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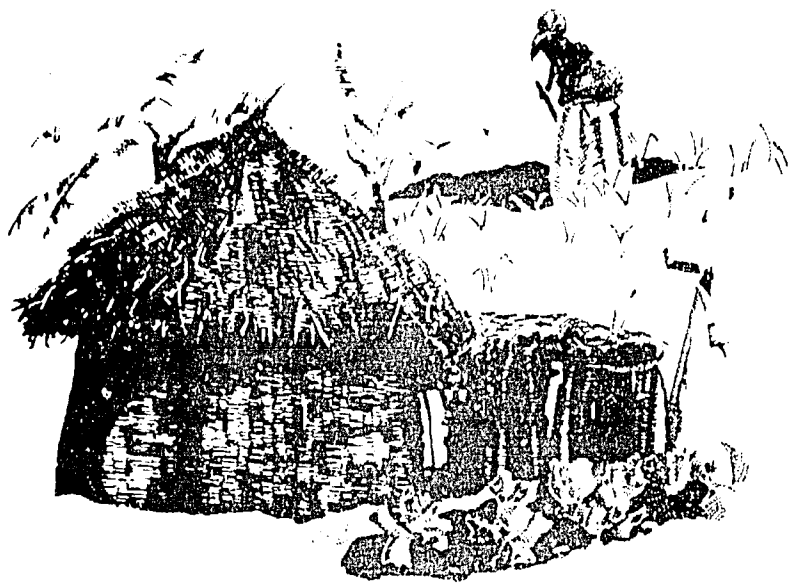

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between

The University of Arkansas, Fayetteville
(International Agricultural Programs)

and

The Rwandan Ministry of Agriculture
Rwandan Institute for Agricultural Sciences (ISAR)

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Green Manuring with Vetch on Acid Soil in the Highland Region of Rwanda

Charles Yamoah, Val J. Eylands
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Report # 62

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GREEN MANURING WITH VETCH ON ACID SOIL IN THE HIGHLAND REGION OF RWANDA

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INTRODUCTION

The advantages ascribed to legume green manuring are numerous and include improvement in soil fertility, increased cation exchange capacity (CEC), increased water retention, enhanced microbial activity and improved soil structure (Faulkner, 1934; Greensill, 1975; Agboola, 1974; Wade and Sanchez, 1983; Hargrove, 1986; Mahler and Auld, 1989; Rattray and Ellis, 1952; Wilson et al., 1986).

Among the factors that discourage total acceptance of green manuring by small farmers are 1) high labor investment and time requirement for planting and incorporation (Agboola, 1974; Wade and Sanchez, 1983; Mundy, 1928; USDA, 1980; Webster and Wilson, 1980); 2) soil moisture required for growth and decomposition of the green manure (USDA, 1980; Duncan, 1974; Mundy; 1928; Wilson et al., 1986); 3) short-lived nature of green manuring in dealing with soil fertility maintenance (Rattray and Ellis, 1952; Wade and Sanchez, 1983; Agboola, 1981); and 4) the possibility of rendering soils acidic, especially in areas with pH < 5 (Mundy, 1928; Sanchez and Miller, 1986).

Vetch (*Vicia sativa L*) is a potential green manure crop in the East-Central African highland region where soils are generally acidic (Nizeyimana and Bicki, 1988; Vander Zaag et al., 1984; Neel and De Prins, 1974; Yamoah et al., 1990). In this area, vetch grows relatively fast, assumes a quick soil cover to check ground erosion and produces high biomass (Potts et al., 1989; Yamoah and Mayfield, 1990). In Southern Africa (Mundy, 1928), the USA (Roberts et al., 1989) and other developed and developing countries (Papendick and Elliot, 1984), vetch has been successfully used as a green manure and cover crop to raise soil productivity.

The beneficial effects of using vetch for green manuring are yet to be exploited in Rwanda where biological nitrogen fixing systems are a key to soil fertility maintenance. As in many countries in the third world and even in parts of the Soviet Union (Van Meter, 1986), most farmers in Rwanda cannot afford the huge quantities of inorganic fertilizers necessary to sustain crop yields. The purpose of this study, therefore, is to assess the value of vetch used as a green manure crop on acid soil prevalent in the highland region of Rwanda. Bean (*Phaseolus vulgaris*) and wheat (*Triticum aestivum*) yields and soil chemical analysis following incorporation of vetch were used to evaluate success in improvement of soil fertility.

