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# Devising fertiliser recommendations for diverse cropping systems in a region: the case of low-input bean/maize intercropping in a tropical highland of Haïti

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**Abstract** – Variability of the efficiency of N, P, K and Mg fertilisation on a low-input bean/maize intercrop (BMI) was analysed in an upland of Haïti using the combination of a simple equation predicting the fertiliser requirements and an agronomic diagnosis in farmers' fields. The study results in a classification of cropping systems according to factors limiting the fertiliser response of the intercrop species (mainly bean root necrosis and high soil K supply) and in fertilisation rules specifically adapted to the diversity of agronomic conditions. Bean root necrosis due to a parasitic complex with *Fusarium solani* f. sp. *phaseoli* decreased the fertiliser efficiency and was higher wherever the topography of a field was concave and where beans were frequent in the rotation. High soil exchangeable K content was generally found where the preceding crop was cabbage, a cash crop that is given large amounts of N-P-K fertiliser. Additional fertiliser applied to the BMI decreased nodulation of the bean, N and Mg uptake and bean yield. Because of the competition from the associated bean crop, the maize did not respond to fertiliser.

low-input system / bean-maize intercropping / fertiliser rules / ferralsols / tropical highland

**Résumé** – Élaboration de règles de fertilisation pour la diversité des systèmes de culture d'une région : le cas d'une association haricot/maïs à bas intrants dans une région d'altitude d'Haïti. La variabilité de l'efficacité d'un engrais complet (N, P, K, Mg) sur une association culturale haricot/maïs à bas niveau d'intrants cultivée dans une petite région d'altitude en Haïti, est analysée en combinant l'utilisation d'une équation simple de calcul de dose d'engrais et un diagnostic en parcelles d'agriculteurs. Une classification des systèmes de culture en fonction des facteurs limitants de la réponse à l'engrais de l'association (principalement les nécroses racinaires du haricot et la richesse du sol en K) permet d'adapter la fertilisation à la diversité des conditions agronomiques de la région. Les nécroses des racines du haricot, dues à un complexe parasitaire dominé par *Fusarium solani* f. sp. *phaseoli*, sont à l'origine d'une faible efficacité de l'engrais sur cette espèce ; elles sont importantes sur les sols à topographie concave, et dans les rotations où le haricot revient fréquemment. Une teneur élevée du sol en K échangeable est observée sur les parcelles antérieurement cultivées en chou, culture de vente fortement fertilisée. Sur ces parcelles, l'apport d'engrais à l'association haricot/maïs entraîne une diminution de la nodulation et du rendement du haricot, ainsi que du prélèvement de N et de K par cette culture. À cause de la structure de l'association, la concurrence du haricot empêche toute réponse du maïs aux apports d'engrais.

système à bas intrants / association haricot-maïs / fertilisation / sols ferrallitiques / zone tropicale d'altitude

## 1. INTRODUCTION

Formulating rules for fertiliser application is a frequent theme in developing countries [13, 24, 26, 30]. In the low-input cropping systems of the inter-tropical area, one of the main difficulties is the need to cope with a great diversity of farming practices and soils [15, 34] whose characteristics and behaviour are sometimes little known. Another is dealing with the

interactions between several mineral nutrients, often thought to be major yield constraints [14]; and a third is dealing with intercropping, about which few local references are available, as regards either the relationships between the component species or the consequences of such relationships on fertiliser efficiency [11, 23, 31, 36]. Because of either the limited data available about soils and cropping systems, or the shortage of funds available for research, use of a detailed growth crop

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model such as those of McKinion et al. [16], Meynard et al. [21], Rötter and Van Keulen [27], Ten Berge et al. [35] and Sinclair et al. [32] is rarely practicable for predicting the required fertilisation. It seems easier to use simple equations predicting fertiliser requirements in which a limited number of parameters can be estimated from preliminary experiments on a regional scale [14, 20]. Stanford [33] proposed a good example of such an equation:

$$\text{Fertiliser dose (kg}\cdot\text{ha}^{-1}) = [(Y_t/E) - P_0] / Ra \quad (1)$$

where:

$Y_t$  = target yield (kg grain yield $\cdot$ ha $^{-1}$ );

$E$  = nutrient conversion efficiency into yield (kg grain yield $\cdot$ kg $^{-1}$  nutrient uptake);

$Ra$  = apparent fertiliser recovery (kg $\cdot$ kg $^{-1}$ );

$P_0$  = level of nutrient uptake by the crop without fertilisation (kg $\cdot$ ha $^{-1}$ ) (indicating the current soil mineral supply).

If the values for nutrient conversion efficiencies remain high and constant between the fertilised and unfertilised plots – which is only valid when the target yields for the fertilised plots are far from the potential – equation (1) can be further simplified:

$$\text{Fertiliser dose} = (Y_t - Y_0) / (E * Ra) \quad (2)$$

where  $Y_0$  (kg grain yield $\cdot$ ha $^{-1}$ ) is the yield without fertiliser application.

