Wheat Sterility Induced by Boron Deficiency in Nepal

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Abstract

This paper describes the nature and extent of wheat sterility in Nepal, its relation to boron deficiency in soil, and research carried out to circumvent the problem. Sterility (grain set failure) problems in wheat in Nepal have been reported since the introduction of semi-dwarf wheat varieties during the mid 1960s. The problem is widespread in the eastern, central plains, and mid hill areas of Nepal. The extent of the problem is severe, ranging from 0 to 100% grain set failure depending upon genotypes. Boron deficiency has been considered a major factor among the various factors causing wheat sterility. Boron deficiency problems have also been reported in some other crops such as vegetables and legumes.

Application of boron to the soil at sowing has a significant positive effect on the number of grains per spike, reduction of sterility, and increased wheat grain yields. Screening of a large number of genotypes in a boron deficient soil showed great genetic variation in sterility ranging from 0 to 100%, suggesting the possibility of selection for low soil boron efficient genotypes.

Introduction

Bread wheat (*Triticum aestivum* L.) is the third largest cereal crop in Nepal after rice and maize and plays an important role in the country's food security. Nepal produces 1.387 million tonnes of wheat annually from 0.665 million hectares. The present national average wheat yield is 2087 kilograms per hectare. Although wheat is grown throughout the country, 93% of its total acreage lies in the mid hills and plains. More than 85% of the wheat area of the country is farmed in a rice-wheat system. The remaining 15% includes maize-wheat, maize+millet-wheat, and other combinations. The total and partial factor productivity of the rice-wheat cropping system has declined in recent years (Hobbs and Morris 1996). Soil micronutrient deficiencies are widespread in the 12 million hectares in South Asia where the rice-wheat system is followed (Nayar et al. 2001) and have contributed to declining productivity in this system. Of these zinc (Zn), boron (B), iron (Fe), molybdenum (Mo), and manganese (Mn) are the major micronutrients found to be insufficient in the soil.

Wheat sterility was first observed in Brazil in 1962 (da Silva and da Andrade 1980). Widespread sterility was observed in Nepal in 1964 when improved, high-yielding Mexican wheat was introduced and in introduced Indian cultivars in the following year (Mishra et al. 1992). Factors suggested to be responsible for sterility include boron deficiency (Rerkasem and Loneragan 1994), low radiation (cloudy dull weather, morning fogs, mists) (Willey and Holliday 1971, Saifuzzaman 1995), low temperature during reproductive development (Sthapit et al. 1989; Subedi 1992), waterlogging at flowering, low soil nitrogen and dry wind (Mishra et al. 1992), high temperatures (Saini and Aspinall 1982), high humidity (Dawson and Wardlaw 1989), low humidity (Galrao and Sousa 1988), drought or water shortage (Saini and Aspinall 1981), and high pH (Bell and Dell 1995). Of all these factors, boron deficiency and cold temperatures are the only causes that have been conclusively proven: sterility was effectively reduced by boron application in one study (Sthapit 1988). A soil boron concentration of <1 ppm is considered deficient (Landon 1992). In some cases, however, notably at higher altitudes, low temperature stress was suspected as a contributing factor because boron application did not cure sterility (Sthapit 1988).

Soil boron deficiency not only results in sterile young terminal florets but also in sterile older florets situated at the base of a spikelet. Boron is essential for cell wall development of the generative organs and wheat pollen is very sensitive to adequate boron supply for germination and growth (Matoh et al. 1992; Rerkasem and Loneragan 1994). Boron deficiency results in the failure of pollen tube growth due to a reduction in development of the pollen tube cell wall leading to failure in fertilisation, or sterility (Blevins and Lukaszewski 1998; Rerkasem and Jamjod 1997). Therefore, a crop of a wheat variety susceptible to sterility may have luxurious vegetative growth, but boron deficiency at the critical stage of anthesis would result in sterile spikes with low yield.

Climatic conditions (such as cloudy days and low or high temperature), very high soil pH, waterlogging, and so on influence the degree of crop response to boron application in wheat (Bell and Dell 1995; Saifuzzaman 1995; Mishra et al. 1992). Boron is readily leached. It is estimated that there is a 30% reduction in soil boron concentration after 25 mm of rainfall. The occurrence of such a fall during the reproductive stages is also likely to cause boron deficiency (Ralph 1992).