MATERIALS AND METHODS

The study was carried out during four cropping seasons (November 1987 to August 1989) at the Institute of Agronomic Sciences of Rwanda's (ISAR) high-elevation (2300 m) experimental station. The Farming Systems Research Program (FSRP) of the University of Arkansas is based in this area and is located in northern Rwanda at longitude 29 53' east and latitude 1 32' south. The bimodal rainfall pattern allows two cropping seasons, the first from March to June and the second from September to March. The average annual rainfall is 1200 mm, and this rainfall has about an 80% chance of occurring during a growing season. The soils are classified in the USDA system as Oxisols (RRAM, 1987; Franzel et al., 1985) and are underlain by granite and schists complex (RRAM, 1987). Soils of the experimental station are typically acidic with the following characteristics: pH = 4.7; exchangeable aluminum (Al) = 2.9 meq/100 g; effective cation exchange capacity (ECEC) = 7.1 meq/100 g and Bray 1 phosphorus (P) = 5.2 ppm. For a detailed fertility capability characterization of the soils in this zone, see Yamoah et al. (1990). Mean monthly temperature is 13 C, but temperatures as low as 5 C are possible.

Vetch was grown for five months from November 1987 to April 1988 on a 20 x 30 m plot prior to its incorporation as green manure. An adjacent plot under short fallow after potato served as a control (without vetch). The vetch-treated

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and control plots were divided into 12 subplots and allocated to wheat and bean crops. Nitrogen (N) fertilizer as urea at 0, 30, 60, 90, 120 and 150 kg N/ha was assigned randomly to the same wheat and bean subplots during each of the three subsequent growing seasons. All plots received basal applications of P as single superphosphate and K as muriate of potash at 30 kg /ha for only the first crop. There were three replications for each treatment combination in both the vetch and control sites. Food crops, wheat (variety Rugezi) and bean (variety Rubona 5) were planted immediately after incorporation of the vetch. Two tons of lime per hectare was applied to the whole experimental unit and allowed to incubate for four weeks before seeding the third crop. The bean variety Rubona 5 was replaced with Bataaf during the third season because it was observed to be highly susceptible to beanfly, *Rhizoctonia solani* and *Ascochyta* sp.

Soil was sampled at the beginning of the second growing season and analyzed for pH, exchangeable Al, organic carbon (OC), N, P, K and ECEC by standard analytical methods as described in IITA (1979). A second soil sampling was done for analysis prior to planting the third crop. Yield and yield components of crops were assessed at harvest.
Following observations made during the first growing season, a separate study was initiated to investigate the decomposition and nutrient release pattern of vetch using 2-mm mesh size nylon bags measuring 50 x 50 cm (Anderson and Ingram, 1989; Wilson and Hargrove, 1986). There were 21 samples in all. Comparisons among treatments were made using analysis of variance (ANOVA) with LSD = 0.05 on MSTAT software.

RESULTS

Soil Fertility Status

Overall, soil fertility was poorer at the vetch site than at the control site. Table 1 shows the fertility status of soils at the two sites after incorporation of vetch and liming. Relative to the control, pH was low, exchangeable Al was high, and basic cations (Ca, Mg, K) and ECEC were significantly less at the site where vetch was turned into the soil as green manure. The 1% increase in organic carbon content before liming at the vetch site compared to the control was not significant. This is probably due to the initial high soil organic matter content (Table 1). Environmental temperatures in this region are low; therefore, rate of disappearance of organic matter is less compared to other parts of the country. Even though the above trend persisted, application of lime raised exchangeable Ca, K and ECEC but not pH and reduced exchangeable Al (Table 1). The 2-ton application of lime was based on a prediction equation developed by Yamoah et al. (1990) with the aim of neutralizing exchangeable Al. To raise the soil pH to an appreciable level would require a high dose of lime since the soil was clayey (40% clay) and high in organic matter. The local lime material used for this experiment contained more Ca (38%) compared to Mg (1.15%) and K (521 ppm). Apart from the small contribution of K from the liming material, improved faunal activity resulting from liming might have further enhanced the release of K and other nutrients from both incorporated and native organic matter.

