# Evaluation of the Potential of Using Nitrogen Fixing Legumes in Smallholder Farms of Meru South District, Kenya

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## Abstract

Soil fertility depletion in sub-Saharan Africa is a big constraint to increased food production to feed the ever-growing human population. Use of legumes to improve soil fertility is an option in the central highlands of Kenya and this study evaluated soil characteristics on farms and screened effectiveness of five rhizobia strains on four legumes. Soils sampled from 31 farms showed that the soils were generally acidic with more than 50% of the farms having pH in the range of extremely acidic and strongly acidic (pH < 5.0). Organic carbon was low (<2%) on most farms and total nitrogen was deficient with more than 80% having <0.2% N while P ranged from 1.3 to 15.8 ppm with more than 70% of the farms being critically deficient in P. Nodulation on *Mucuna pruriens* and *Crotalaria ochroleuca* was observed to be variable within farms with individual farms having fewer nodules per plant than on-farm researcher managed trial. Consequently trials to evaluate effectiveness of rhizobia strains were conducted under glass house conditions. Results showed that KWN35 and TAL 1145 were highly effective on *C. calothyrsus* and *L. trichandra* and not on *C. ochroleuca*. *Crotalaria ochroleuca* nodulated effectively only with CP354 and NGR457. The NGR 457 was highly effective on all the legume plants while NGR185 was only effective on *L. trichandra*. These studies showed that performance of legumes among the smallholder farms was likely to vary due to varying soil characteristics and that there could be potential for improving legume performance within the smallholder farms through inoculation

*Key words:* Legumes, Rhizobia strains, Soil characteristics

## Introduction

Land, the natural resource base on which agriculture depends is becoming severely degraded through deforestation, soil fertility depletion, water scarcity, erosion of both soil and genetic resources (ICRAF, 2000). Soil fertility depletion is particularly becoming severe and nutrient budgets for sub-Saharan Africa show a net annual depletion of N, P and K as a result of long-term cropping with little or no external nutrients inputs (Stoorvogel and Smaling, 1990). This depletion of soil nutrients is particularly high in the densely populated humid and subhumid highlands of East Africa (Smaling et al., 1997). This has greatly affected per capita food production which has been reported to be low and declining in many parts of Africa.

In central highlands of Kenya, where there is high population pressure (> 500 persons km$^2$), nitrogen has been found to be one of the most limiting soil nutrient with an annual net depletion of 30 kg N ha$^{-1}$ (Ikombo, 1984) resulting in declining soil productivity. For instance, maize varieties with yield potentials of 7–12 Mg ha$^{-1}$have been developed in onstation sites but the yields rarely exceed 1.5 Mg ha$^{-1}$ at the farm level (Wokabi, 1994). Use of fertilizer N to replenish soil N is the obvious source to counterbalance the

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nutrient depletion in this region. However, this presents a challenge because of the high costs, poor efficiency of utilization of N from fertilizers (seldom exceeding 50%) and increasing awareness of the environmental costs of N lost from fertilizers (Bohlool et al., 1992). The use of N fixing legumes to address the current soil nutrient depletion and increase crop yields is a system that maximises use of natural methods of maintaining soil fertility and therefore has more capacity for stable and sustainable crop yields in the long term.

Several studies have shown legumes to be effective in improving soil fertility in many areas (Giller et al., 1997; Lathwell, 1990). However most of these studies have been conducted on-station under optimum conditions including rhizobium inoculation and P-fertilizer application. Adoption of legumes at the farm level is low as the legumes have not been adequately evaluated under conditions and in niches in which they are likely to be planted on-farm, where many soils could be severely depleted in nutrients that could affect performance of the legumes and consequently reduce the potential for nitrogen fixation. Nodulation of legumes is an indicator of the ability to fix N but nodulation is affected by site characteristics such as nutrient deficiencies and presence of native rhizobia capable of nodulating the legumes (Dommergues, 1995). There is a need to understand more the conditions under which these legumes are being introduced to on-farm conditions. This study therefore aimed at describing soil characteristics in on-farm trial sites, evaluate nodulation of the legumes, and screen response of the legumes to inoculation.

