Climate-smart Soil Fertility Improvement Techniques Increase Grain Yield in the Ethiopian Highlands

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Subsistence agriculture, the mainstay of the Ethiopian economy, is challenged by declining soil fertility. Smallholder farmers recognize the spatial variability of soils within farms and often apply recommended rates of fertilizer. Taking the response of wheat (*Triticum aestivum* L.) to N and P fertilizers (rates increased from 0-0 to 69-69 kg N-P ha^{-1}), grain yield significantly increased. However, the critical nutrient levels of various soils are less known. Setting maximum yield that received 69 kg N ha^{-1}, the critical soil phosphorus concentration was found to be about 6 mg kg^{-1} for the Vertic Cambisol (Table 1), 4.32 mg kg^{-1} for the Arenic Cambisol, 5.89 mg kg^{-1} for the Pellic Vertisol, and 6.62 mg kg^{-1} for the Calcaric Regosol. Thus, for some soil types in northern Ethiopia, it was actually found that P rates, in terms of DAP equivalent, would have been 124 kg DAP ha^{-1} for the Vertic Cambisols, 80 kg DAP ha^{-1} for the Arenic Cambisols, 129 kg DAP ha^{-1} for the Pellic Vertisols, and 134 kg DAP ha^{-1} for the Calcaric Regosols. These results suggest that the blanket fertilizer recommendations that the agricultural extension service set at 50 kg DAP ha^{-1} for dry areas or 100 kg DAP ha^{-1} for wet areas need to be revised.

Table 1. Amount of P fertilizer required determined based on the Critical P levels and P requirement factors for the different soil types of northern Ethiopia.

Soil type	P_0 (mg kg^{-1})	P_c	P_c-P_0 (mg kg^{-1})	P_f (kg P ha^{-1})/ (mg kg^{-1})	P required (kg P ha^{-1})
Vertic Cambisol	3.13	6.00	2.87	8.59	25
Arenic Cambisol	0.28	4.32	4.04	4.03	16
Pellic Vertisol	1.66	5.89	4.23	6.07	26
Calcaric Regosol	0.51	6.62	6.11	4.40	27

Taking in-situ soil moisture conservation measures, the grain yield of sorghum (2827 kg ha^{-1} for tied-ridge vs. 1472 kg ha^{-1} for flat-bed) on Vertisols (Table 2) was significantly higher when tied-ridges were used than when flat-beds were used.

In faba bean experiments for crop rotations, the application of 15 kg Zn ha^{-1}, along with increasing P rates, enhanced effective root nodule development (Figure 1). The N_{tot} in the soil after crop harvest was also improved when 15-23 kg Zn-P ha^{-1} was applied, compared to the P only fertilizer treatment.

Similarly, soil available P after harvest was improved by the application of Zn. This could probably be due to the fact that lower rhizosphere pH, enhanced by optimal Zn application, could increase P availability in the soil. Substantial increases in grain food production can be achieved by establishing optimum fertilizer application rates, using moisture conservation technologies, and maintaining legumes in the cropping system. A holistic approach towards integrated soil fertility management could address the food demands of resource-poor farmers in developing countries.

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Table 2. Effects of *in-situ* soil moisture conservation and N and P fertilizer application on sorghum grain yield in the southwestern lowlands of Tigray, northern Ethiopia.

	Vertisol			Calcisol			Cambisol		
Treatment	Yield (kg ha^{-1})	Diff.*	%	Yield (kg ha^{-1})	Diff.	%	Yield (kg ha^{-1})	Diff.	%
Tied-ridge									
Fertilized	2827	803	40	1494	677	83	1745	570	49
Unfertilized	2024			817			1175		
Flat-bed									
Fertilized	1472	366	33	279	154	123	318	214	206
Unfertilized	1106			125			104		
Tied-ridge fertilized vs flat-bed fertilized									
Tied-ridge fertilized	2827	1355	92	1494	1215	435	1745	1427	449
Flat-bed fertilized	1472			279			318		
Tied-ridge unfertilized vs flat-bed unfertilized									
Tied-ridge unfertilized	2024	918	83	817	692	534	1175	1071	1030
Flat-bed unfertilized	1106			125			104		
Tied-ridge unfertilized vs flat-bed fertilized									
Tied-ridge unfertilized	2024	552	38	817	538	193	1175	857	269
Flat-bed fertilized	1472			279			318		

* 'Diff.' on the column titles refers to 'Difference'.