Compared with equation (1), the advantage of equation (2) is that it does not require weighty investigations to predict the soil supply, which is generally low in low-input tropical systems. The test of equation (2) could be based on simple trials comparing “fertilised” and “non-fertilised” plots on a sample of fields representing the diversity of soil types and cropping practices. To identify the origin of field-to-field variability in yield response to fertiliser, an agronomic diagnosis could be performed, as it was by Meynard et al. [20] to improve N fertilisation of wheat, or Dejoux et al. [5] to improve the sowing date of oil seed rape. If required, additional trials could be set up, with the aim of elucidating a specific point or testing a hypothesis suggested by the data collected in the on-farm experiments [7].

In the small area of upland Haïti where this study was carried out, the first fertiliser trials with the bean/maize intercrop (BMI) (*Phaseolus vulgaris* L./*Zea mays* L.) on farmers’ fields showed that although considerable yield increase could be achieved (at least for the bean), these gains were by no means certain, as the effects of fertiliser were small, nil, or even negative in some fields [4]. The purpose of the present study was to conceive, test and improve fertiliser recommendations for this BMI practised under various soil types and cropping practices. As a first step, we calculated the requirement of each element using equation (2). The second step, which is the core of this paper, was to apply the calculated fertiliser rates to farmers’ fields in order to diagnosis why fertiliser use was not always profitable, and so identify the types of field that could benefit from fertiliser input. In the third step, additional trials were carried out in order to consolidate the hypotheses formulated from the results of the preceding step. The whole study is also seen as the test of a rather cheap method, that could be

used to introduce fertilisation in regions where the knowledge about soils and crops is very limited.

## 2. MATERIALS AND METHODS

### 2.1. Description of the study area

The research was conducted in the “Plateau des Rochelois” in Haiti (18.4° North, 73.2° East), at an altitude of 900 m. The weather during the period of study (July to November 1989 and July to November 1990) was typical for the region. The mean temperature increased steadily from 19 °C in February to 24 °C in August. The annual rainfall reached 2100 mm, with the most rainy period from April to October (about 210 mm per month). Cabidoche [2] classified the soils of the limestone “Plateau des Rochelois” into three groups according to FAO-UNESCO classification [8]: (i) deep orthic ferralsols (DOF) where the ferrallitic weathering has been extreme – the CEC of these soils mainly depends on organic matter content and does not exceed 12 cmol $_{(+)}$ ·kg $^{-1}$ , and pH $_{H_2O}$  is about 5; (ii) medium deep calcic ferralsols (MCF) with limestone surface stones, where the CEC varies between 12 and 25 cmol $_{(+)}$ ·kg $^{-1}$  and the pH $_{H_2O}$  between 6 and 7, and (iii) Rendzinas (RDZ), shallow and stony, with the highest CEC values (>25 cmol $_{(+)}$ ·kg $^{-1}$ ) and pH $_{H_2O}$  between 7 and 8. These three soil types represent a typical catena which occurs over a short distance, the DOF being located on plane and concave topographic positions, MCF on moderate and regular slopes, and RDZ on the convex slopes.

### 2.2. Description of the bean-maize intercrop (BMI)

Two seasons of BMI are generally practised by the farmers: sowing both crops in July and harvesting beans in September and maize in December; and sowing in February and harvesting beans in April and maize in June. This study only concerns the July sowing. The bean variety “Salagnac 86” is a pure line of determinate bush type, with a growth duration of about 70 days in this area. It was bred from local lines for its resistance to leaf diseases (rust and powdery mildew) that often occur in this climate [18]. The maximum yield recorded for this variety growing in optimal conditions is 1700 kg $\cdot$ ha $^{-1}$  [18]. The maize was from a local population, with a growth duration of about 130 days in the region and maximum yield of about 1000 kg $\cdot$ ha $^{-1}$  reported by the farmers when it is sown at a density of 40 000 p $\cdot$ ha $^{-1}$  and intercropped with beans (whereas 2500 kg $\cdot$ ha $^{-1}$  have been obtained in fertiliser experiments with this variety in pure stand) [4]. Both species were sown on the same day, by hand according to a grid pattern. Maize was sown at two seeds per hole, spaced about 75 cm apart (40 000 plants per ha), and bean at two seeds per hole, spaced 20 cm apart (500 000 plants per ha). Maize stem elongation in the intercrop began at the end of bean flowering, and maize anthesis occurred roughly 15 days after the beans had been harvested. Manual weeding, about 22 days after sowing, is usual. The crop rotation was to grow the BMI either every year or every two or three years, and sometimes to settle a two-month cabbage crop harvested just before the BMI sowing. As a rule, no fertiliser was applied to the BMI, but the cabbage was given about 130, 35 and 130 kg $\cdot$ ha $^{-1}$  of N, P and K, respectively.

**Table I.** Values of the parameters used to predict fertiliser requirements of a low-input bean-maize intercrop in an upland of Haiti (Plateau des Rochelais) (Eq. (2)).

