The Soil micronutrients maps were prepared using in Arc GIS to demarcate level of deficiency in various region of the district. Critical limits used to categorized level of deficiency were 0.60 mg kg^{-1} soil for DTPA-extractable Zn, 4.50 mg kg^{-1} soil for DTPA-extractable Fe, 0.20 mg kg^{-1} soil for DTPA-extractable Cu, 3.50 mg kg^{-1} soil for DTPA-extractable Mn, 0.45 mg kg^{-1} soil for hot water soluble B and 0.10 mg kg^{-1} for available Mo in soil.

SOIL MICRONUTRIENTS STATUS

A. Delineation and Mapping of Micronutrients Deficiency

The availability of micronutrients is particularly sensitive to changes in soil environment and factors that affect the contents of such micronutrients are organic matter, soil pH, lime content, sand, silt, and clay contents, and other micronutrients. The nature and extent of micronutrient deficiencies vary with soil type, crop genotype, management and agro-ecological situations(21, 27).

1. DTPA-Zn

Zinc deficiency in crops is the most common micronutrient problem world over. Therefore Zn malnutrition has become a major health burden among the resource poor people (17). Zn soil is an index of Zn content in fodders and grain, which significantly rely on available Zn content in soils (20). The critical limits used for Zn in the study was 0.6 mg kg^{-1} soil however it varies with soil and crop types and in Tarai soil the critical limit below which crop showed response to Zn application in rice was 1.20 mg kg^{-1} soil. For clear prediction of possible deficiencies, their critical limits have to be refined with reference to the soil characteristics and plant parts for individual crops as the soils and crops vary widely in their nutrient supplying and utilization efficiency.

Systematic survey and analysis of 2575 soil samples analysed under the aegis of AICRP-MSPE indicated deficiency of Zn to the extent of 9.6% however, status of micronutrients vary with soil types, agro-ecological zones and more importantly management and productivity of crops and cropping systems (16). Although Zn deficiency in Uttarakhand is much below the national average of 43%. The reason for low Zn deficiency in Uttarakhand is low level of soil pH, favourable ecology and regular use of Zn fertiliser. About 1,825 tonnes zinc sulphate is used in state to mitigate Zn deficiency in soil (4). Although the total Zn content in soil may be higher but available Zn was not very high as it ranged from 0.03-25.86 mg kg^{-1} soil across the state. Among the 13 districts, the highest Zn deficiency was recorded in U. S. Nagar and Nainital district (18-20%) while no Zn deficiency was reported in Bageshwar district. The Zn deficiency was less than five percent in Pithoragarh (**Table 1 and Map 1**). The Zn deficiency in the soils of Almora, Chamoli, Champawat, Pauri Garhwal, Rudraprayag and Tehri Garhwal districts, ranged from 5-10%.

Map 1 – Status and distribution of DTPA-extractable Zn in the different districts of Uttarakhand

2. DTPA- Fe

Fe is another limiting micronutrient for crops as plant Fe deficiency is known to occur since long in many parts of the country in Indian soils. After oxygen, silicon and aluminium, Fe is present in large quantities as it constitutes about 3-5% of soil, making it fourth most abundant element of the Earth crust.

However, most of the Fe in soils is unavailable for plant absorption (11). Fe solubility increases with reduction in soil pH. Since the most of soils of Uttarakhand have pH less than 7.0 hence, deficiency of Fe is very less in these soils. However, continuous growing of crops without Fe replenishment is resulting in reduction of available Fe levels in these soils. Usually Fe availability is generally high in acid soils but due to antagonistic relation with Cu, Zn, Mn and phosphate ions renders the plant with non-availability of Fe.

Metabolically, Fe is essential for chlorophyll and protein formation, photosynthesis, electron transfer, oxidation and reduction of nitrates and sulphates and other enzyme activities. Its deficiency causes interveinal chlorosis in newly emerging young leaves due to reduced chlorophyll synthesis resulting in poor growth and loss in yield (12). Among crops, Fe response was frequently noticed in sugarcane and upland rice, pulses and horticultural crops grown in Uttarakhand. However, Fe status in soils of Uttarakhand state is not a serious concern except in upland rice and some horticulture crops. The Fe deficiency in the state ranged from 0-5% with an average of 1.4% (**Table 1 and Map 2**). There are only three districts where Fe deficiency varies from 4-5% while available Fe status in all other districts is sufficient to meet the crop requirements.

3. DTPA-Mn

The total manganese content in soil have been reported to be very high in soils of Uttarakhand. However, its availability becomes a problem in sandy loam soils which frequently undergoes wetting and drying. Moreover, the availability/solubility depends upon the parent material, geomorphic, physico-chemical, biological processes of soil that control the total Mn content as well as its distribution in soils and supply to crops grown on it**.** In India, the deficiency of Mn has been observed in light textured and calcareous soils (9, 17).

