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Potassium (K): Principal Constraint to Maize Production in *Imperata*-infested fields at Central Sulawesi, Indonesia

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Abstract

On tropical soils that are generally acidic and of low fertility, the low-input annual crop cultivation tends to collapse because of *Imperata* weed infestation. Once infested with *Imperata,* the farmers may only have one or two harvests (e.g. maize) before the weeds completely cover the land. Formerly cultivated fields are fallowed and eventually abandoned when cultivation no longer provides economic returns.

A study was conducted in 2003 / 2004 in a rainforest margin in Central Sulawesi prone to *Imperata* infestation to identify the underlying factor constraining maize production. Maize was planted in fields with different levels of *Imperata* infestation. Before maize cropping, *Imperata* was controlled by shallow or deep hoeing or herbicide application. Maize was grown with and without fertilizer application (NPKS).

Fertilizer application significantly enhanced maize growth in all fields as well as improved the maize grain yield production for 2 cropping periods, particularly in highly-*Imperata* infested field (4.0 t ha^{-1} against 0.1 t ha^{-1}) but also in medium-infested field (8.8 t ha^{-1} against 3.0 t ha^{-1}), and low-infested field (6.3 t ha^{-1} against 2.4 t ha^{-1}). Without any fertility inputs, maize grain production in highly-*Imperata* infested field was severely impeded, but with fertilizer application gave the highest stover yield (10.9 t ha^{-1}).

A detailed analysis of maize nutrient accumulation revealed that K was the key constraining nutrient. In the high-infested field, K levels in the stover tissue were very low, the primary cause for the poor grain development in the highly- *Imperata* infested field. The stover source strength of K was apparently unable to meet the sink demand for grain production. Although many reports state that farmers abandon the field when they can no longer cope with the *Imperata* as the cropping period proceeds, it could be that poor grain production that is discouraging farmers in cultivating such fields. Fertilizing the fields early in the infestation process might be a suitable measure to counter *Imperata*.

INTRODUCTION

In Southeast Asia, maize is the second most important staple food and a major component of animal feeds. As the demand for maize is rapidly outpacing the supply and suitable land for intensive lowland agriculture is no longer available, farmers are growing more maize in the uplands (CIMMYT, 1999). Indonesia is the country with largest area planted with maize (Witt et al., 2006). However, the cultivation for agricultural food crops using low-level inputs in the uplands, especially on acid soils, has been shown to collapse because of weed infestation (Sanchez et al., 1987; von Uexküll, 1995).

The invasion of *Imperata cylindrica* is a huge land degradation problem affecting millions of hectares in the region (Garrity et al., 1997; Giller, 2003). Once the field is invaded, the farmers may only have one or two harvests before the weeds completely cover the land. Farmers abandon the field when they can no longer control the *Imperata* as the cropping period proceeds, and cultivation is no longer economic (Santoso et al., 1994; van Noordwijk et al., 1997).

Terry et al., (1997) indicated that the knowledge on the control of *Imperata* is such that it need not be a problem where resources are available. Integrated control approaches are emphasized (Menz et al., 1998; MacDonald, 2004; Chikoye, 2005), while maintaining an adequate soil nutrient status is indicated as one of the keys for preventing *Imperata* encroachment and stabilizing crop productivity (van Noordwijk et al., 1997).

To date, little is known about the site and system specificity of control strategies. Also, what nutrients constraining maize crop production in field infested with *Imperata*. This study investigates and compares cultivation management strategies to control *Imperata* at various stages of infestation in maize cultivation. Specifically, this study identifies the most probable nutrient constraining maize yields and favoring *Imperata* infestation in the study area.

METHODOLOGY

Study area

The field research was conducted in the buffer zone of the Lore Lindu National Park (LLNP), situated about 50 km south-east of Palu, the capital of Central Sulawesi, Indonesia. The experimental site is located in the rainforests margin of the Napu valley, with an average elevation of 1,140 m above sea level.

Following forests clearing and burning, the cleared lands are primarily planted with maize as monoculture sometimes followed by root crops like cassava. Farmers do not use fertilizer and engage in continuous cultivation without fallow period. Initially, maize yields are relatively high but declining after several periods of continuous cultivation (Dechert et al., 2005). Farmers often blame weed infestation or weather conditions for the low yields. After 2-3 years of maize cultivation, farmers either switch to cacao-coffee agroforestry, or fields are fallowed or totally abandoned fully covered with *Imperata*.