	N	P	K	Mg
Apparent fertiliser recovery (Ra)	0.50	0.10	0.25	0.40
Conversion efficiency of nutrient into bean grain yield (kg of grain yield/kg of nutrients taken up by the bean crop) (E)	21.5	208	42.4	178
Nutrient requirements (kg·ha <sup>-1</sup> ) for a bean yield improvement of 500 kg·ha <sup>-1</sup> : (500/E*Ra)]	46.4	24.0	47.2	7.0
Fertiliser applied for beans (kg·ha <sup>-1</sup> )	10 (a)	26	50	5
Conversion efficiency of nutrient into maize grain yield (kg of grain yield/kg of nutrients taken up by the maize) (Em)	33	187	35.7	dm (b)
Nutrient requirements (kg·ha <sup>-1</sup> ) for a maize yield improvement of 300 kg·ha <sup>-1</sup> : (300/Em*Ra)	18	16	33.6	dm
Fertiliser applied for maize (kg·ha <sup>-1</sup> )	20	22	41	10
Total fertiliser rate for the intercrop (kg·ha <sup>-1</sup> )	30	48	91	15

(a) 80% of the N requirements are assumed to be satisfied by symbiotic fixation; (b) dm = data missing.

### 2.3. 1989 on-farm experiments

Trials were designed to measure fertiliser response on 28 farmers' fields with a BMI sown between July 4 and 7, 1989. Fields were distributed over the different soil types of the region (13 on DOF, 8 on MCF and 7 on RDZ) and the two most usual preceding crops for a BMI sown in July (18 fields with a BMI of the previous July as preceding crop, and 10 fields with cabbage sown the previous April as preceding crop). The previous six years' cropping history of each field was recorded from the farmer's account. In each field, two 25 m<sup>2</sup> plots were marked out, one with fertiliser applied and one without. To minimise sources of variation other than the fertiliser application, the two plots were selected side by side, and all observations of the environment and cropping practices were strictly confined to these plots. The fertilisers applied contained N, P, K and Mg at different rates for each of the two species, using equation (2) for each element. Table I shows the values selected at the beginning of the study for the different parameters of equation (2):

- The grain yield increase sought was 500 kg·ha<sup>-1</sup> for the beans and 300 kg·ha<sup>-1</sup> for the maize. Assuming a mean yield of 500 kg·ha<sup>-1</sup> and 300 kg·ha<sup>-1</sup> for unfertilised beans and maize, respectively [1], the planned yields with fertiliser were, respectively, 1000 and 600 kg·ha<sup>-1</sup>. Although they were substantially lower than the maximum level found under conditions of high nutrient supply, these yield targets were from a farmer's point of view commensurate with the intercropping system and climatic and plant disease risks.
- The values for nutrient conversion efficiencies were estimated on pure stand trials with no limiting factors other than the studied nutrients. They were not significantly different within the yield range predicted for unfertilised and fertilised crops [4], which allowed the use of equation (2).
- The values of fertiliser recoveries used in equation (2) corresponded to the highest values observed in 1987 for the bean crop in a set of 13 on-farm experiments [4] comparing treatments receiving and not receiving a complete NPK fertiliser. So, values of fertiliser recoveries integrated the possible increase in soil availability for each element resulting

from the supply of the others [14]. For lack of specific data, identical values of apparent fertiliser recovery were assumed for the mixed maize crop.

The N, P, K and Mg were provided in the form of urea, triple superphosphate, potassium sulphate and magnesium sulphate, respectively. The beans were given 10, 26, 50 and 5 kg·ha<sup>-1</sup> of N, P, K and Mg, respectively, applied by broadcasting, half at sowing and half 22 days after sowing. The second application was carried out in the afternoon, taking care to avoid burning the plant leaves by prolonged contact with the urea granules. The maize was given 20, 22, 41 and 10 kg·ha<sup>-1</sup> of N, P, K and Mg, placed beside the plants, with a quarter of the N and half of the other elements at sowing and the rest after the bean harvest. Apart from the fertiliser applications, which were carried out by the researchers, all other husbandry was left to the farmer. Soil samples were collected before sowing from the 0–15 cm layer of each plot. Each sample was a composite of five subsamples taken from around the edge of the pair of plots. The samples were analysed for pH (KCl and H<sub>2</sub>O, 1:2.5), exchangeable (exch) bases, cation exchange capacity (CEC) (1N NH<sub>4</sub>-acetate at pH 7), organic carbon (sulfochromic oxidation by the Afnor X31-109 method), total N (Kjeldahl method) and available P following the isotopic exchange kinetics method as described by Fardeau [9]. The main parameters assessed by this method were: (i) Cp, the P concentration in the soil solution (mg P·l<sup>-1</sup>); (ii) E<sub>pie1</sub>, the size of the pool of instantaneously available phosphorus (mg P kg·soil<sup>-1</sup>), and (iii) the ratio R/r1 which is the inverse of the fraction of the radioactivity remaining in solution one minute after injection of the <sup>32</sup>P; the higher this ratio, the greater the soil "fixing" capacity.