The DTPA-Mn in the surface soils of Uttarakhand varied from 0.02-133.25 mg kg^{-1} soil with an overall deficiency of 4.7% **(Table 2 and**

Map 2 – Status and distribution of DTPA-extractable Fe in the different districts of Uttarakhand

Table 1 – Available zinc and iron status (DTPA-extractable) in soils of different districts of Uttarakhand

District	DTPA-Zn			DTPA-Fe		
	Range	Mean±SE	PSD	Range	Mean±SE	PSD
Almora	0.39-14.18	1.93±0.14	5.6	6.45-82.88	27.29±1.43	0.0
Bageshwar	0.57-23.90	2.98±0.28	0.8	1.47-53.81	24.45±1.01	0.8
Chamoli	0.21-25.86	3.35±0.29	7.0	7.46-283.62	77.65±5.19	0.0
Champawat	0.29-25.52	3.54±0.26	6.0	7.94-193.66	42.69±1.47	0.0
Dehradun	0.29-19.28	2.47±0.21	10.0	2.83-62.80	20.78±0.92	1.5
Haridwar	0.17-12.14	2.02±0.12	10.0	1.70-124.70	29.17±1.52	4.0
Nainital	0.30-16.43	2.43±0.25	18.4	3.69-160.21	45.64±3.26	0.7
Pauri Garhwal	0.28-22.09	4.20±0.36	6.0	3.73-688.39	217.13±9.06	0.5
Pithoragarh	0.14-17.86	3.14±0.22	3.5	3.48-53.58	18.01±0.81	3.5
Rudraprayag	0.11-17.18	2.83±0.20	5.5	0.47-106.14	26.13±1.60	5.0
Tehri Garhwal	0.21-18.14	2.77±0.21	9.5	3.74-79.32	26.60±1.23	0.5
U. S. Nagar	0.03-12.70	1.66±0.08	19.4	2.65-110.28	31.19±1.24	0.9
Uttarakashi	0.15-17.11	2.79±0.23	16.0	6.75-128.99	55.34±2.10	0.0
Uttarakhand	**0.03-25.86**	**2.73±0.06**	**9.6**	**0.47-688.39**	**49.49±1.35**	**1.4**

Table 2 – Available copper and manganese status (DTPA-extractable) in soils of different districts of Uttarakhand

District	DTPA-Mn			DTPA-Cu		
	Range	Mean±SE	PSD	Range	Mean±SE	PSD
Almora	2.49-53.45	18.27±0.73	0.6	0.08-6.86	0.95±0.06	1.7
Bageshwar	0.10-54.15	19.40±1.17	1.6	0.34-4.17	1.47±0.08	0.0
Chamoli	0.78-133.25	15.74±1.23	14	0.02-9.86	1.63±0.10	3.0
Champawat	0.02-74.31	18.49±0.82	2.5	0.05-4.68	1.48±0.06	3.5
Dehradun	0.23-54.53	22.84±1.00	2.0	0.18-7.88	1.11±0.08	1.5
Haridwar	1.84-63.24	17.56±0.99	5.5	0.15-20.86	1.19±0.11	1.0
Nainital	1.38-55.47	14.42±0.82	4.1	0.15-10.79	1.93±0.12	0.7
Pauri Garhwal	3.38-62.14	29.23±1.06	0.5	0.13-9.51	1.31±0.09	3.0
Pithoragarh	1.67-54.58	20.08±0.83	1.5	0.06-8.26	1.68±0.09	1.0
Rudraprayag	0.03-64.42	12.39±0.89	21.5	0.11-4.82	1.63±0.07	3.0
Tehri Garhwal	1.99-55.86	18.95±1.03	4.5	0.38-14.96	2.25±0.17	0.0
U. S. Nagar	1.37-68.73	17.12±0.56	1.2	0.32-12.44	1.85±0.07	0.0
Uttarakashi	1.96-80.52	29.94±1.34	2.5	0.23-7.98	2.42±0.11	0.0
Uttarakhand	**0.02-133.25**	**19.58±0.28**	**4.7**	**0.02-20.86**	**1.62±0.03**	**1.4**

Map 3). Out of 13 districts of the state, soils of districts Rudraprayag showed maximum deficiency (21.5%), followed by Chamoli (14.0%), Haridwar (5.5%), Nainital (4.1%), Champawat (2.50%) Dehradun (2.0%). Mn deficiency in all other districts was recorded negligible (<1.5%).

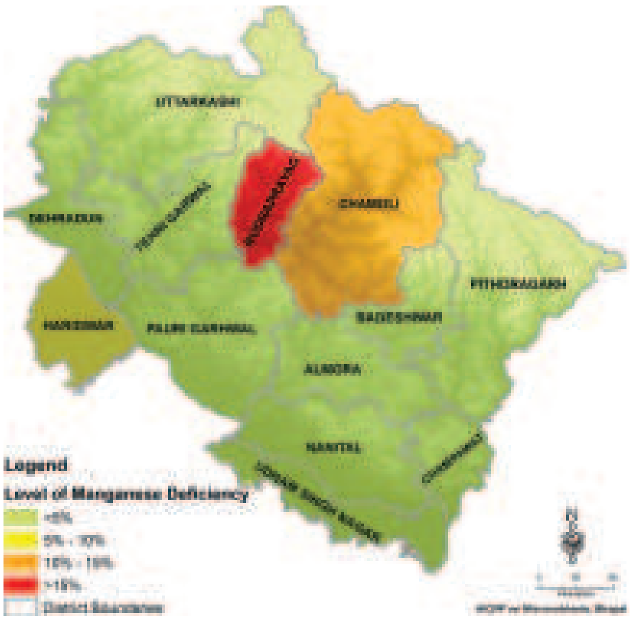
4. DTPA-Cu

The DTPA-extractable Cu in soils of Uttarakhand ranged from **0.02-20.86** mg kg^{-1} soil and overall deficiency was observed to be 1.4 % (**Table 2 and Map 4**). Moreover, none of the districts showed Cu deficiency more than 5%. The deficiency in Champawat (3.5%), Chamoli (3.0%), Pauri Garhwal (3.0%), Rudraprayag (3.0%), Almora (1.7%), Dehradun (1.5%) and Nainital (0.7%) districts has been observed to be less than 5% **(Table 2)**.