Nitrogen fertilizer tended to decrease soil pH (data not shown). Although the relationship was weak, it pinpointed the fact that there is a tendency to increase acidity of these soils with frequent application of acid-forming fertilizers such as urea. Olu Obi (1989) reached a similar conclusion with regard to continuous application of ammonium sulphate as N source to soils of southwestern Nigeria. It may be desirable in the future to explore other sources of N in addition to lime to amend soil fertility in this region.

Crop Growth and Yield

Total wheat and bean yields during the first season were significantly smaller in the vetch-treated plots than in the control (Fig. 1). Nitrogen fertilizer did not significantly affect wheat and bean yields. Rainfall during the first two months after incorporation of vetch was below average, and this, among other factors, resulted in wilting and subsequent poor performance of the first season wheat and bean crops at the vetch site. Under drought conditions N fixation, organic matter decomposition and subsequent mineralization of nutrient elements are suppressed (Vallis, 1972).

Bean yield more than wheat yield was adversely affected by exchangeable Al. The respective correlation coefficients were r = 0.93 ** and r = 0.79 ** (Fig. 4). Usually, soil organic matter chelates Al and reduces its toxicity to crops (Sanchez and Miller, 1986; Adams and Moore, 1983). However, decomposing organic materials produce H ions that react with silicate clays to release exchangeable Al (Coleman and Thomas, 1967). Due to soil acidifying effects of both the incorporated vetch and the urea fertilizer, a range of exchangeable Al was created across the 12 treatment combinations. With a soil exchangeable Al value of 2 meq/100 g, bean yielded only 250 kg/ha as compared to about 1700 kg/ha when no exchangeable Al was present. Wheat, however, at exchangeable Al of 2 meq/100 g, yielded over 1000 kg/ha (Fig. 4).

Although the relationship between P and yields is generally curvilinear, we noticed a positive and a linear relationship between the soil P and crop yields (Fig. 5). The correlation coefficients were r = 0.88** and r = 0.64* for bean and wheat, respectively. This implies that low soil P affected bean more than wheat. For instance, at soil P of 3.0 ppm, bean yield was about 250 kg/ha as opposed to a wheat yield of about 1250 kg/ha (Fig. 5). The picture was somewhat different

during the second season. No wilting of food crops was observed during this period. There was no significant difference in yield between the food crops at the vetch and control sites (Fig. 2). Wheat but not bean responded to N fertilizer during the second season. Wheat yield for the third season was higher in the control plot but not significantly different from that in the vetch plot. Bean yield, however, was significantly lower in the vetch than in the control site (Fig. 3).

Growth and yield components of bean and wheat are shown in Table 2. First season's bean and wheat populations were unaffected by vetch treatment, but number of bean pods/plant was significantly reduced at the vetch site. Weight per 100 pods and number of pods/plant for bean as well as number of grains/20 heads for wheat did not differ significantly between the two sites for the second crop. Growth of the third bean crop (Bataaf) was better in the control plot than in the vetch-incorporated site. Bean in the latter plot was observed to be less vigorous and more diseased than that of the former.

Vetch treatment did not influence growth of wheat in the third season, but wheat growth responded significantly to N application, unlike the bean. Dry matter yield of wheat at harvest differed significantly between the two sites whereas root weight, weight of 20 heads and number of plants/m^2 did not (Table 2). Bean population but not weight of 10 pods was significantly less in the vetch site than in the control. We have observed that severity of bean fly infestation, which results in poor crop stand and yield, is more pronounced on impoverished and acid soils.

Decomposition and Nutrient Release

During the five-month growing period, Vetch produced approximately 8 tons dry matter per hectare containing an average of 4.0% N, 0.34% P, 2.9% K and 0.6% Ca. Decomposition and nutrient release patterns of vetch are shown in Fig. 6. About 50% of the incorporated vetch material had decayed by the third week. Nutrient release pattern during early stages of decomposition followed the order: K > N > P > Ca. More than 75% of fixed N and about 90% of accumulated K in the vetch biomass during fallow was liberated by the end of the second week whereas less than 20% of immobilized Ca and P were released at this time. Potassium is reported to leach out faster than other elements in decomposing materials (Palm, 1988) as it is abundant in the cytoplasm. The release of K, P and Ca plateaued at 6, 8 and 12 weeks after incorporation, respectively. The above pattern conforms to results obtained by Palm (1988) for decomposition and nutrient release of prunings of some woody species in the Amazon region.