The data recorded on the stand on each pair of plots in a field were as follows: (i) the percentage of bean plants showing symptoms of diseases on either their shoots or roots (NEC) - these observations were made at flowering on all bean plants sampled on a 2 m<sup>2</sup> subplot, i.e. about 100 plants per field; (ii) the mean number of nodules per bean plant (NOD), by counting the nodules on the same sample of plants as above - only nodules retained by a 1mm-mesh sieve were counted; (iii) the percentage of maize plants showing symptoms of

**Table II.** Chemical characteristics of the medium deep calcic ferral-sols (MCF) and of the deep orthic ferralsol (DOF) of the 1990 inter-cropping trials.

Determination	MCF soil trial	DOF soil trial
pH H <sub>2</sub> O	5.59	6.06
pH KCl	4.93	5.40
Total N (%)	0.24	0.26
Organic carbon (%)	2.73	2.73
exch K (cmol·kg <sup>-1</sup> )	0.09	0.16
exch Na (cmol·kg <sup>-1</sup> )	0.07	0.07
exch Ca (cmol·kg <sup>-1</sup> )	1.93	4.46
exch Mg (cmol·kg <sup>-1</sup> )	0.45	0.67
CEC (cmol·kg <sup>-1</sup> )	8.92	10
E <sub>pie1</sub> (mg P kg·sol <sup>-1</sup> )	dm(a)	dm

(a) dm = data missing.

diseases or insect damage on their shoots - these observations were carried out at the mid-stem elongation stage in the maize, on the entire area of each plot, and (iv) the amount of nutrient uptake by the bean crop and the yield and its components for both bean and maize, obtained for each plot at harvest, from a subplot of 4 m<sup>2</sup> for bean and 8 m<sup>2</sup> for maize. The dry weight of straw/stem and grains was measured after oven-drying at 80 °C to constant weight. Plant samples were analysed using the Kjeldahl method for N and acid digestion (with HCl, d = 1.19, after calcination at 480 °C), and measurement by atomic absorption spectrophotometry for K, Mg and Ca and colorimetry for P.

## 2.4. Additional studies

### 2.4.1. 1990 field survey

In 1990, a survey suggested by the first results of the on-farm experiments presented above was carried out to analyse the impact of the bean cultivation frequency during the recent cropping history of fields on bean soil-borne diseases. 25 farmers' fields were chosen according to the frequency of bean crops for the past six years: 9 fields with beans cropped every year, 9 with beans cropped every two years and 7 with beans cropped every three years. Based on the results of the 1989 on-farm experiments also showing impact of the field topography on the incidence of the bean root rot disease, these fields were also characterised by this criterion: 8 fields were in concave topography and DOF soil type and 17 fields were in either flat land, moderate regular or convex slopes associated with DOF, MCF and RDZ soil types, respectively. In each field sown with the genotype "Salagnac 86", a sample of 200 plants harvested on a subplot of 4 m<sup>2</sup> was observed at the flowering period in order to count the number of bean plants with root necrosis.

### 2.4.2. 1990 intercropping trials

The aim of this study was to analyse competition for nutrients between the two intercropped species. Two identical trials were sown on the MCF soil type (MCF trial) and DOF soil

type (DOF trial) on 19 and 26 July 1990, respectively. The chemical properties of the soils are presented in Table II. In both fields a 3 × 2 factorial experiment was carried out, with crops as the first factor (BMI, bean sole crop and maize sole crop) and NPK fertilisation as the second (0 fertilisation versus NPK fertilisation). A randomised block design with three replicates was used. Single crops were maintained at the same densities and the same planting pattern as in the intercrop. The fertilisation and planting patterns were identical to those used in the experiments on farmers' fields described above. The aerial biomass of each species after drying at 80 °C and its content of N, P, K and Mg were measured: in the MCF trial, at 27, 35, 41, 55 and 70 days after sowing (DAS); and in the DOF trial at 23, 35, 47, 56 and 70 DAS. The method of analysis was the same as in the 1989 on-farm experiments. On each date, plant samples were taken on a 2 m<sup>2</sup> area of each plot. The leaf areas of these samples were measured by planimetry before drying. At bean flowering (35 DAS in both trials), the nodules were counted and root diseases recorded for 100 plants per plot. Due to a severe storm which occurred before harvest, the measured grain yields were not reliable. Therefore, analysis of the competition within the intercrop was based on monitored biomass only.

## 2.5. Statistical processing

Statistical analysis was performed using SAS software [29]. Principal Component Analysis (PCA) was used as a first step to see how the different variables collected in the 1989 on-farm experiments were related to one another: soil pH<sub>H2O</sub>, E<sub>pie1</sub>, R/r1, CEC, exch K, Mg, and the exch K/exch Mg ratio, the percentage of bean plants with root necrosis (NEC) and the number of nodules per bean plant (NOD). Because the N and C contents of the soils were strongly correlated with CEC, and exch Ca highly correlated with soil pH<sub>H2O</sub>, these variables were excluded from the PCA. The main variables responsible for variability in yield and yield response to fertiliser were found using stepwise multiple regression. In the intercropping trials, ANOVA was used to determine the main effects and interactions of fertilisation, intercropping system and date of measurement on plant biomass and nutrient concentration.