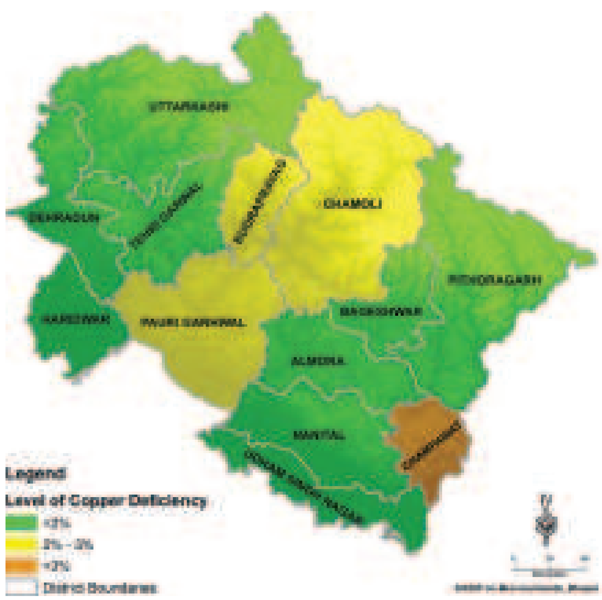
HWS-B

Boron (B) is a unique non-metal micronutrient required for normal growth and development of plants. It is mobile in soils and more often gets leached down the soil profile with excess moisture. B deficiency and toxicity range is very narrow. Boron concentration and its bioavailability in soils is affected by several factors including parent material, texture, nature of clay minerals, pH, liming, organic matter content, sources of irrigation, interrelationship with other elements, and environmental conditions like moderate to heavy rainfall, dry weather and high light intensity (13).

Therefore, knowledge of these factors affecting B uptake is essential for the assessment of B deficiency and toxicity under different conditions. Upon mineralization from organic matter or B addition to soils through irrigation or application of fertilisers, a proportion of it remains in the soil solution while remaining is absorbed by soil particles and other soil constituents. Boron deficiency in



Map 3 – Status and distribution of DTPA-extractable Mn in the different districts of Uttarakhand



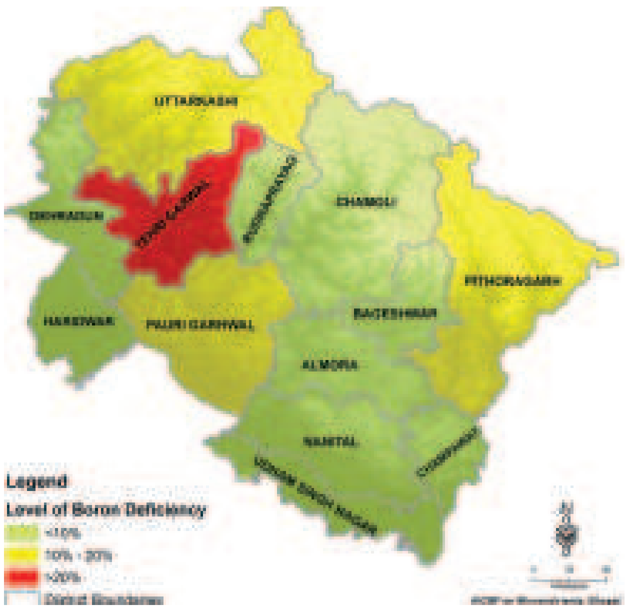
Map 4 – Status and distribution of DTPA-extractable Cu in the different districts of Uttarakhand

soils of the state has been recorded to be **7.0**% (**Table 3**). Among the 13 districts, the highest B deficiency was recorded in Tehri Garhwal (43%) followed by Uttarakashi (15.5%), Pithoragarh (12.4%) and Pauri Garhwal (10.5%), Rudraprayag (4.0%), Dehradun (2.0%) and Haridwar (1.5%) districts. Soil samples collected from Almora Bageshwar, Chamoli, Champawat and Nainital did not show B deficiency **(Table 3 and Map 5)**.

5. Available Mo

Mo availability is adequate in Indian soils, however, its deficiency in plants may be observed in highly leached acidic soils. The available Mo content in Uttarakhand soils varied from 0.011 to 9.15 mg kg^{-1} with an average of 1.11±0.020 mg kg^{-1} soil. Out of 13 districts, Mo deficiency has been observed in soils of Pithoragarh (4.46%), Dehradun (4.0%), Tehri Garhwal (1.50%), Nainital (0.68%), Pauri Garhwal (0.50%) and Rudraprayag (0.50%) **(Table 3)**. Low molybdenum status is reported in north eastern high rainfall zone of Uttarakhand. Soil pH is one of the most important factors that affect the availability of Mo to plants. As pH decreases, the absorption of Mo increases and maximum absorption of Mo is reported to take place at pH 4. Soil pH in most of the district of Uttarakhand is acidic to neutral in reaction. However, Mo deficiency in the state was recorded in only 1.0% soil samples **(Table 3 and Map 6)**.