DISCUSSION

Crop yield response to organic matter is highly variable and is a function of climate, soil type, litter quality, crops and management system (Parr et al., 1984). Yield reduction following incorporation of green manure crop is rare but not impossible (Mundy, 1928; USDA, 1980; Sanchez and Miller, 1986). The poor performance of the first food crops after the green manuring is not unusual (Russel, 1950; USDA, 1980). Probable causes for the mediocre growth and yields of the crops include 1) acidification of the soil medium during decomposition of the vetch fresh matter turned into the soil (Russel, 1950); 2) water stress induced by the decomposing material (USDA, 1980; Mundy, 1928); and 3) possible allelopathic effects. Erratic rainfall experienced during the first season aggravated the situation at the vetch site with respect to reduced uptake of applied and vetch-released nutrients.

Related to above factors, low environmental temperatures and poor site characteristics, particularly low pH, might have retarded biochemical processes leading to slow mineralization and release of nutrients from vetch. Thus, the crops' nutrient requirements were not properly synchronized with the nutrient release pattern of vetch. This in itself affected the nutrient-use efficiency of the green manure system (Swift, 1985; Wilson and Hargrove, 1986).

Hydrogen ions furnished by the decomposing vetch made the already acid soil more acid. In the acidic environment that was created, exchangeable Al became the dominant cation (Sanchez, 1976) that either inhibited uptake of other nutrients or proved toxic to the bean and wheat crops (Rengel and Robinson, 1989). Studies by Shuman et al. (1990) demonstrated that soil solution Al activity and concentration are more toxic and therefore are better predictors of crop response to Al toxicity than exchangeable Al. The experimental site had Al saturation of < 60%; hence soil solution Al is expected to be low (< 1 ppm) (Evans and Krampath, 1970). In this case, exchangeable Al becomes an appropriate index for measuring Al toxicity to crops. In addition, exchangeable Al is relatively inexpensive to determine and is strongly associated with percent Al saturation ($r = 0.93^{**}$) for soils in this agroecological zone. Exchangeable Al was inversely related to crop yields (Fig. 4) while soil P was positively related to the same (Fig. 5). Exchangeable Al was high and available P low in the vetch plots, partly accounting for the observed low yields at this site compared to those for the control. In acid soils, the role of soil organic matter may be less important or even exert a negative influence by reducing ECEC (Lopes and Cox, 1977; Sanchez and Miller, 1986). In practice, it may be necessary to incorporate lime with the green manure material in acid soil as recommended by Mundy (1928) and Sanchez and Miller (1986) in order to realize the beneficial effects of the manure. The fact that Ca is released much more slowly from the prunings than the other nutrients (Fig. 6) further underscores the need for initial lime application to neutralize soil acidity prior to planting of food crops.

Lime is available in parts of the Rwandan highlands and is presently used primarily for construction and painting. Preliminary evaluation of its agronomic value demonstrates high potential in correcting soil acidity and improving crop yields Yamoah et al. (unpublished, 1989). As suggested by Sanchez and Benites (1987) and Juo and Ballaux (1977), wood ash could replace lime in situations in which finances and transportation are problematic. It is also important that about three weeks be allowed between incorporation of green matter and planting of crops so as to minimize deleterious side effects of the decomposition material.

The lack of growth and yield differences between the vetch and control sites during the second season (Fig. 2) indicated that soil conditions were returning to normal. Given that decomposition of vetch was virtually completed by this period (Fig. 6), it is expected that nutrient elements accumulated in the vetch biomass during fallow were freed for crop uptake. Besides, it is likely that the decomposed vetch matter temporarily complexed free Al ions, thereby alleviating Al toxicity. But, as noted elsewhere, it must be reiterated that the organo-Al complex is short-lived (Sanchez et al., 1983) and cannot be relied upon as an effective means of correcting soil acidity. This may be partially supported by the increased yield gap between vetch and control sites in the third season compared to those in the second. Perhaps frequent additions of organic materials as practiced in alley cropping systems would have kept Al toxicity at relatively low levels as opposed to the single application of vetch used in this study. The apparent crop yield enhancement for the third season relative to the first is due to the application of lime, which lowered exchangeable Al, increased Ca and raised nutrient retention capacity of the soil (Table 1).