## 3. RESULTS

### 3.1. 1989 on-farm experiments

#### 3.1.1. Relationships between recorded variables

The output of the PCA revealed that axes 1 and 2 together explained 59% of the total variation. Axis 1 was mainly defined by CEC, E<sub>pie1</sub>, R/r1 and weakly by exch Mg. Axis 2 was defined by exch K, the exch K/exch Mg ratio and NEC. NOD was associated with both axis 1 and 2 (Fig. 1). Projecting individual cases on the plane of the first two axes showed that axis 1 contrasted the deep orthic ferralsols (DOF) (with low CEC and low pH<sub>H2O</sub> and strong P-fixing capacity) with the other two soil types; axis 2 contrasted fields where the preceding crop was cabbage (high soil exch K level, K/Mg ratio and NEC) with those where the preceding crop was the BMI.

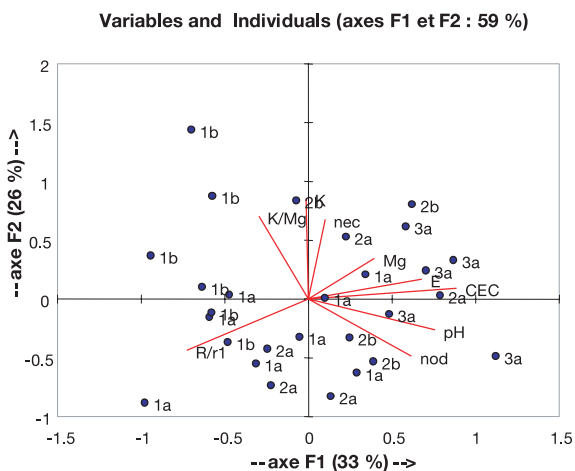
**Table III.** Effect of fertilisation on bean yields, nutrient uptake at maturity and number of nodules /bean plant at flowering in “low yielding” and “high yielding” groups of fields of the 1989 on-farm experiments carried out in an upland of Haiti (paired comparison T test).

(a) Low yielding group (10 plots)

	Yield (kg·ha <sup>-1</sup> )	N uptake (kg·ha <sup>-1</sup> )	P uptake (kg·ha <sup>-1</sup> )	K uptake (kg·ha <sup>-1</sup> )	Mg uptake (kg·ha <sup>-1</sup> )	Nodule number/p
With fertiliser	603	31.4	4.8	25.7	2.7	24.6
Without fertiliser	345	21.4	3.1	10.5	2.0	22.1
Significance	<0.01	<0.05	<0.10	<0.01	<0.10	<0.10

(b) High yielding group (18 plots)

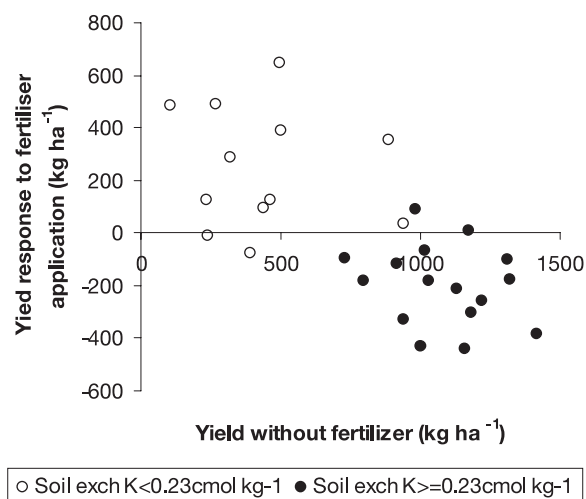
	Yield (kg·ha <sup>-1</sup> )	N uptake (kg·ha <sup>-1</sup> )	P uptake (kg·ha <sup>-1</sup> )	K uptake (kg·ha <sup>-1</sup> )	Mg uptake (kg·ha <sup>-1</sup> )	Nodule number/p
With fertiliser	909	53.2	7.7	47.4	4.2	14.2
Without fertiliser	1062	59.2	8.0	40.7	5.0	20.3
Significance	<0.01	<0.01	>0.10	<0.10	<0.01	<0.05



**Figure 1.** Projection of variables and individual fields of the 1989 on-farm experiments on the first plot of the PCA – Variables are percentage of bean plants with root necrosis (NEC), number of nodules per bean plant (NOD), soil isotopically exchangeable phosphorus (E), phosphorus fixing capacity (R/r1), water pH (pH), exch K (K), exch Mg (Mg), K/Mg ratio (K/Mg), CEC (CEC). Fields are classified based on soil type (1 = DOF; 2 = MCF; 3 = RDZ) and preceding crop of the growing BMI (a = BMI; b = cabbage).