Availability of Mo is also influenced by sesquioxide ratio and organic matter content in soil. Adsorption of Mo is positively correlated with Fe and Al oxides and negatively correlated with organic matter content (22). Since Uttarakhand soils are high in organic matter, availability of Mo is not a serious concern. Dissolved Mo in soil solutions is the result of ion complexation, adsorption desorption, precipitation and dissolution processes which ultimately govern the solubility, availability and mobility of Mo in soils. There are interactions between Mo and a number of nutrients, such as sulphur, nitrogen, phosphorus and copper that can affect its plant availability. Although Mo is important for both plants and animals but report shows that high concentrations of Mo in soil did not show gain in crop yield. Feeding of large crops, containing Mo in excess of 10 mg kg^{-1}, when fed to ruminants, can produce severe Mo toxicity (Mo induced Cu deficiency). Unlike other micronutrients, Mo is readily translocated and its deficiency symptoms generally appear on the whole plant. Adequate Mo prevent dental caries, mouth and gum disorders, esophageal cancer and



Map 5 – Status and distribution of HWS- Boron in the different districts of Uttarakhand

Table 3 – Available boron and molybdenum status in soils of different districts of Uttarakhand

District	Available B			Available Mo		
	Range	Mean±SE	PSD	Range	Mean±SE	PSD
Almora	0.72-3.28	1.76±0.05	0.0	0.126-8.628	0.994±0.087	0.00
Bageshwar	0.57-6.13	2.59±0.12	0.0	0.313-7.386	1.448±0.120	0.00
Chamoli	0.76-5.35	2.03±0.05	0.0	0.121-1.485	0.383±0.016	0.00
Champawat	0.75-3.81	1.78±0.06	0.0	0.238-8.559	0.998±0.088	0.00
Dehradun	0.03-2.45	1.12±0.03	2.0	0.060-8.130	0.910±0.099	4.00
Haridwar	0.41-5.85	2.70±0.07	1.5	0.229-9.150	0.946±0.085	0.00
Nainital	0.61-3.91	2.04±0.05	0.0	0.011-7.205	0.930±0.083	0.68
Pauri Garhwal	0.03-3.07	1.10±0.04	10.5	0.056-4.792	1.823±0.077	0.50
Pithoragarh	0.38-5.31	1.56±0.06	12.4	0.095-3.149	0.762±0.041	4.46
Rudraprayag	0.08-10.75	1.85±0.10	4.0	0.096-7.550	2.139±0.105	0.50
Tehri Garhwal	0.03-3.87	0.76±0.05	43.0	0.040-4.950	1.171±0.072	1.50
U. S. Nagar	0.43-14.72	2.45±0.11	0.9	0.122-1.845	0.580±0.020	0.00
Uttarakashi	0.13-2.22	0.82±0.02	15.5	0.163-5.788	1.749±0.076	0.00
Uttarakhand	**0.03-14.72**	**1.74±0.02**	**7.0**	**0.011-9.150**	**1.11±0.020**	**0.90**

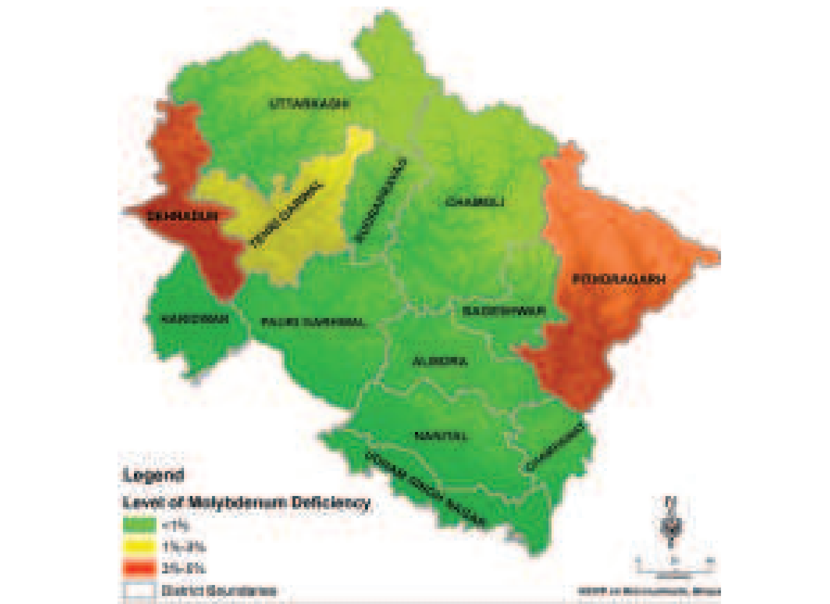
sexual impotence in old people.

B. Frequency Distribution of Micronutrients and Fertiliser Need

Usually crops respond to application of micronutrients only when the level of micronutrients is below critical limits, but sometimes crops may also respond to micronutrients even when level of micronutrients is above critical limit. This indicates that crop response varied to micronutrients application depending upon crop type, soil type and agro climate of the region (18). Hence, distribution of micronutrients into different category range is useful in making micronutrients fertiliser recommendation.

Frequency Distribution of Zn

Soils having Zn content $\leq$ 0.6 mg kg^{-1}are categorized as deficient while those falling between 0.6 to 1.20 mg kg^{-1}are considered as medium in Zn supply and those above 1.50 mg kg^{-1} are classed as high Zn soils. In order to develop better nutrient prescription, it is useful to categorize samples in to more frequency ranges. Of the total samples analysed for Zn in the state, 1.7% samples fall in acute Zn deficient category (< 0.3 mg kg^{-1}) and 7.9% in deficient category (0.3 to 0.6 mg kg^{-1}) which showed wide response to Zn application. Samples having Zn levels between 0.6-0.9 mg kg^{-1} are considered potentially susceptible to deficient in near future (**Figure 1**). Now farmers are applying maintenance dose of Zn in this category soils as awareness created through frontline demonstration under AICRP-MSN project in the state. About 11.4% soils (having >0.9 to 1.2 mg Zn kg^{-1} soil) classed as moderate Zn deficient may potentially respond to Zn application depending upon the type of crops grown and agro-climatic conditions. About 54% of the soils of the state are having very high level of Zn content (>1.5 mg kg^{-1} soil) and thus, Zn application to these soils may be skipped. However, in soils which have available Zn level between



Map 6 – Status and distribution of Available Mo in the different districts of Uttarakhand

>1.2 to ≤ 1.5 mg Zn kg^{-1} may be given only Zn maintenance doses once in three years to sustain yield level as well as soil Zn reserve.