During the late 1960s and early 1970s, wheat sterility in Nepal was confined to the eastern Terai (Sarlahi to Jhapa) and Chitwan Valley (Figure1), but it is now increasing and extending to other areas where it was not a problem before. It is seen in the low hills, high hill rainfed lands, and Terai areas of the central and western development region. The problem is slowly extending towards the western and mid-western Terai. The extent of the problem ranges from 0 to 100% sterility, depending upon the wheat variety.

Sterility caused by cold temperature can be managed to some extent in the high hills by adjusting planting dates. Application of boron at a rate of 2 kg/ha has been observed to be very effective in mitigating the sterility to a great extent, but some varieties have been reported to be non-responsive. The best solution would appear to be to breed varieties tolerant to low soil boron content. Genetic variability for tolerance to low soil boron exists, and varieties can be selected for this trait (Bhatta 2000; Rerkasem and Jamjod 1997; Sthapit 1988; Joshi and Sthapit 1995). This paper summarises the results of variety screening with and without boron in boron deficient soils.

Methods of sterility estimation

There are six methods of sterility estimation described by Sthapit and Subedi (1990): 1) the visual method; 2) Lumle Agricultural Centre (LAC) method; 3) modified Chinese method; 4) International Maize and Wheat Improvement Centre (CIMMYT) method; 5) Thai method; and 6) Chinese method. The most commonly used methods in Nepal are the visual, LAC, and Thai methods. In the visual method, spike sterility in per cent is estimated by visual observation after the anthesis and later stages. However, this method needs some experience in identifying sterile spikes.

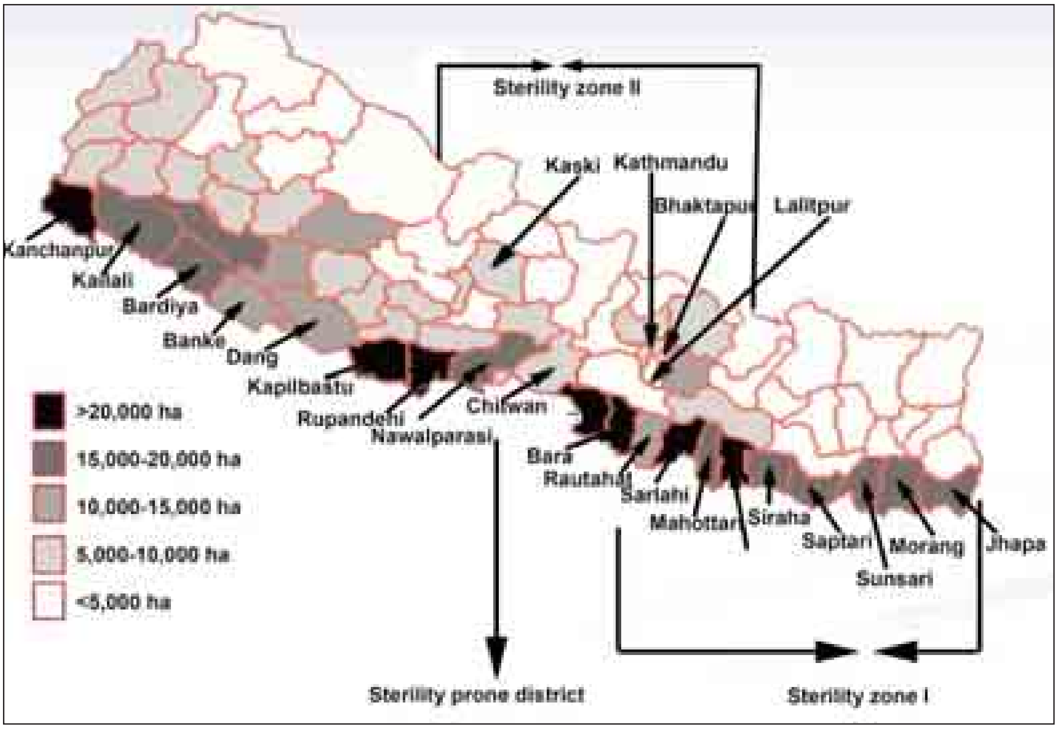

Figure 1: **Wheat growing areas and sterility prone zones in Nepal**

In the LAC method:

$$\text{sterility}\,\% = \frac{a-b}{a.100}$$

where, a = the number of florets per spike, b = number of grains set per spike.

In the Thai method:

$$\text{sterility}\,\% = \frac{c-d}{c.100}$$

where, c = number of F1+F2 florets per ten central spikelets, d = number of grains per ten F1 + F2 florets of ten spikelets.