### 3.1.2. Maize yield and fertiliser response

Maize yield data were missing from 16 sites where farmers let cattle graze shortly after the bean harvest because they expected a very low maize yield. For the 12 fields where the maize was harvested, maize yields varied between 200 and 1000 kg·ha<sup>-1</sup>. In several situations, particularly those which were not harvested, serious noctuid moth (*Spodoptera frugiperda*) damage was observed on the leaves and growing points of plants at the mid-stem elongation stage. Fertiliser

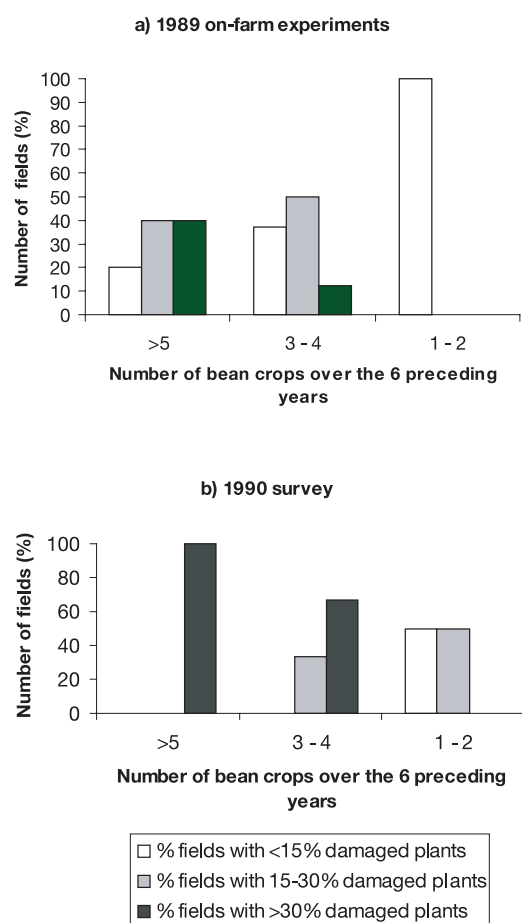


**Figure 2.** Relationship between the bean yield without fertiliser and its response to fertiliser application in the 1989 on farm-experiments.

input did not have a significant effect on maize yield (n = 12, t = 0.71, P > 0.10).

### 3.1.3. Bean yield and fertiliser response.

Without fertiliser, bean yields varied between 100 and 1400 kg·ha<sup>-1</sup>. Fertiliser response, i.e. the difference in yield between plots with and without fertiliser, varied between -400 and +600 kg·ha<sup>-1</sup>. Fields that yielded poorly without fertiliser, i.e. below 600 kg·ha<sup>-1</sup> (hereafter referred to as the “low yielding group”), showed a zero or positive response to fertiliser associated with a significant increase in the quantities of N, P, K and Mg absorbed, whereas those yielding more than 600 kg·ha<sup>-1</sup> without fertiliser (“high yielding group”) usually showed a negative fertiliser response (Fig. 2) associated with a significant drop in bean nodulation and uptake of two



**Figure 3.** Frequency of bean crop and root necrosis in the 1989 on-farm experiments and 1990 fields survey (fields of concave topography excluded).

elements: Mg ( $P < 0.02$ ) and N ( $P < 0.05$ ) (Tab. III). Neither of the two groups of fields was specific to a particular soil type. The “high yielding group”, however, included all the fields previously cropped with cabbage, and as a general rule, all fields where soil exch K was more than  $0.23 \text{ cmol}\cdot\text{kg}^{-1}$  (Fig. 2) due to having grown fertilised cabbage at least in the past two years. Stepwise multiple regression selected the number of bean nodules, the soil P-fixing capacity (R/r1) and CEC as the main explanatory variables for variation in bean yield over the unfertilised treatments of the “low yielding group” of fields. The same analysis performed on the fertiliser response of this group highlighted the percentage of bean plants with necrotic roots and the soil pH (Tab. IV). Root damage attributed to a *Fusarium* complex [4] was widespread on all fields with a concave topography. 6 fields on DOF were in this situation. Elsewhere, infestations were more or less significant according to the frequency of bean crops in the preceding years: the more frequently bean was grown, the more significant were risks of a high infestation level of the field (Fig. 3).

**Table IV.** Results of a stepwise regression analysis for bean yield and yield response to fertiliser in the “low yielding” group of fields of the 1989 on-farm experiments in an upland of Haiti.

	Yield of the unfertilised treatments ( $Y_0$ )	Yield response to fertiliser application ( $Y - Y_0$ )
R square ( $r^2$ ) (a)	0.98	0.75
Significance of effects		
% bean plants with root necrosis at flowering (NEC)	ns (b)	<0.01
nodule number/plant at flowering (NOD)	<0.01	ns
Soil pH at sowing	ns	0.04
Soil $E_{\text{pie1}}$ at sowing	ns	ns
R/r1 at sowing	<0.01	ns
CEC at sowing	<0.01	ns
Soil exch K at sowing	ns	ns
Soil exch Mg at sowing	ns	ns
Soil exch K/exch Mg at sowing	ns	ns
Model equation	$Y = 4.85\text{NOD} + 7.08\text{CEC} - 1.1(\text{R/r1}) + 240.75$	$Y = 104.27\text{pH} - 13.54\text{NEC} - 133.84$

(a) All variables left in the model are significant at the 0.05 level; (b) ns = the effect is not significant at  $\alpha = 5\%$ .