Frequency Distribution of Fe

Regarding Fe, soil samples having Fe content above 7.5 mg kg^{-1} soil are classed as sufficient category. Crops grown in such soils do not respond to Fe application and soils containing Fe <3.5 mg kg^{-1} soil are grouped in to Fe deficient category. In state , above 2.6% soil samples are deficient and 3.8% samples fall in the range of >5.5- 7.5 mg Fe kg^{-1} soil are considered as potentially deficient category (**Figure 2**). Intensive cropping, particularly with horticultural and corn crops in these soils may exhibit Fe deficiency in crops, if maintenance doses are not provided. About 84% soils are having enough Fe content in soil to support the intensive farming provided sufficient moisture should be available in the fields.

Frequency Distribution of Mn and Cu

The frequency distribution of the Mn in soils of the state revealed that about 1.7% of the samples contained a Mn level below the 2.0 mg Mn kg^{-1} soil. Further, about 4.2% samples fall in the range of 2.0 to 4.0 mg Mn kg^{-1} soil may be considered potentially deficient in future. About 71.8% soils of the state having Mn content more than 10.0 mgkg^{-1} are considered sufficient to meet the crop demand for longer period (**Figure 3**).

Of total analysed soil samples, 1.4% samples contained <0.2 mg Cu kg^{-1} soil may be considered as responsive category while another 5.7% samples fall in the category of >0.2-0.4 mg Cu kg^{-1} soil, may be potentially susceptible to Cu deficiency in future (**Figure 4**). More than 62% soils in the state have very high level Cu, which can meet crop

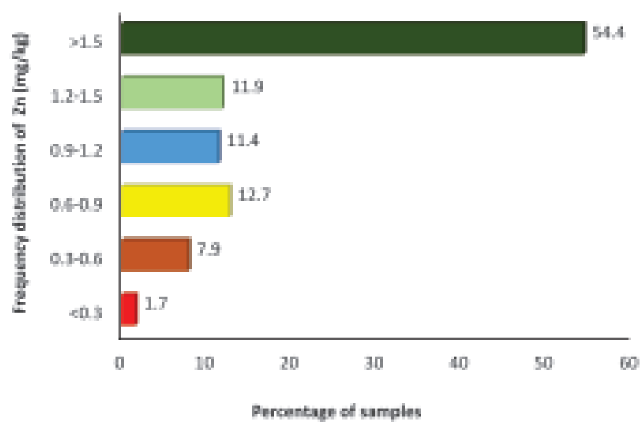


Figure 1 – Frequency distribution of Zn availability in soils of Uttarakhand state

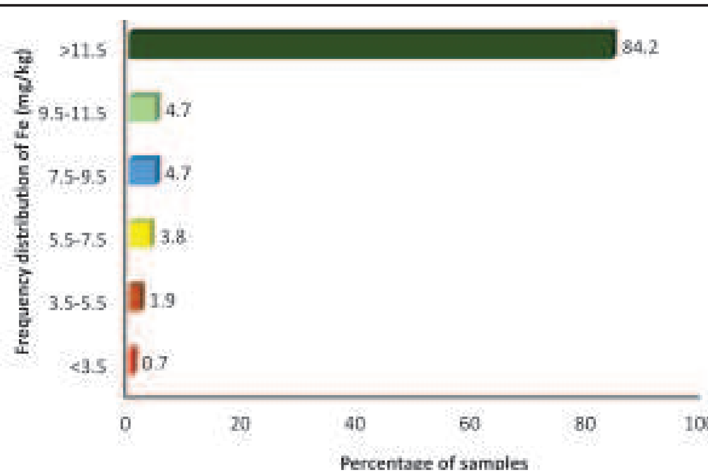


Figure 2 – Frequency distribution of Fe availability in soils of Uttarakhand state

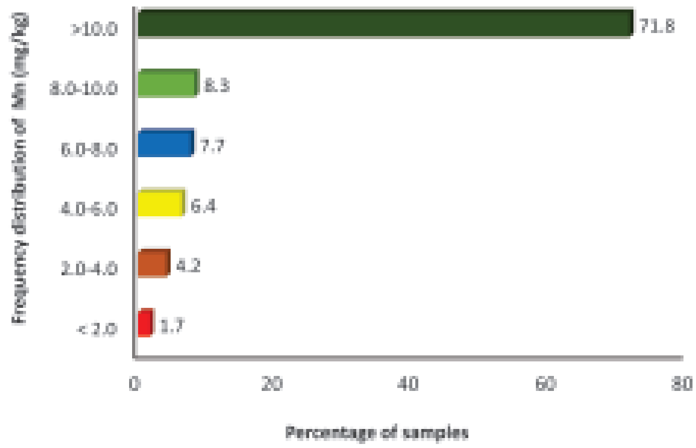


Figure 3 – Frequency distribution of Mn availability in soils of Uttarakhand state