All six methods for estimating sterility were studied by Sthapit and Subedi (1990) and a similarity was found among all methods. They concluded that for variety screening, the visual method of estimating sterility is useful, easy, rapid, and labour saving.

Materials and Methods

Many investigators of wheat sterility in Nepal have carried out studies during the last two decades. Past studies on wheat sterility mainly concentrated on finding the causes of sterility, surveying wheat sterility, methods of estimating sterility, and the effect of boron and other nutrients on sterility. So far there have been no reports of variety screening for genotypes with low soil boron tolerance, despite the availability of sufficient genetic variability among wheat germplasm.

In earlier investigations, data was gathered on boron sensitive genotypes and other factors affecting sterility. During the 1999 wheat season, 31 wheat genotypes with wide genetic bases were planted in four rows of plots two metres long, with and without boron, on the Sipaghat rice-wheat site in Kabre district. Sipaghat is situated at a fairly low altitude (650-750 masl). Boron at a rate of 2 kg/ha was used as a basal application. Visual observation of sterility was made at Zadok's growth stage 71 by carefully looking at and grasping the spike.

Another experiment with two dates for planting and three wheat varieties was carried out at Tarahara Agricultural Station during the 1987/88 wheat season to study the effect of boron, date of planting, and variety on spike sterility. Boron was applied to the soil in amounts of 1.65 kg/ ha before sowing. Other nutrients (nitrogen, phosphorous, and potassium [NPK]) were applied as per recommendations. Wheat was planted on December 8th and 22nd to investigate the effects of planting time on sterility. Estimation of sterility was arrived at using the LAC method described in this paper. Three popular wheat varieties, Nepal 297, UP 262, and BL 1022 were selected for the study.

The National Wheat Research Programme (NWRP) has emphasised the need to identify genotypes tolerant to low soil boron content. For this purpose, the Jute Research Programme (JRP) situated at Itahari in Sunsari district has been selected as a screening location. The soils at the JRP site are light textured and deficient in soil boron (<0.2 ppm), and susceptible wheat genotypes exhibit 100 per cent sterility. The NWRP is screening a large number of genotypes for the purpose of identifying sterility tolerant varieties. Two hundred genotypes were planted during the wheat seasons of 2002/03 and 317 genotypes during 2003/04. They had different genetic bases and were planted in two rows of plots two metres long. Other inputs and management conditions were provided as per recommendations. Sterility percentage of genotypes was recorded on the basis of visual observation during the post anthesis stage.

During the 2003/04 wheat season, participatory varietal selection consisting of seven genotypes took place in six farmers' fields differing in boron content in Kaski district. Soil analysis was carried out for available NPK, organic matter, boron, and pH. The percentage sterility for a susceptible genotype, BL 1813, was assessed using the LAC method.

Results and Discussion

Varietal differences and response of applied boron

The thirty-one wheat genotypes evaluated at the Sipaghat rice-wheat site during the 1999 wheat season, with and without boron, showed great genotypic variation in terms of sterility (Table 1). There was a clear-cut difference among genotypes in spike sterility. Sterility among genotypes in plots without added boron (boron minus) varied from 1 to 100 %. There was a drastic reduction in sterility in plots to which boron was added (boron plus), indicating that boron deficiency is a major cause of sterility in the area. Sterility among genotypes in boron plus plots varied from 0 to a maximum of 5 %, whereas in boron minus plots some varieties exhibited up to 100% sterility. Two of the control varieties, Achyut and Annapurna^{-1}, had a high degree of sterility (70 to 80%) in boron minus plots.

SN.	Genotype	Sterility % (+ Boron) [1]	Sterility % (- Boron) [1]
1	BL 1473	1	4
2	WK 823	1	5
3	NL 769	2	5
4	NL 810	1	70
5	WK 831	2	99
6	NL 818	1	99
7	NL 783	2	60
8	NL 816	1	95
9	NL 820	4	90
10	BL 1692	1	5
11	BL 1720	5	100
12	BL 1724	0	5
13	BL 1810	1	95
14	NL 750	0	15
15	NL 753	2	90
16	NL 781	2	70
17	NL 792	2	60
18	NL 867	1	2
19	NL 868	5	95
20	NL 870	2	70
21	NL 872	0	1
22	NL 876	1	15
23	NL 901	0	3
24	NL 902	0	1
25	NL 903	0	1
26	RR 21 (control)	0	2
27	UP 262 (control)	1	3
28	Bhrikuti (control)	3	15
29	Rohini (control)	0	2
30	Achyut (control)	2	80
31	Annapurna^{-1} (control)	0	70

Table 1: **Response of 31 wheat genotypes to applied boron (2 kg/ha) in a sterility screening nursery, Sipaghat, Kabre district, 1999**

Source: Bhatta 1999 (u npublished data) ; [1] Sterility scores were based on visual observation

Response to planting dates and applied boron

In the 1987/88 study, a wide variation was found in spike sterility (0 to 82%) among the different treatments: planting date, variety, and boron application (Table 2). Application of boron at 1.65 kg/ha significantly reduced spike sterility, regardless of planting date but there were varietal differences (Table 2).