## Materials and methods

### *Study site*

The study was conducted in Chuka division, Meru South district, Kenya. According to Jaetzold and Schmidt (1983), the area is referred to as Upper Midlands 1 and 2 (UM1-UM3) or the main coffee/dairy land use system with an altitude of approximately 1500 m above sea level. Mean annual rainfall is about 1200 mm which falls in two seasons; the long rains lasting from March through June, forming the long rains season (LR) and short rains from October through December, forming the short rains season (SR). Annual mean temperature is about 20°C. The soils are mainly humic Nitisols (Jaetzold and Schmidt, 1983) that are deep, well weathered with moderate to high inherent fertility. Land sizes in Chuka location are small ranging from 0.1–3 ha with an average of 1.2 ha. The main cash crops are coffee and tea while the main staple food crop is maize, which is cultivated from season to season mostly intercropped with beans. Farming is the major occupation of the population and farmers are faced with a problem of decreasing crop yields over time due to declining soil fertility.

### *Soil characterization*

Soil samples were collected from 31 farms in Chuka experimental farms from 0–15 cm soil depth. The samples were analyzed for pH, exchangeable acidity, exchangeable magnesium, calcium, phosphorus and potassium, total organic carbon, available phosphorus and total nitrogen. All the analysis was carried out at ICRAF laboratories using ICRAF methods (ICRAF, 1995).

### *Nodulation assessment*

Nodulation and N fixation characteristics were assessed approximately three months after planting. The area for assessment was selected at random, and 6 and 3 plants of crotalaria and mucuna respectively were uprooted. After the plants were uprooted, the soil was carefully washed off the roots with water and then examined for nodules. The parameters recorded included the number of nodules per plant, shape and size of nodules, internal colour and position and distribution on the roots.

### *Effectiveness of rhizobia strain*

The legumes introduced on-farms (mucuna, crotalaria, calliandra and leucaena) were screened for ability to nodulate with different rhizobia strains. This work was carried out in a glasshouse at the Kenya Forestry Research Institute (KEFRI), Muguga, located 25 kilometers North West of Nairobi. The Rhizobia isolates used in this study were isolated from EU-calliandra project (KWN35), EU-IMPALA Project (CP 354), two strains from Canada (NGR 457 and NGR 185) and TAL 1145 from NIFTAL which was included as a positive control. The test plants were *Calliandra calothyrsus*, *Leucaena trichandra* and *Crotalaria ochroleuca*. The experimental design was a randomized block design with four replications.

Well germinated seedlings were planted in pairs in Leonard jars containing N-free nutrient solution. The Leonard jar tops were filled with washed vermiculite as a rooting media and the bottom half acted as the nutrient reservoir. The plants were harvested at 12 weeks after planting. At harvest a stream of water from hose pipe was used to wash off the vermiculite and expose the nodules. Where nodulation occurred nodules were carefully handled not to cause any damage or breakage. The plants were analyzed for height, nodule number, nodule fresh weight, shoot dry weight, and nodule dry weight. After determining height, plants were cut to separate the shoot and the root. Shoot height was recorded in cm using a meter rule. Nodules were detached from the root, counted and fresh weight also recorded at the same time. The different parts of the plant were then put in brown paper bags and oven dried at 60° C for 3 days. The dry weights of the plants were then taken separately using an electronic weighing balance. Data on shoot height, nodule number, and shoot, root and nodule dry weight were statistically analyzed using Genstat programme (Genstat, 1995).

## Results and discussions

### *Soil characterization*

The pH of all soils ranged from 4.1 to 6.0 (Table 1) indicating that soils in smallholder farms of Chuka are acidic. Majority of the farms (67%) had soils in the category of extremely acidic or very strongly acidic and only 7% had their soils in the moderately acidic range (Figure 1). Under very acid soils the soil solution is occupied mostly by aluminium and hydrogen ions thus limiting availability of base forming cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$). The acidic nature of the soil could thus affect availability of macro plant nutrients and especially phosphorus, which is readily available under medium pH range. Nitrogen fixation could also be affected as most rhizobia are not tolerant to acidity (Odee, 1996).