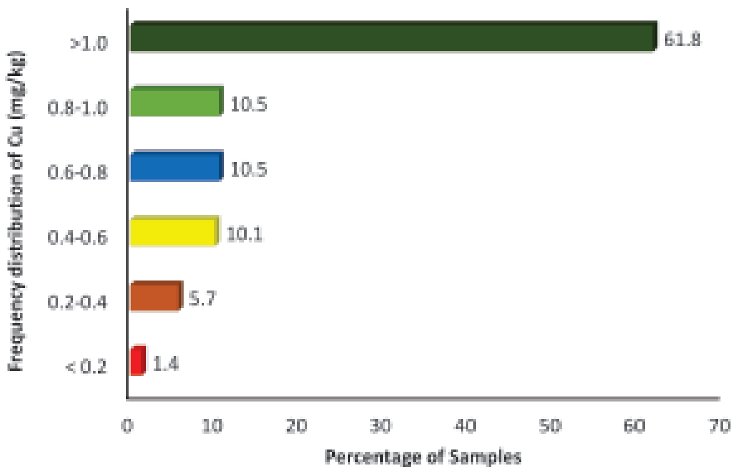


Figure 4 – Frequency distribution of Cu availability in soils of Uttarakhand state

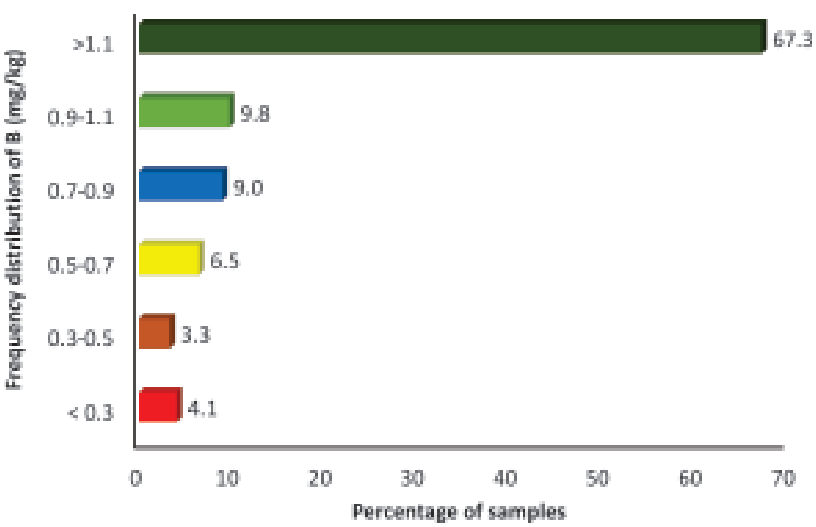


Figure 5 – Frequency distribution of B availability in soils of Uttarakhand state

demand in future for longer period.

Frequency Distribution of B

For B, soil samples having B content less than 0.30 mg kg^{-1} are considered as acute deficient and those fall between 0.3 to 0.5 mg kg^{-1} soils are grouped as deficient category. On average, 4.1% of soil samples fall in acute B deficient category and 3.3% soil samples fall in deficient category. About 6.5% samples falling in the range of 0.5 to 0.7 mg kg^{-1} B are categorized as marginal category and such soils did not show B deficiency in crops except some cole crops, which respond to B application. Samples having B content >0.7-0.9 mg B kg^{-1} soil are grouped into adequate B category level (9.0%). The samples having B content above >0.9 mg kg^{-1} soil are classed as high B soils and there is no need of external B application at present (**Figure 5**).

Frequency Distribution of Mo

There are very few soils showing Mo deficiency. Soils contain Mo levels below 0.10 mg kg^{-1} are classed as acute deficiency category and only 1% soil samples fall in this category. Soils having Mo content between 0.10 to 0.20 mg kg^{-1} are considered as potentially deficient in future, if intensive cultivation is continued without replenishment of maintenance doses of Mo. Large area (63.8%) is having more than adequate level of Mo, which do not need Mo application in near future.

C. Multiple Micronutrients Deficiency

In the preceding sections, individual micronutrients have been dealt in detail, however; micronutrient deficiencies rarely occur in isolation (6, 7). Therefore, in soil plant system, there may often be a need to address several micronutrient deficiencies simultaneously. However, in soils of Uttarakhand multiple micronutrients deficiency has not

Table 4 – Response of Crops to Application of Micronutrient

Crop	Nutrient	Response (%)
Hybrid rice- wheat	Zn	10.7-10.8
Pearl millet- wheat	Zn	14.30-14.94
Mustard	Zn	22.9
Groundnut	Zn	16.1
Soybean	Zn	20.2-38.3
Lentil	Zn	8.3-34.8
Hybrid rice- wheat	B	7.4 -10.4
Soybean	B	28.1-37.7
Lentil	B	1.0-22.0
Tomato	B	8.5-9.85
Okra	B	174

been observed (data not show) except some soil showing combined deficiency of Zn and B.

D. Crop Response and Micronutrients Management

Plants differ in their micronutrient requirements and response depending upon soil type, crop/plant types, agro climatic effect, field variability, crop sensitivity and other soil factors (1). The response to micronutrients is often less predictable than response to macronutrients. Sometimes, dramatic responses to micronutrients may be seen if the nutrient is deficient, but usually, responses are measured in terms of incremental yield gain or quality improvements (25). Micronutrient chemistry in the soil is complex and there are numerous interactions with other nutrients and environmental conditions. While predictability of micronutrient response may be less than some other nutrients, it can be improved by considering the interactions with some of the factors affecting crop nutrient response (19). Commonly, soil micronutrient levels vary dramatically across a field and natural or man-caused field variability often affects crop response to micronutrients. These differences may be associated with changes in soil pH, soil organic matter, top soil thickness, drainage and landscape position. Grid sampling has identified significant areas of fields that are deficient in one or more micronutrients when field-average samples otherwise indicate adequate levels. When this occurs, producers lose potential profits in these areas by inadequate fertilization. These profits can be captured by properly accounting for natural or man-made variability (23). The ratings of low, medium and high are used to indicate the relative degree of responsiveness. Crops vary greatly in sensitivity to micronutrients. Understanding a crop's specific nutrient