Nitrogen in the system was assumed to be depleted by the third crop, thus explaining why wheat growth but not bean growth responded to applied N. The bean, a legume, probably met some of its N requirement through symbiotic fixation. A recent study by Burleigh et al. (unpublished, 1989) revealed N response and Al toxicity as the most important soil variables determining wheat yield on farmers' fields in the Buberuka Highland region of Rwanda.

CONCLUSION

Vetch has been used as green manure and as a cover crop to improve soil productivity in developed and developing countries alike. In the Rwandan highlands, vetch grows rapidly and provides a quick cover to control erosion. However, its use for green manuring on the acid soils in this region must be treated with caution. Decomposing vetch material initially made the soil acidic, and crops that immediately followed vetch incorporation suffered severe yield losses. For better results, it may be advisable to allow three to four weeks after incorporation before seeding food crops. In addition, lime application may be necessary to counteract adverse effects of soil acidity during early stages of decomposition and also to supply Ca. Field trials currently underway show positive response from vetch and other green manure materials when lime was added.

ACKNOWLEDGMENT

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Table 1. Soil chemical properties as affected by incorporation of vetch and lime on an acid soil from northern Rwanda.[1]

	Before Liming		After Liming	
Property	vetch	non-vetch	vetch	non-vetch
pH	4.70a[2]	5.00b	4.70a	5.03b
Al(meq/100g)	1.71a	0.69b	0.79a	0.07b
Acidity(meq/100g)	2.13a	0.94b	nd[3]	nd
Total N (%)	0.26	0.28	nd	nd
Org. C (%)	2.91	2.88	2.77	2.91
Bray 1 P(ppm)	3.64	4.98	nd	nd
Ca (meq/100g)	3.66a	5.49b	6.27a	7.87b
Mg (meq/100g)	1.42a	1.97b	1.38a	1.81b
K (meq/100g)	0.30a	0.46b	0.38a	0.55b
ECEC (meq/100g)	7.55a	8.26b	9.45a	10.52b

[1]Mean of 36 samples
[2]Properties with different superscripts differ significantly at $P = 0.05$
[3]nd = not determined

Table 2. Growth and yield components of bean and wheat as affected by green manuring with vetch in the Rwandan Highlands.

Component	Vetch	Non-Vetch
Bean (1)[1]:		
Plants/m2	31a[2]	25a
Pods/10 plants	39a	70b
Bean (2):		
Pods/10 plants	57a	61a
Weight/100 pods (g)	165a	165a
Bean (3):		
Plants/plot	112a	143b
Weight/10 pods (g)	14.5a	14.8a
Dry matter yield/2 plants	33a	51b
Wheat (1):		
Plants/m2	273a	311a
Wheat (2):		
No. of grains/20 heads	360a	381a
Wheat (3):		
Plants/m2	334a	335a
Dry weight/20 plants at harvest (g)	90a	111b
Height at harvest (cm)	111a	117a
Dry matter yield/10 plants aat heading (g)	14a	14
Root weight/20 plants at harvest	8.6a	8.6a
Shoot weight/20 plants harvest (g)	31a	43b
Weight/20 heads	32a	37a

[1](1) = Season 1; (2) = Season 2; (3) = Season 3
[2]Components with different superscripts differ significantly at $P = 0.05$