Experimental fields

A cultivated area directly adjacent to a forest and surrounding croplands, with different degrees of *Imperata* infestation (covering the critical range from early infestation to the point of abandonment) was selected for the experiments. Selected fields were currently or in the past under continuous maize cultivation. The fields were categorized according to *Imperata* density by counting shoots m^{-2}. The exact coverage was assessed as summarized in Table 1. The 500 m^{-2} was used as reference since a natural sward of *Imperata* areas has 300-500 shoots m^{-2} (IRRI, NRI and ICRAF, 1996). A sampling conducted in long abandoned fields covered with *Imperata* show that 300-400 shoots m^{-2} is the full coverage in the research area. Fields with shoots counts above 75 % was already considered for reclamation or total rehabilitation.

Table 1: Categorization of selected cultivated area by degree of *Imperata* infestation using 500 shoots m^{-2} as full coverage of shoots per m^2

Field	Degree of *Imperata* infestation [500 shoots m^{-2} as full coverage]		Shoots counts (shoots m^{-2})	Range of infestation (%)	Cleared from natural forest	Years of maize cultivation
A	Low	[1 % - 25 %]	12-130	2.4 - 20.6	2001	2
B	Medium	[26 % - 50 %]	131-250	26.2 - 50.0	1996	4
C	High	[51 % - 75 %]	277-355	55.4 -71.0	1995	5

Field experiments

The study was carried out in two sets of field experiments. The first experiment was a two cropping cycle trial on all three fields (A, B, C) with treatments, land preparation method (deep hoeing or herbicide application) superimposed with a cropping strategy (mineral NPKS fertilizer application or mucuna relay or without both as control). Residual effects were measured in the subsequent crop cycle. The second experiment had only one cropping cycle on low (A) and high (C) infested fields. Shallow hoeing was used as land preparation method followed by the same cropping strategies to determine whether a minimum tillage is sufficient as an *Imperata* control, and at which level of infestation. The purpose of the combined treatments was to control and suppress *Imperata* re-growth by soil fertility maintenance to enhanced maize growth and DM production, and most importantly to achieve an optimum maize grain yield.

Data collection and analysis

Soil samples were collected before cropping and plants samples before, during and after cropping. Soil samples were analyzed to determine the total organic C, N, S, the available P (Bray-1), exchangeable cations, pH, and soil texture. Also, the bulk density was determined. Plant samples were collected to determine the density, DM production and nutrient accumulation. The plant (e.g. *Imperata*, other weeds, mucuna and maize) samples were analyzed for total N, P, K and S. Nitrogen (N) recovery and the biological nitrogen fixation (BNF) of the mucuna relay were also determined.

Analysis of variance (ANOVA) of the split-plot design was used to test the effects of the treatment by field, randomized complete block design for the overall effects of the cultivation practices. Tukey means separation for comparison of significant effects between the three fields and three cropping strategies, least significance difference (LSD) for the comparison of two fields and two land preparation practices. T-statistic test was also used to differentiate the identified critical point (as the critical minimum nutrient concentration) to other nutrient concentrations in maize biomass.

RESULTS

As land preparation method to control, deep hoeing (DH) and herbicide application (HA) were equally effective in eradicating the initial *Imperata* infestation in all fields, while shallow hoeing was effective in eradicating initial *Imperata* infestation in fields with low infestation but not with high-infestation (Table 2).

Table 2: Effect of land preparation methods in controlling initial *Imperata* infestation

IMPERATA RESPONSE	Low		Medium		High	
***Imperata* counts**			[shoots m^{-2}]			
Intensive land preparation by deep hoeing (DH) and herbicide application (HA)						
Before experimentation	**69 a**		**178 b**		**312 c**	
	DH	HA	DH	HA	DH	HA
After 1st cropping	**11 ns**	**10 ns**	**17 ns**	**20 ns**	**18 ns**	**32 ns**
After 2nd cropping	**2 ns**	**3 ns**	**2 ns**	**6 ns**	**8 ns**	**9 ns**
After experimentation	**3 a**		**4 ab**		**8 b**	
Minimum tillage by shallow hoeing						
Before experimentation	**38 a**				**286 b**	
After experimentation (after one cropping)	**9 a**				**137 b**	

Tukey test ($p<0.05$): Letter a, b, c denote significant difference, ns denote no significant difference between field mean values (n=3)

The effective elimination of *Imperata* during land preparation does not mean that maize crop is already free from other weeds interference, and from eventual potential *Imperata* re-infestations. But more importantly, the elimination of *Imperata* prior to cropping opens up the opportunity to enhance and supply the nutrients needed by maize in all fields with the application of fertilizers.

The superimposed cropping management practice (a soil fertility enhancement strategy) during maize cropping, is considered vital after *Imperata* control. A suppressive effect of fertilizer application and mucuna relay was observed after two maize cropping periods in all fields. But fertilizer application or mucuna relay superimposed following shallow hoeing did not show significant suppressive effects after one cropping period in either field.