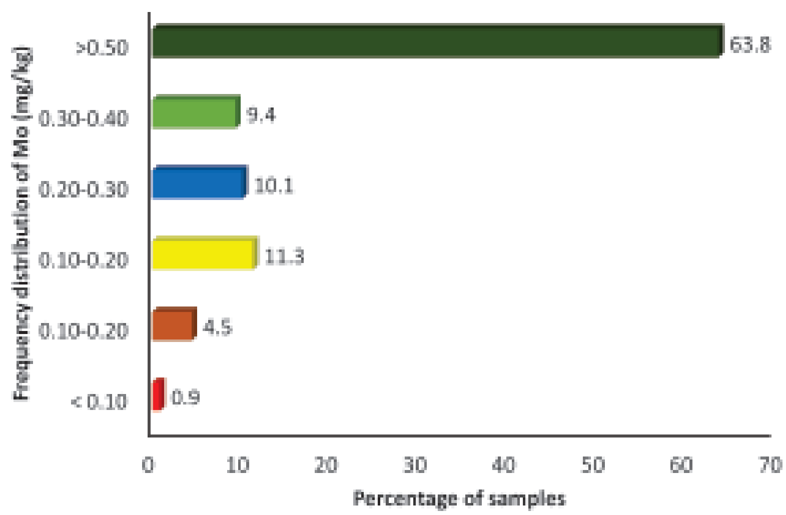


Figure 6 – Frequency distribution of Mo availability in soils of Uttarakhand state

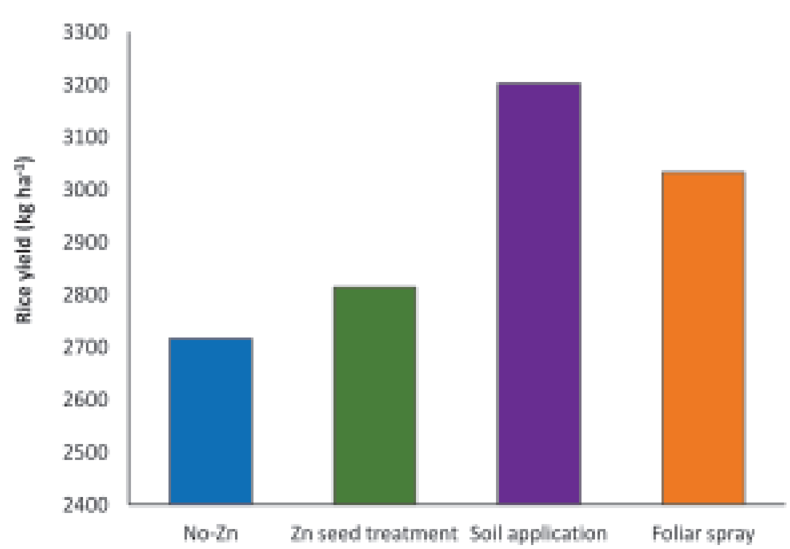


Figure 7 – Effect of methods of Zn application on rice yield

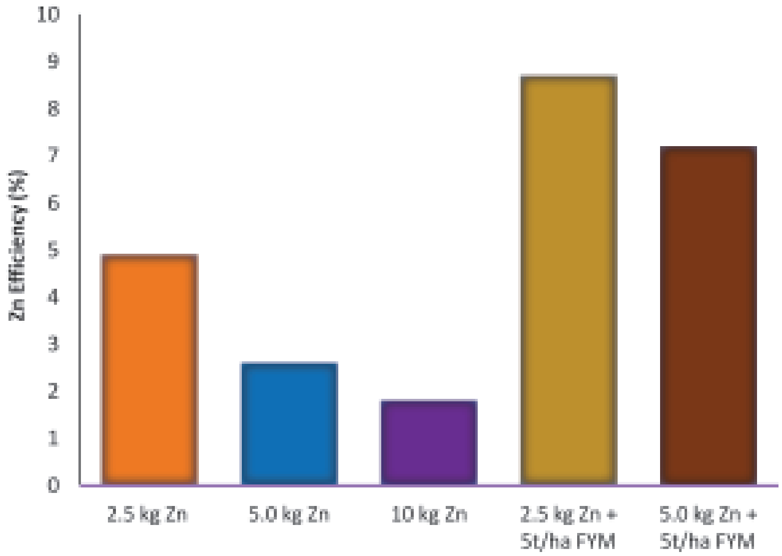


Figure 8 – Effect of Zn rates and integration of FYM on Zn use efficiency in rice-wheat system

requirements will help improve prediction of micronutrient needs and maximize economic benefits of the nutrient management programme.

Large number of micronutrients response trials conducted on various crops grown in Uttarakhand exhibited variable response as governed by various factors explained in above para **(Table 4)**. The effect of Zn rates and frequency of application on yields and Zn uptake in hybrid rice-wheat rotation assessed through five year field experimentation revealed that application of 10 kg Zn ha^{-1} to first rice crop and 5 kg Zn ha^{-1} to second rice crop evidenced the most cost-effective opportunity among various Zn propositions appraised. The cumulative benefit of accrued was Rs.32316/- during five crop cycles.