*Table 1.* pH rating of soils sampled from farms in Chuka, Kenya

| Category | Ratings of pH | No. of farms | % farms |
|---|---|---|---|
| Extremely acidic | 4.0–4.4 | 6 | 19 |
| Very strongly acidic | 4.5–5.0 | 15 | 48 |
| Strongly acidic | 5.1–5.5 | 8 | 25 |
| Moderately acidic | 5.6–6.0 | 2 | 7 |

Rating adapted from Landon (1984).

Total organic carbon and nitrogen were found to be low in most farms ranging from 1.45% to 2.26% and 0.05% to 0.25% respectively (Figure 2 & 3). Of the 31 farms sampled, 3 farms had very low soil N of less than 0.1% while more than 60% of the farms had low N of 0.11 to 0.2% (Table 2). Only 2 farms had organic carbon >2% (Figure 2) which according to rating by Landon (1984) is low. All the other farms had organic carbon in the very low range meaning that the soils lack the positive soil attributes provided by soil organic matter (SOM) such as, increased porosity and supply of N. This is critical because of all plant nutrients, N is required in the greatest quantity for plant growth and the capacity of the soil to supply N to plants is inextricably linked to the amount and nature of the soil organic matter which is the main source of available soil N in the soil (Giller et al., 1997).

The low SOM and N in these soils is mainly attributed to intensive cultivation as a result of population pressure leading to net losses of soil organic matter, reduced organic inputs, and faster rate of SOM turn over. There is usually net removal of soil nutrients through crop harvest as the crop residues are fed to livestock (Kihanda, 1996). The amounts of soil nutrients consequently applied via organic materials, mainly animal manure, are inadequate to counterbalance the nutrients removed in the previous cropping seasons. Soil organic matter high turnover is expected in these sites, which receive high rainfall and experience high temperatures. Faster SOM turnover rates have been reported in tropical soils caused by high temperature and available water that favour decomposition. Because of low SOM and N in Chuka soils supplementation with mineral fertilizers, manure or other organic residues is essential to ensure reasonable crop yields.

Phosphorus (P) was found to be low, ranging from 1.3 to 15.8 ppm with more than 70% of the farms being critically deficient in P (Table 3). Only 2 farms (6%) of the farms had P in the adequate range of 13–22 ppm. The low P could drastically affect crop production as P is a major plant nutrient needed for numerous metabolic processes. It is very important for photosynthetic processes, crop maturation and root development. Low P levels have earlier been reported in the region (Micheni et al., 2000) and seem to be widespread on the farms.

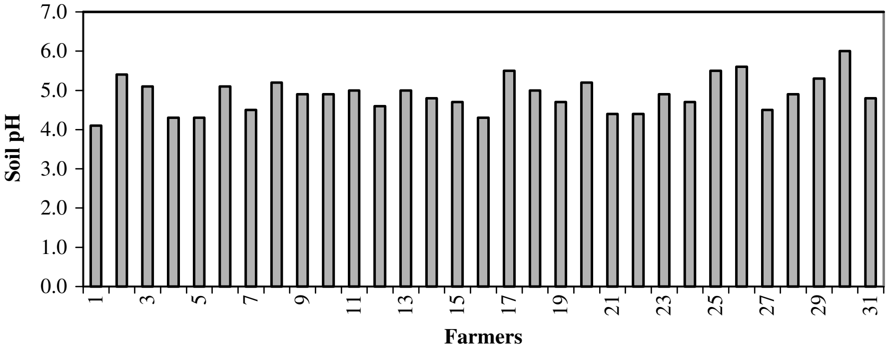

*Figure 1.* Soil pH of soils sampled from individual farms at Chuka.