Maize total DM production was higher when initial *Imperata* infestation was effectively controlled before maize cropping. Fertilizer application was effective in enhancing maize total DM production in all fields (Table 3). However, particularly in the high-infested field, fertilizer application only significantly enhanced the stover production and the harvest index remained unusually low. Compared to the other fields, grain production in the high-infested was still lower even with fertilizer application. Most especially, in the high-infested field where there was still high *Imperata* competition. The maize cob tissue was mostly without kernels. The grain production potential was still impeded by nutritional constraints even with fertilizer inputs. This was aggravated with the high competition of the regrowing *Imperata* for the nutrients.

On the other hand, the mucuna relay did not have a significant effect on maize yield during first maize cropping period, but the residual beneficial effect was significant on the subsequent maize yield.

Table 3: Effect of the superimposed cropping strategies

MAIZE RESPONSE FOLLOWING INTENSIVE LAND PREPARATION

Average Harvest index	Low	Medium	High
1st cropping period	0.3 b	0.5 c	0.1 a
2nd cropping period	0.3 b	0.4 b	0.1 a

		Fertilizer	Mucuna	Control	Fertilizer	Mucuna	Control
Harvest index							
	Low	ab 0.4 ns	b 0.3 ns	b 0.4 ns	b 0.4 ns	b 0.3 ns	b 0.4 ns
	Medium	b 0.5 b	b 0.4 a	b 0.5 b	b 0.5 ns	b 0.4 ns	b 0.4 b
	High	a 0.3 b	a 0.03 a	a 0.03 a	a 0.2 b	a 0.07 a	a 0.05 a
Stover				[t ha^{-1}]			
	Low	ns 8.3 b	ns 5.2 a	ns 4.5 a	ab 11.7 b	b 8.0 b	ns 3.7 a
	Medium	ns 7.3 b	ns 4.9 a	ns 4.4 a	a 10.4 c	a 4.8 b	ns 2.5 a
	High	ns 7.9 b	ns 4.9 a	ns 4.5 a	b 13.8 b	ab 5.6 a	ns 3.1 a
Grain				[t ha^{-1}]			
	Low	a 4.8 b	b 2.6 a	b 2.8 a	ab 7.8 b	b 3.6 a	b 2.1 a
	Medium	b 8.8 c	b 3.2 a	b 4.3 b	b 8.8 c	b 3.2 b	b 1.7 a
	High	a 3.6 b	a 0.1 a	a 0.1 a	a 4.3 b	a 0.6 a	a 0.2 a

Tukey test ($p<0.05$): Letters a, b, c denote significant difference, ns denote no significant difference
Between cropping strategies within field (column), mean values (n=3)
Between field by cropping strategy (rows), mean values (n=6), combined data of the two land preparation

MAIZE RESPONSE FOLLOWING MINIMUM TILLAGE

		Fertilizer	Mucuna	Control
Harvest index				
	Low	b 0.3 ns	b 0.2 ns	b 0.2 ns
	High	a 0.07 ns	a 0.00 ns	a 0.07 a
Stover			[t ha^{-1}]	
	Low	b 17.2 b	b 9.4 a	b 10.2 a
	High	a 10.3 b	a 3.8 a	a 3.8 a
Grain			[t ha^{-1}]	
	Low	b 7.3 b	b 3.3 a	b 3.6 a
	High	a 0.9 b	a 0.0 a	a 0.0 a

Tukey test ($p<0.05$): Letters a, b denote significant difference, ns denote no significant difference
Between cropping strategies within field (column), mean values (n=3)
Between field by cropping strategy (rows), mean values (n=3)

Without superimposing a cropping strategy, there was high infestation of other weeds replacing *Imperata*, high potential *Imperata* re-infestation, and low maize yield and eventual reduction on the succeeding maize cropping in all fields. Most especially, it resulted to a maize crop failure in the high-infested field.

Applying the Liebig´s law of the minimum, the analysis of nutrient levels in maize DM suggests that among the four nutrients, K was the primary factor determining higher grain yield in the low- and medium-infested fields, and for the lower grain yield in the high-infested field (Table 4). In the high-infested field, the K nutrient was always limiting in the leaves and stover, especially with mucuna and in the control. Whereas, the mineral fertilizer application was able to enhanced the nutrient supply needed by maize for its growth, but not enough to enhance to supply the grain production. On the subsequent cropping, the K nutrient limiting factor in the stover was accompanied by S limitation.