Table 2: Percentage spike sterility of wheat cultivars (UP 262, Nepal 297, and BL 1022) as influenced by dates of boron application at Tarahara agricultural station, 1987				
Variety	**Planting date**			
	Minus boron		**Plus boron @ 1.65 kg/ha**	
	8 Dec	**22 Dec**	**8 Dec**	**22 Dec**
UP 262	27.0	3.0	0.3	0.0
Nepal 297	41.7	8.3	10.0	1.0
BL 1022	15.0	81.7	0.0	1.7
Source: Sthapit 1988				

Genotypic variability to low soil boron content

A large number of wheat genotypes were evaluated at the Jute Research Programme, Itahari, Sunsari district, under low soil boron content (<0.2 ppm) in the wheat seasons of 2003 and 2004. Two hundred genotypes with differing genetic base were included in the test during 2003 and 317 during 2004. Spike sterility among genotypes ranged from 0 to 100% in both years (Figures 2 and 3). Several genotypes had 0 to 5% spike sterility, demonstrating tolerance to low soil boron content. During the 2004 season, 43 genotypes of the 317 genotypes screened exhibited 0% spike sterility, and 76 showed very low (1-5%) sterility. In contrast, 58 showed 100% spike sterility. This study showed that boron efficient genotypes could be identified and selected in terms of good agronomic types simultaneously.

Participatory varietal selection

In participatory variety selection (PVS) trials carried out on six farmers' fields, the degree of spike sterility of wheat variety BL 1813 was found to vary with soil pH and boron content of the soil (Table 3). The lowest sterility (11.6%) was observed in Madhav Baral's field, which had slightly acidic soils and a boron content of 0.39 ppm. The table indicates some relationship between soil pH, boron content, and spike sterility. Spike sterility was highest in Gita Adhikari's field (85%) despite it having the highest soil boron (0.83 ppm) presumably as a result of the high soil pH; a similarly high sterility was observed in Mukti Tiwari's field despite the comparatively low pH, presumably as a result of the very low soil boron (0.08 ppm), whereas low sterility was observed in Madhav Baral's field with slightly acidic soil and high organic matter, although boron was only medium. In general, it seemed that high soil pH restricts the availability of boron and plays a role in sterility.

The wheat genotypes listed in Table 4 were identified and selected from a hot spot in the eastern Terai. These genotypes not only have low spike sterility but are also good agronomic types. These types show that it is possible to select genotypes that are both good agronomic types and sterility tolerant through plant breeding and screening them in hot spots.

Conclusions and Recommendations

a) Wheat sterility has become a potential threat to wheat production in many parts of the country, including the mid-hills and the Terai.
b) Boron deficiency, cold temperature, and waterlogging at anthesis are considered to be the major factors causing spike sterility in wheat in Nepal.
c) Boron deficiency induced sterility is serious in the low hills and the Terai where the rice-wheat system is common.

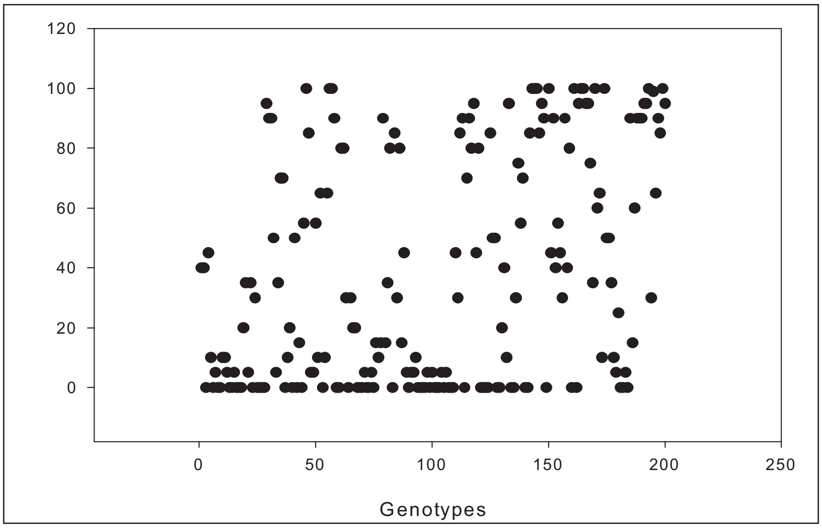

Figure 2: **Genotypic variation in wheat sterility, Jute Research Programme, 2003**