Type of micronutrients fertiliser and its rate, frequency and method of application play important role in predicting use efficiency(14). Method of B application evaluated in Okra showed that both basal as well as foliar spray of B had an edge over either basal or foliar feeding alone. The fresh yield of okra was recorded 8511 kg ha^{-1} with basal B application which was statistically comparable with half dose of basal and half as foliar application (8315 kg ha^{-1}) at 45 days after emergence. Study conducted on rate and frequency of B application in hybrid rice (Pant Dhan-1) - wheat (UP - 2425) established no response to B application on grain yields of hybrid rice-wheat grown in system during the first two years. However, a significant response was noted 3rd year onward. The cumulative yields and B uptake in hybrid rice and wheat during the five years were the highest when 1 kg B ha^{-1} was applied during Ist year hybrid rice. The cumulative B uptake for hybrid rice and wheat was 36.2 and 20.6 % higher over no-B. However, the cumulative B uptake was the highest under the treatment received 2.0 kg B ha^{-1} to Ist year rice crop and 0.5 kg B ha^{-1} to subsequent wheat crop. The magnitude of increase in B uptake was recorded 56.7 and 36.9 % higher in hybrid rice and wheat, respectively over no-B application.

Figure 7 shows data representing method of different Zn fertiliser application. The application of Zn through seed treatment is least effective in mitigating the Zn deficiency in crops and crops suffers to a great extent resulting in yield loss. However, as already discussed only 10% of the areas represented samples below a critical level of 0.60 ppm DTPA-Zn. At this level, some yield loss from Zn deficiency could be expected. The most common method of micronutrient application for crops is soil application. Uniform application of micronutrient sources separately in the field is difficult as the quantity of micronutrients used in crops is very less. Uniform application could be obtained through foliar sprays. In order to get quick response to the applied micronutrient and mitigate deficiencies during the growing season foliar spray is widely used to apply micronutrients, especially iron and manganese. Soluble inorganic salts generally are as effective as synthetic chelates in foliar sprays, so the inorganic salts usually are chosen because of lower costs.

Foliar feeding should be avoided if nutrient demand is high and the plants are small and leaf surface is insufficient for foliar absorption. Maximum yields may not be possible if spraying is delayed until deficiency symptoms appear. Including micronutrients with mixed fertilisers is a convenient method of application, and allows more uniform distribution with conventional application equipment. Costs are also reduced by eliminating a separate application. Hence, micronutrient fertilisers should be chosen to apply or blend accurately within the management system of the grower and with other fertiliser applications. Products that do not blend uniformly with other fertilisers will not be uniformly applied in the field. This is even more important for micronutrients than for macronutrient fertilisers because of the small amounts applied. Poor blending of a few pounds of micronutrient carrier in a bulk blend can result in poor product performance, improper fertilization, and lost profits. Chelates and foliar applications are effective means of supplying micronutrients if used properly.

Apparent Zn fertiliser use efficiency also enhanced when Zn fertilisers are blended with organic manure. Thus, application of micronutrients along with organic manure improves the system productivity as well as fertiliser use efficiency. An experiment in pearl-millet-wheat rotation on a Typic Ustipsamments for three consecutive years proved that application of 10 kg Zn ha^{-1} could leave its residual effect to three consecutive years and cumulative grain yield increased by 15 per cent over no-Zn control. A conjoint application of Zn and FYM (2.5 kg Zn + 5 t FYM ha^{-1}) contributed much higher yields than application of Zn alone (**Figure 8**). However, on high pH soils application of smaller dose of Zn alone every year or at least on alternate years gives better beneficial effect.

Field average sampling and recommendation would unlikely advice additional micronutrients application. Thus, site-specific strategy would more accurately represent the actual nutrient needs and make better use of micronutrient resources than that of field-average strategy. Confident diagnosis of micronutrient needs requires more than a scan of laboratory analysis of surface soil sample. Crop response increases dramatically when considering overall fertility management, management level of the producer, soil type and conditions, crop sensitivity, and past observations of crop response, quality, or deficiency symptoms. The better recommendations can be given and improve the probability of economic return if this additional information is used in making micronutrient recommendations.

CONCLUSION

Micronutrient deficiencies in soils are widely associated with crop productivity and animal and human health. Advance tool, like Global Positioning Systems (GPS) facilitate accurate and precise location and geo-referencing of sampling sites. Geo information system (GIS) aid in the acquisition, analysis, storage, and display of georeferenced information and the development of digital maps. The GPS and GIS tools used to survey and map the geographic distribution of soil micronutrient content and availability at scales ranging from district, block and village to sites within single production fields. Soil micronutrient status maps would be highly useful in improving our understanding regarding nature and extent of micronutrient problems and aid in determining their relationships with animal and human health. Better scale maps developed at block or village level covering information regarding all fields will be useful in delineating specific areas where deficiencies or toxicities are likely for agriculture, and in determining localized soil characteristics that may be associated with such problems. The geostatistical analysis may contribute information useful for estimating soil micronutrient content in intervening unsampled areas also. The maps of soil micronutrient content and availability in individual fields will be useful in developing site-specific precision nutrient management options. Research in precision nutrient management will improve our understanding and management of spatially variable soil micronutrient availability in agricultural production fields. Soil micronutrient maps may also foster the relationships between soil micronutrient content and availability and some human and livestock health problems. The spatial distribution of soil micronutrients and other properties can be derived from intensive soil and/or plant sampling carried out along transects or in regular or irregular grids at intervals ranging from several to hundreds of meters. Sample site location and geo referencing can be determined using GPS. Thus, study of micronutrients in soil-plant-animal/human continuum will establish a link between soil health and human health. Thus, it will provide quantitative support for decision and policy making to improve agricultural approaches to balanced micronutrient nutrition.

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