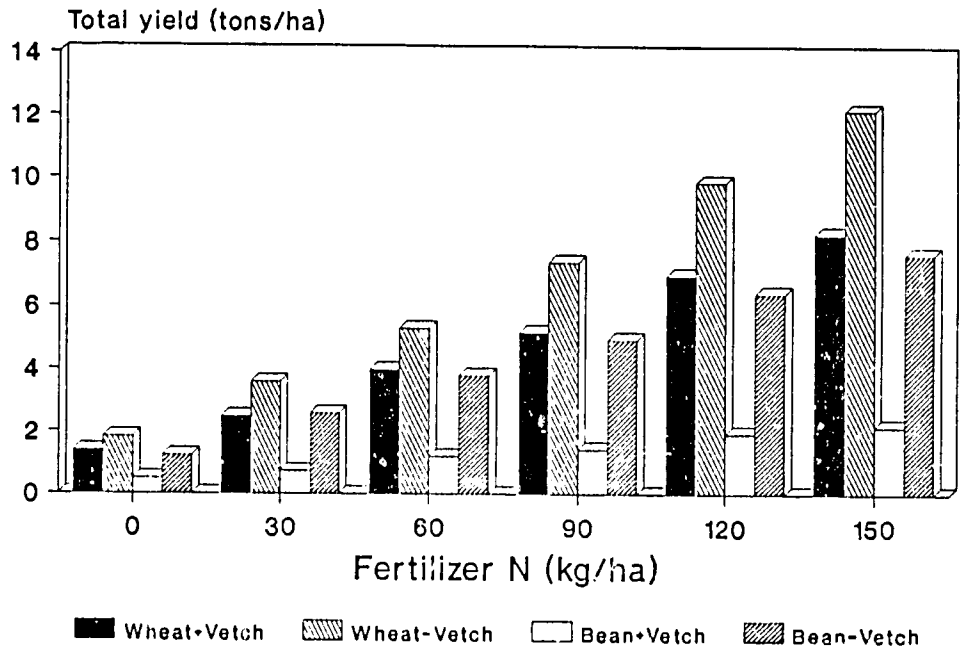

Fig. 1: Effect of green manuring with vetch and N on wheat and bean yields on an acid soil in Rwanda, first season

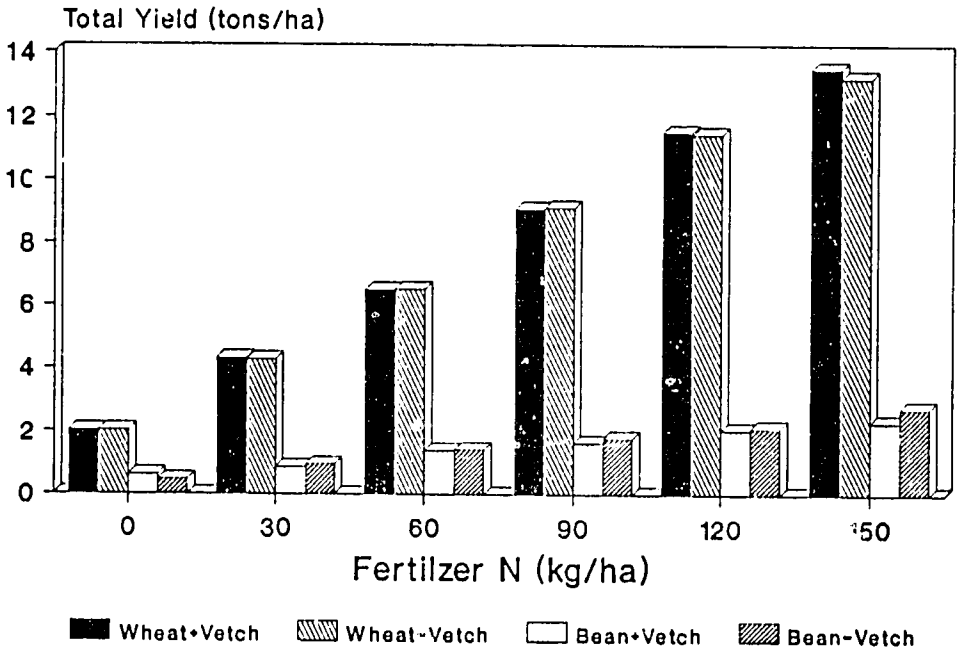

Fig. 2: Effect of green manuring with vetch and N on wheat and bean yields on an acid soil in Rwanda, second season