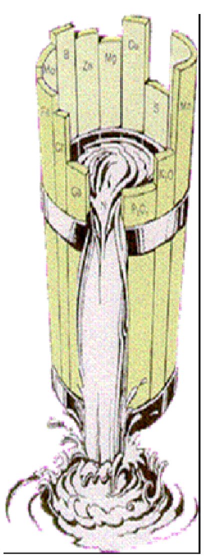
In the second set of experiments with minimum tillage, grain production in the high-infested field was severely impeded. Like in the second cropping periods of the first set of experiments, K nutrient limitation in the stover was also accompanied by S limitation, and even with fertilizer application.

The rate of K fertilizer applied seemed insufficient to fully satisfy the needs of the maize crop. The stover seems to have been a poor source of K (poor source strength) when there was a strong demand for the transfer of this nutrient in order to facilitate grain production. Further, in the high-infested field where *Imperata* was not fully eradicated by shallow hoeing, the K limitation was aggravated by *Imperata* strong competition for nutrients. Thereby limiting availability to maize crop and thus producing a cob tissue, which was mostly without kernels.

Liebig´s "Law of the Minimum"

"Crop yields are proportional to the amount of the most limited nutrient, whichever nutrient that may be."

Table 4: LIMITING NUTRIENTS IN MAIZE LEAVES (L) AND STOVER (S)



FOLLOWING INTENSIVE LAND PREPARATION

	Fertilizer		Mucuna		Control	
	L	S	L	S	L	S
1st period						
Low	✓	- P	✓	-P, -S	✓	-P, -S
Medium	✓	- P	-N, -P, -S	-N, -P, -S	-N, -P, -S	-N, -P, -S
High	✓	✓	-N, -K, -S	-K	-N, -K, -S	-K
2nd period						
Low	✓	-N, -P	✓	-N, -P, -S	-N, -P, -K	-N, -P, -K. -S
Medium	✓	-N, - P, -S	-N, -P, -S	-N, -P, -S	-N, -P,	-N, -P, -S
High	✓	-S	-N, -K, -S	-K, -S	N, -K, -S	-K, -S

FOLLOWING MINIMUM TILLAGE

	Fertilizer		Mucuna		Control	
	L	S	L	S	L	S
Low	✓	- P	N, -P, -K, -S	-N, -S	N, -P, -K, -S	-N, -S
High	- P	-K, -S	-N, -S	-K, -S	-N, -S	-K, -S

It is indicated that the low level of K in an *Imperata* areas is due to the extensive belowground rhizome network (Daneshgar et al., 2005) as well as to association with mycorrhizae (Brook, 1989), which accounts for the ability to exploit soil K (Collins, 2005). Further, a decrease in soil K have serious implication for recruitment and growth of other plant species since K is known to affect cell division, formation of carbohydrates, translocation of sugars, and several other functions (Plaster, 1992).

The symptoms exhibited in the high-infested fields are a classic example of K deficiencies in maize. According to Jones Jr. (2003), K deficiency severely reduces yield in maize. The poor cob formation and grain fill in maize resulting in low starch level are consequences of low K. As indicated by Beringer (1980), better K nutrition improved grain setting in the ear, i.e. stimulated the storage capacity for assimilates, which can be seen from the remarkable increase in single grain weight and number of grains/ear. It was also reported by Mussgnug et al. (2005) that K was the most yield-limiting macronutrient, and regular K applications were required to make investments in the application of other mineral nutrients profitable.

CONCLUSIONS AND RECOMMENDATIONS

If no economic return can be derived from cultivating the fields due to *Imperata* invasion, farmers would eventually abandon the land and seek other potential cultivation areas in the forest. *Imperata* can be combated and suppressed by appropriate combination of land preparation and crop management practices. When *Imperata* infestation in the field is dense with deeply established rhizomes, intensive land preparation such as deep hoeing or herbicide use is necessary to effectively destroy the rhizomes. When *Imperata* has newly established in the field, minimum tillage by shallow hoeing is still feasible. After eradicating the initial *Imperata* infestation during land preparation, superimposing a soil fertility enhancement cropping strategy is vital to suppress *Imperata* and smother other weeds. Thus, the primary crop is given a chance to compete with the weeds and provide a reasonable yield. The key concept of enhancing the soil fertility lies in correcting the limiting nutrients in the infested fields with the right kinds and amounts of fertilizer.

In the study area, the grain production in fields with high *Imperata* infestation was found impeded by K limitations. However, additional studies are recommended to verify this result and to further assess the best economic rates of K fertilization for the region. Conclusive findings regarding K as the nutrient limiting maize yield should be based on a factorial experimentation with N, P, K, and S fertilizer application.

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