## 3.2. Additional studies

### 3.2.1. 1990 field survey: causes of field-to-field variability of bean root rot disease

The results of the 1990 survey confirmed those of the 1989 on-farm experiments, showing a positive relationship between the frequency of bean cultivation in the recent cropping history of the field and the incidence of bean root necrosis: except in 8 concave fields where infestations were very significant (more than 30% of damaged plants), the frequency of highly infested fields was the most significant where the bean was cropped at least every year. Where bean was cropped once every three years the risk of a high infestation level was nil (Fig. 3).

### 3.2.2. 1990 intercropping trials: nutrient relationships between the two species

In the MCF trial, both maize and bean were significantly affected by being intercropped, except in the non-fertilised treatments where no significant effect of the bean on the maize growth was found (Tab. V). Fertiliser application produced a significant increase of 65% in bean biomass, whereas maize biomass increased with fertiliser application only when grown alone (Tab. V). The maximum leaf area index of the mixture reached 1.75. At this time, which occurred towards the end of bean flowering, both species' canopies were virtually the same

**Table V.** Effects of the fertilisation and the intercropping system on the mean aerial biomass over the sampling dates of bean and maize of the 1990 intercropping trials.

(a) Results of the MCF soil trial		
	Bean	Maize
R square ( $r^2$ )	0.63	0.82
Significance of effects		
1- Date of sampling	<0.01	<0.01
2- Cropping system	<0.01	<0.01
3- Fertilisation	0.03	<0.01
4- Fertilisation $\times$ Cropping system	ns(a)	0.05(b)
Aerial biomass (% of the control treatment)		
Single crop	122%	212% (in fertilised plots only)
Fertilised crop	165%	170% (in pure stand plots only)
(b) Results of the DOF soil trial		
	Bean	Maize
R square ( $r^2$ )	0.73	0.86
Significance of effects		
1- Date of sampling	<0.01	<0.01
2- Cropping system	ns	0.05
3- Fertilisation	<0.01	ns
4- Fertilisation $\times$ Cropping system	ns	ns
Aerial biomass (% of the control treatment)		
Single crop	103%	133%
Fertilised crop	131%	120%

(a) ns = the effect is not significant at  $\alpha = 5\%$ ; (b) cropping system effect is significant only in fertilised plots and fertiliser effect is significant only in pure stand.

height above the ground. The mean number of nodules per bean plant over the studied treatments ranged from 35 to 39, with no significant differences between them. With total biomass not exceeding  $1000 \text{ kg}\cdot\text{ha}^{-1}$  up to the 35th day after sowing (bean flowering), the N content of the shoots of the bean plants were always below the value of 4.8%, which is the reference for shoots of C3 plants well supplied with N, as reported by Greenwood et al. [12]. The effect of intercropping on the N, P, K and Mg contents of the bean shoots was not significant, whereas fertiliser application had a significantly positive effect on the K and P content. Maize N content and biomass were, right from the second sampling, below the reference for non-limiting nutrition [12]. Intercropping had a significant negative effect on N and P content of maize, whereas fertilisation had significant positive effects on the P, K and Mg content (data not shown).

In the DOF trial, a non-significant decline in bean growth due to the presence of maize was recorded, whereas maize growth, whatever the fertilisation, significantly decreased due to the presence of bean (Tab. V). Fertiliser application had a significant positive effect on bean but not on maize biomass. The maximum leaf area index of the mixture reached 1 at the flowering period. The mean number of nodules per bean plant ranged from 4 to 11. No significant effect of intercropping on nodule number was recorded, whereas fertiliser application had a positive effect only in pure stand. With total biomass not exceeding  $1000 \text{ kg}\cdot\text{ha}^{-1}$  up to the flowering, the N content of

the shoots of the bean plants was generally below that of the MCF trial. The effect of intercropping on N, P, K and Mg contents of the bean shoots was not significant, whereas fertiliser application had a significant positive effect on K and Mg content of beans. Maize N content and biomass were below the reference for non-limiting nutrition [12]. Intercropping had a significant negative effect on P content of maize, whereas fertilisation had significant positive effects on the N and K content (data not shown).

## 4. DISCUSSION

### 4.1. Effects of cropping systems on the non-response to fertiliser of maize

The results of the 1989 on-farm experiments confirmed those of the preliminary experiments in this region [4], showing high variability of bean response to fertiliser across the fields. For maize, yields were low and fertiliser responses were non-significant. Analysis of the 1990 intercropping trials suggests that the lack of fertiliser response in the maize is due to competition from the associated bean crop: in the MCF trial where the competition from bean was the highest, maize responded to fertiliser only when grown in pure stand; whereas the fertiliser response of the bean, as well as its nodulation and uptake of nutrients, were not affected by the presence of maize. In



contrast to most reports on BMI [23], the dominant species here is the bean. This result is partly due to its high density (10 times that of the maize). It is also in accordance with the functions of the maize in intercropping: reducing the economic loss if the bean is accidentally lost, and supplying straw for livestock after the bean harvest [25]. The low values recorded for the LAI suggest that competition for light between the species was not very intense. On the contrary, the low N content of bean and maize shoots and the significant reduction in the mineral content of the maize when it is mixed with the bean, suggest an intense competition for mineral nutrients.