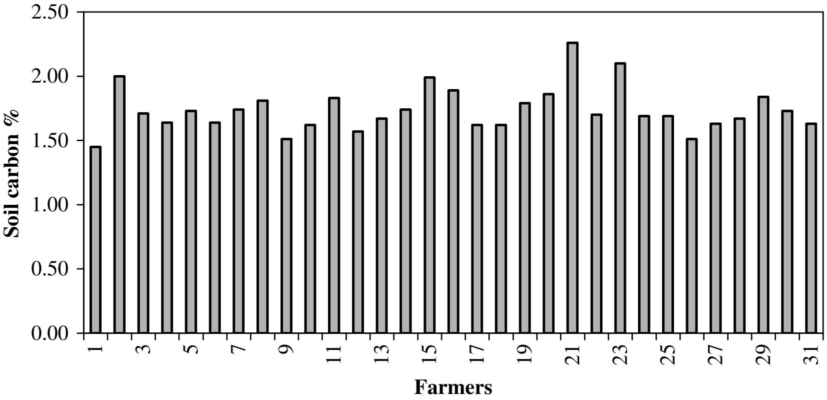

*Figure 2.* Organic carbon levels of soils sampled from farms in Chuka.

*Table 2.* Total nitrogen ratings of soils sampled from farms in Chuka, Kenya

| Category | Nitrogen (%) | No. of farms | % farms |
|---|---|---|---|
| Very high | >1.0 | n.a. | |
| High | 0.5–1.0 | n.a. | |
| Medium | 0.2–0.5 | 6 | 19 |
| Low | 0.1–0.2 | 22 | 71 |
| Very low | <0.1 | 3 | 10 |

Source: Rating adapted from Landon (1991).

Low soil P levels are mainly attributed to inherent low soil P levels, high fixing nature of the predominant soils (Nitisols) and depletion of soil P due to cropping without adequate P inputs. Unlike nitrogen, plant P requirements are not supplied through biochemical fixation and most of it comes from other sources. In these smallholder farms some important sources could be mineral fertilizers, animal manures and plant residues.

### *Nodulation in the field*

Nodulation in the researcher managed on-farm trial located in the school was better than in farmer-managed trials on individual farmers' fields. In the school trial, the number of nodules per plant in crotalaria ranged from 13 to 67 while the mean number in individual farms ranged from 12 to 35 (Tables 4 & 5). For mucuna,

*Table 3.* Extractable phosphorus of soils sampled from farms in Chuka

| Extractable P (ppm) | Rating | Number of farms | Percent farmers |
|---|---|---|---|
| <3 | Acutely deficient | 2 | 6 |
| 3.1–6.5 | Deficient | 16 | 52 |
| 6.6–13 | Marginal | 11 | 36 |
| 13–22 | Adequate | 2 | 6 |
| >22 | Rich | none | n.a. |

Rating adopted from Landon (1984).

*Table 4.* Number of nodules in herbaceous legumes during in June 2003 at on-farm researcher managed trial in a school, Chuka

| Treatment | Number of nodules | |
|---|---|---|
| Crotalaria alone | Mean | 28 (10) |
| (Mean of 3 plots) | Maximum | 38 |
| | Minimum | 13 |
| Crotalaria + 30 Kg N ha$^{-1}$ | Mean | 38 (17) |
| (Mean of 3 plots) | Maximum | 67 |
| | Minimum | 16 |
| Mucuna alone | Mean | 10 (7) |
| (Mean of 3 plots) | Maximum | 22 |
| | Minimum | 2 |
| Mucuna + 30 Kg N ha$^{-1}$ | Mean | 8 (7) |
| (Mean of 3 plots) | Maximum | 22 |
| | Minimum | 2 |

( ) Standard deviation.

*Table 5.* Nodulation of *Crotalaria ochroleuca* on individual farms during June 2003

| Farmers name | Number of nodules | | |
|---|---|---|---|
| | Mean | Minimum | Maximum |
| Ephantus Mwiti | 20 (7) | 10 | 30 |
| Jamleck Njogu | 31 (10) | 21 | 40 |
| Kaari Mbuba | 35 (11) | 18 | 48 |
| Kanga Muga | 22 (10) | 11 | 34 |
| Lilian Kagendo | 12 (8) | 4 | 24 |
| Mbae M'rachi | 13 (10) | 4 | 28 |
| Micheni Kaaria | 17 (11) | 8 | 36 |
| Njeri Gitare | 21 (6) | 15 | 30 |
| Washington Gitonga | 17 (3) | 13 | 21 |
| Zablon Kaaria | 29 (13) | 12 | 47 |
| **Mean** | **22** | **12** | **34** |

( ) Standard deviation.

the school trial had a mean of 10 nodules per plant (mucuna alone) while the mean number of nodules plant$^{-1}$ from farmers' fields was 6. These differences could be attributed to differences in soil nutrient availability. In the school trial, a blanket P fertilization had been done and this could have boosted development of nodules more than in the on-farm trials where farmers applied little or no P fertilizer.