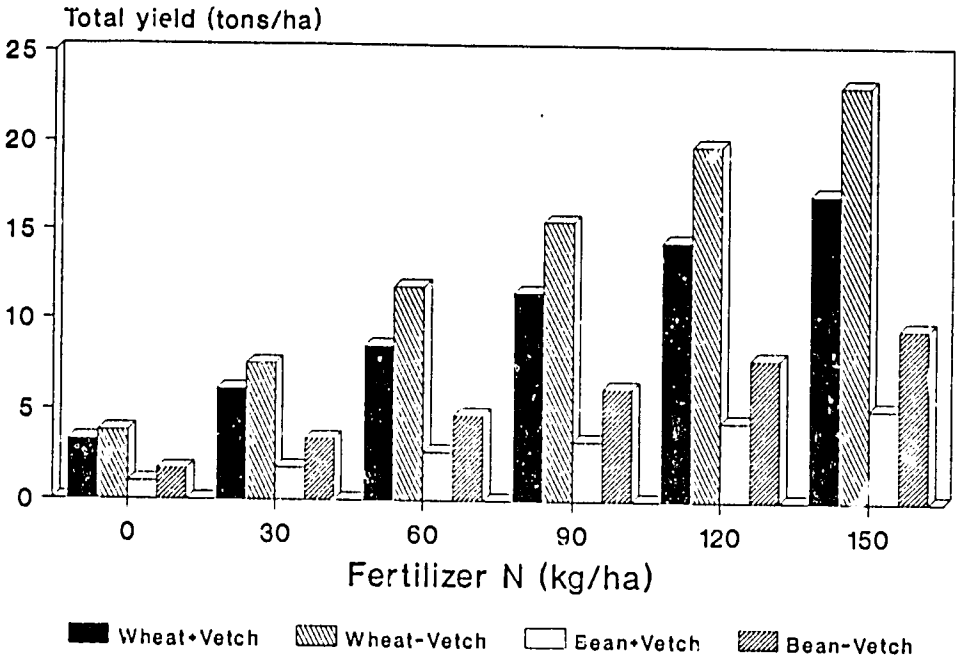

Fig. 3: Effect of green manuring with vetch and N on wheat and bean yields on an acid soil in Rwanda, third season

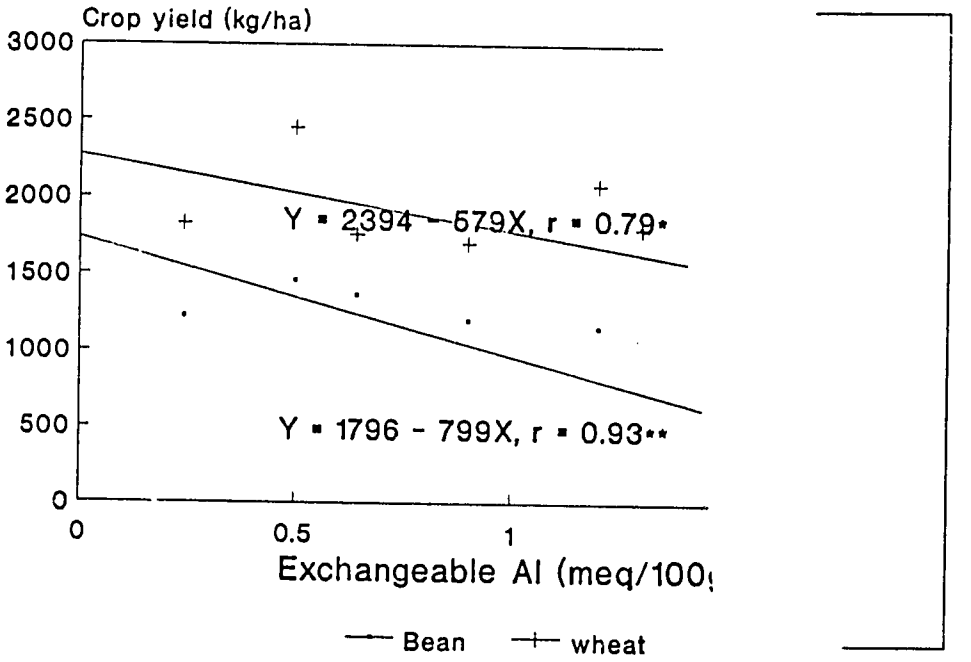

Fig. 4: Bean and wheat yields as affected by exchangeable aluminum on an acid soil in Rwanda