#### 4.2. Effects of cropping systems on the bean response to fertiliser

As the intercropping trials showed that the maize did not greatly affect the bean crop, the variability in bean fertiliser response over the 1989 on-farm experiments can be analysed as for a pure bean stand. The PCA revealed that this set of fields allowed good discrimination of soil type effects from cropping system effects (Fig. 1). Fields of the “high yielding group” were associated with a soil K level above  $0.23 \text{ cmol}\cdot\text{kg}^{-1}$ , which can be qualified as rich in K [10] and not in need of potassium fertilisation. All fields which had recently been cropped with cabbage, a crop generally receiving large amounts of potassium fertiliser, fell into this group. On the contrary, fields of the “low yielding group” had never received fertiliser or grown cabbage in the last six years. Negative effects of fertiliser on bean yield in the soils highly supplied with K of the “high yielding group” could be due to nutritional antagonism between K and Mg. This interpretation is consistent with the depletion of bean Mg uptake recorded in these fields (Tab. III). It is also in accordance with the literature [10, 17]. Induced Mg deficiency of bean could also explain the significant decrease in nodulation and N absorbed in these fields (Tab. III). In the unfertilised treatments of the “low yielding group”, higher bean yield is related to higher mineral nutrition allowed by higher bean nodulation, lower soil P-fixing capacity, and higher CEC of soils (Tab. IV); and root necrosis, doubtless disturbing mineral nutrition early in the crops’ life, prevented the bean from benefiting from the extra mineral provided by the fertiliser (Tab. IV). Increasing root necrosis when bean was grown frequently in a field is consistent with the ability of *Fusarium* inoculum to be well preserved in the soil [6, 28]. The spread of the disease on land with a concave topography is consistent with the fact that a moist soil favours the development of *Fusarium* [3, 22].

#### 4.3. Consequences for devising fertilisation rules

These results can be analysed in order to draw up some simple rules for managing the introduction of fertilisation on low-input BMI. Firstly, as the maize did not respond to mineral fertiliser, it would be reasonable to consider only the beans’ fertiliser response parameters when calculating fertiliser inputs. Secondly, on fields where the soil has already been enriched by earlier fertiliser applications for cabbage, fertiliser application on the following BMI should be avoided. A further study is necessary to specifically adapt the fertiliser rate and composition to these fields. Thirdly, on fields where beans have been

**Table VI.** Parameters of equation (2), for bean – Comparison between predicted values of Table I and mean results recorded for 7 fields where the fertiliser responses were the highest.

	Highest values recorded	Predicted values (Tab. I)
Apparent fertiliser recovery ( $\text{kg}\cdot\text{kg}^{-1}$ )		
N	1.14	0.50
P	0.07	0.10
K	0.29	0.25
Mg	0.17	dm (a)
Nutrient conversion efficiency without fertiliser ( $\text{kg grain yield}\cdot\text{kg}^{-1}$ nutrient uptake)		
N	16	21.5
P	110	208
K	29	42
Mg	158	178
Yield increase ( $\text{kg}\cdot\text{ha}^{-1}$ )	346	500

(a) dm = data missing.

grown every year, or where the topography is concave, fertilisation is likely to be ineffective due to root disease. Obviously, adoption of varieties resistant to *F. solani* [3], or crop diversification so that beans return less often to the same field, are alternative strategies. Fourthly, fields suitable for fertiliser application are those on regular slopes or with a convex topography, not recently cropped with cabbage, and with a bean cropping frequency of no more than once per two or three years. In the 1989 on-farm experiments, seven fields met these specifications. Table VI shows the mean values of the fertiliser rate calculation parameters on these seven fields: while some values adopted a priori from the data available (Tab. I) are validated, others (especially P recovery and efficiency) are doubtless worth correcting. The N fertiliser recovery for bean exceeds 1, probably due to an increase in the contribution of soil N mineralisation and/or N fixation with the fertiliser. Generally the nutrient conversion efficiencies are low, indicating that growth conditions were not as good as during the reference trial. For these seven fields, the mean yield gain was below target ( $345 \text{ kg}\cdot\text{ha}^{-1}$  as against  $500 \text{ kg}\cdot\text{ha}^{-1}$ ), but nonetheless ensured a profit of about 250% on the fertiliser input (at prices at the time of the study).

## 5. CONCLUSION

The operational results obtained in this study validate our approach for developing fertilisation rules suitable for small-holder cropping systems, in situations where previous knowledge of soils and crops are limited. Such an approach, combining a simple predictive equation of fertiliser requirements and an agronomic diagnosis in farmers’ fields, is readily reproducible and could provide a better alternative than standardised recommendations of technical packages that may be ill-suited to local conditions. The need of additional experiments to shed light on the mechanisms involved or consolidate the results of the diagnosis could be a costly part of this approach. However, as

stressed by Meynard and David [19] and Doré et al. [7], this can be simplified if the hypotheses concerning the major limiting factors can be made at the outset. In the part of Haiti concerned in our study, it is now necessary to apply this approach to improving the fertilisation of the cabbage crop, since the results obtained on bean suggest that cabbage crops probably receive too much potassium fertiliser.

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