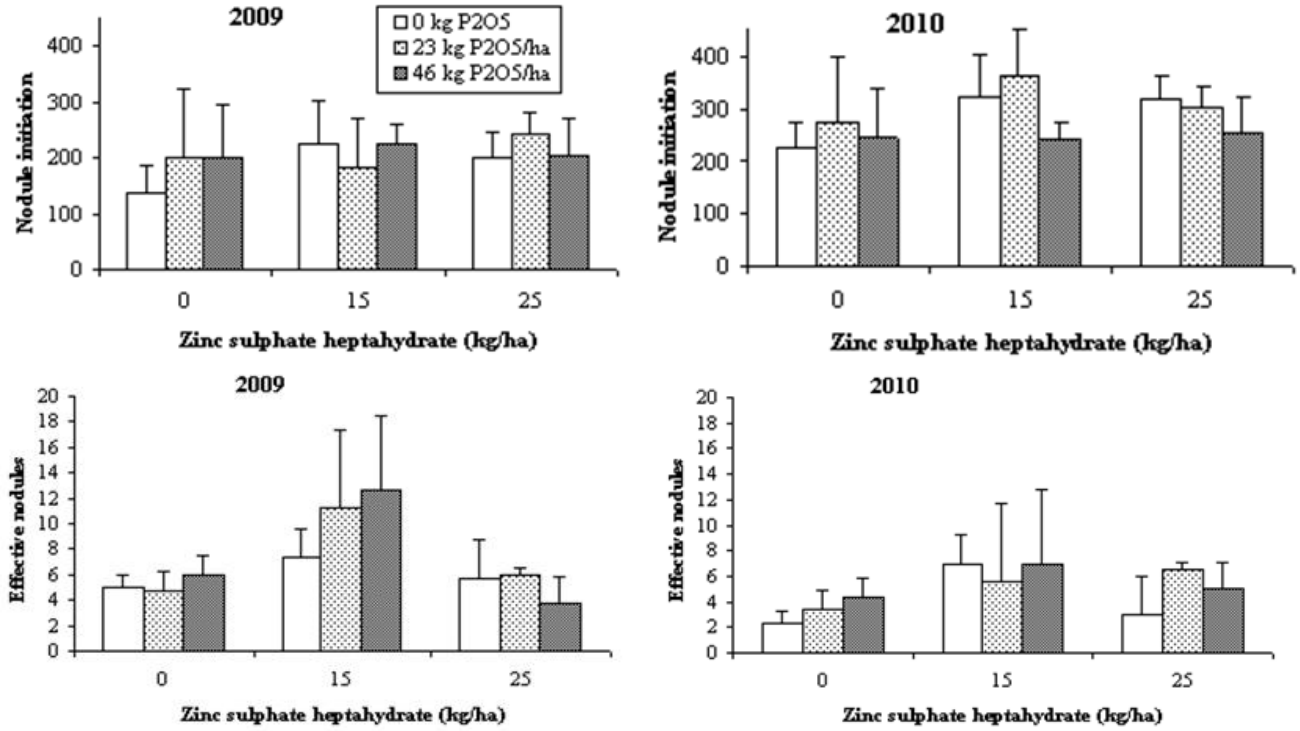

Figure 1. Effect of P and Zn application on nodule initiation (top) and effective nodules (bottom) for faba beans on Calcaric Regosol in northern Ethiopia in 2009-2010.