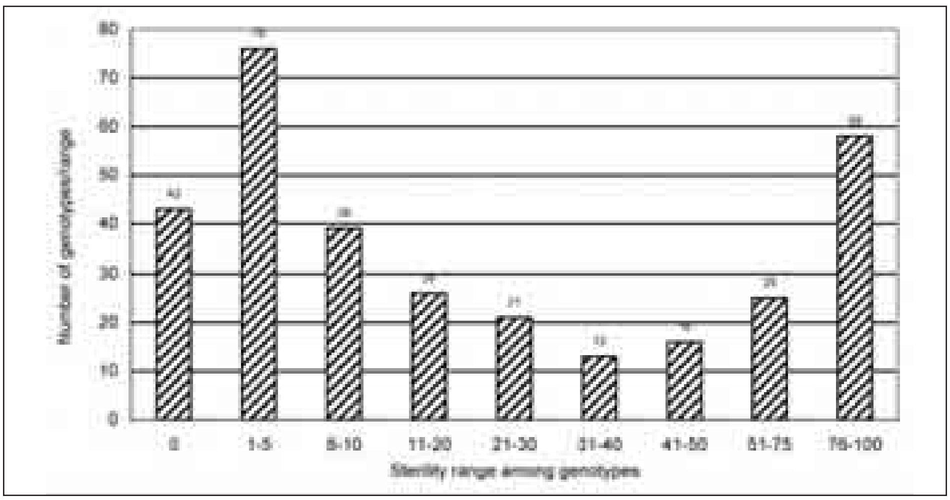

Figure 3: **Differential response of genotypes to wheat sterility, Jute Research Programme, 2004**

Table 3: **Percentage sterility of variety BL 1813 planted in different farmers' fields, and soil characteristics in six mother trials in Kaski (2003/04)**

			Soil characteristics					
Farmers conducting mother trial	**Sterility (%)**	**Soil type**	**pH**	**% OM**	**%N**	**P_2O_5 (mg/kg)**	**K_2O (mg/kg)**	**Boron (ppm)**
Sita Bhandari	63	S. Loam	7.87	1.03	0.07	9.6	16.4	0.21
Madhav Baral	11.6	S. Loam	5.96	3.05	0.16	7.85	21.2	0.39
China Lamichhane	66.7	S. Loam	7.83	1.08	0.07	5.55	21.6	0.15
Mukti Tiwari	81.1	S. Loam	6.4	1.28	0.08	5.6	28.1	0.08
Chandrakanta Pageni	77.4	S. Loam	8.04	2.64	0.14	7.9	51.6	0.09
Gita Adhikari	85	S. Loam	8.05	2.77	0.15	2.1	36	0.83
OM = organic matter								

Table 4: **Wheat varieties/lines that are good agronomic types and have tolerance to sterility under low soil boron conditions in the eastern Terai**	
Varieties/lines	**Sterility %**
BL 2195	5
BL 2196	1
BL 2151	Trace
BL 2173	Trace
BL 2175	1
BL 2153	Trace
BL 2169	Trace
BL 2163	Trace
BL 2158	Trace
BL 2202	Trace
BL 1473*	Trace
Nepal 297*	Trace

Source: Bhatta 2000 (unpublished data)

* Nepal 297 and BL 1473 are the two popular varieties tolerant to sterility in Nepal.

d) The adverse effects of spike sterility in wheat caused by soil boron deficiency could be corrected by applying 2 kg/ha of boron to the soil at planting time.
e) There is wide genetic variability in tolerance to sterility caused by boron deficiency.

The following recommendations are made.

a) Wheat varieties efficient in soils with low boron content that are also good agronomic types need to be developed and identified through plant breeding and screening in hot spot locations.
b) The findings of conventional plant breeding techniques should be linked to biotechnological tools to identify potential donors of sterility tolerant traits through molecular markers.
c) Boron deficient areas in the country need to be identified and GIS (geographical information systems) maps of them prepared.

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