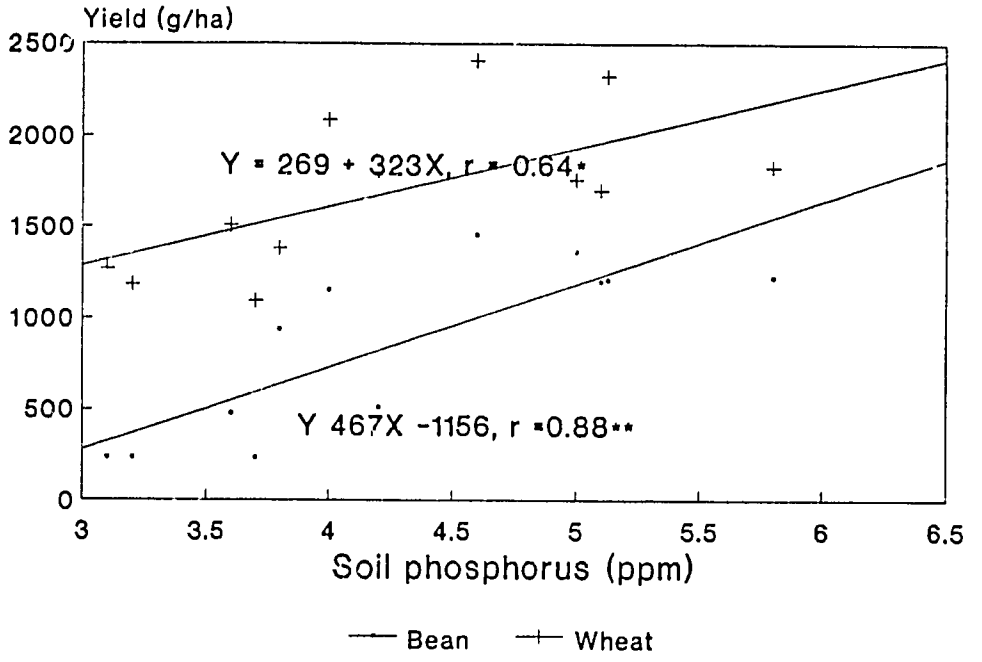

Fig. 5: Bean and wheat yields as affected by soil phosphorous on an acid soil in Rwanda

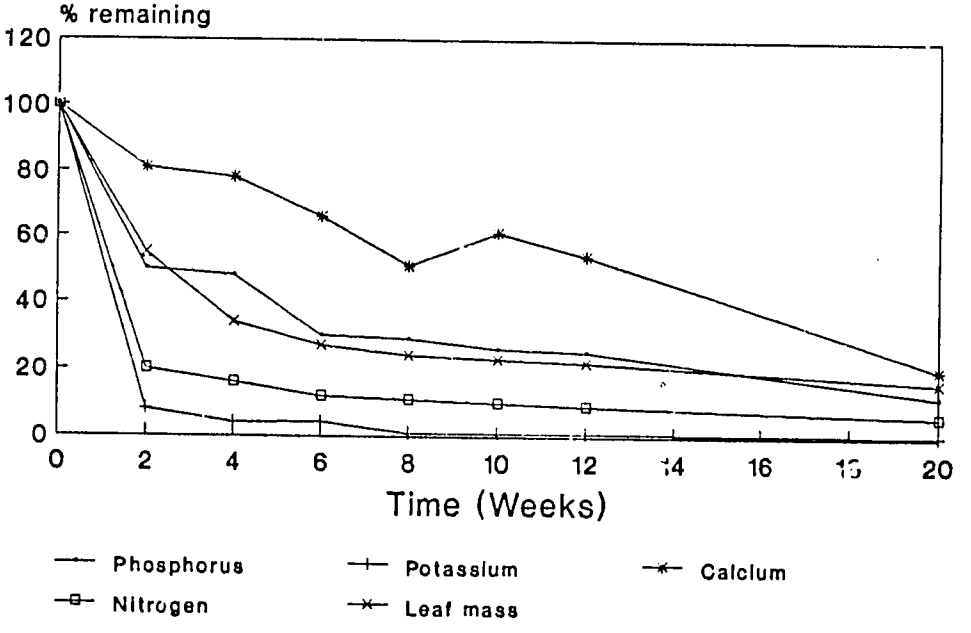

Fig. 6: Decomposition of leaf mass and nutrient release from vetch