The predominant size of mucuna nodules was close to a maize seed. It has an irregular shape. The nodules were black in colour, the periphery of the nodules was brownish while the middle was green and according to CIAT (1988) they were effective. In most plants, about 75% of the nodules were located on the tap root i.e. main root. This agrees with report by Gitare et al. (1997) who reported that the nodule density of mucuna in Gachoka and Karurina sites at Embu, Kenya range from 25–50 with majority being located along the main laterals.

Most of the nodules in crotalaria were located at the main lateral roots. The nodules were small (millet size) and white in color at the surface. When dissected, the colors observed were light green in the middle and brown/pink along the periphery with pink being predominant indicating that they were generally effective.

Generally when compared with studies carried out by the Legume Network Project in Kenya, nodulation in the Chuka site was low especially under individual farms though crotalaria was well established in some farms. Though this project recommended planting of these legumes without innoculation because they felt that the indigenous rhizobium was adequate, it is suspected that lack of innoculation might contribute to low nodulation.

### *Effectiveness of Rhizobia strains*

There was response to inoculation in calliandra. Plant height, shoot and root dry weight, and nodulation were significantly different ($p = 0.05$) among the rhizobia strains with KWN 35 recording the highest height growth and shoot dry weight (Table 7). However the number of nodules per plant was highest in TAL 1145, having 121 nodules, followed by KWN 35 with

*Table 6.* Nodulation of *Mucuna pruriens* on farms during June 2003

| Farmer's name | Number of nodules | | |
|---|---|---|---|
| | Mean | Minimum | Maximum |
| Ephantus Mwiti | 3 (0) | 3 | 3 |
| Jamleck Njogu | 8 (5) | 3 | 13 |
| Kaari Mbuba | 10 (5) | 4 | 14 |
| Kanga Muga | 10 (1) | 10 | 10 |
| Lilian Kagendo | 3 (1) | 2 | 3 |
| Mbae M'rachi | 2 (1) | 2 | 3 |
| Micheni Kaaria | 6 (1) | 5 | 7 |
| Njeri Gitare | 8 (6) | 2 | 15 |
| Washington Gitonga | 2 (1) | 1 | 3 |
| Zablon Kaaria | 2 (1) | 2 | 3 |
| Philis Kirimo | 8 (11) | 1 | 22 |
| **Mean** | **6** | **3** | **9** |

( ) standard deviation.

*Table 7.* Effect of rhizobium strains on plant height, shoot dry weight, root dry weight, nodule numbers per plant, nodule dry weight of *Calliandra calothyrsus* after 12 weeks of growth in Leonard jars

| Strain | Plant height (cm) | Shoot dry weight plant$^{-1}$(g) | Root dry weight plant$^{-1}$ (g) | No. of nodule plant$^{-1}$ | Nodule dry weight plant$^{-1}$ (g) |
|---|---|---|---|---|---|
| CP354 | 13.5 | 0.51 | 0.56 | 28 | 0.26 |
| KWN 35 | 22.4 | 1.10 | 0.75 | 76 | 0.36 |
| NGR 185 | 15.2 | 0.64 | 0.02 | 58 | 0.37 |
| NGR 457 | 16.4 | 0.74 | 0.46 | 54 | 0.48 |
| TAL 1145 | 16.9 | 1.18 | 0.66 | 121 | 0.52 |
| Control +N | 6.8 | 0.31 | 0.34 | 0 | 0 |
| Control –N | 10.6 | 0.09 | 0.02 | 0 | 0 |
| **SED** | **2.2** | **0.14** | **0.17** | **13** | **0.08** |

Each value is the mean of 4 replicates.

76 nodules. The Canadian strains showed medium performance with 58 and 54 nodules per plant for NGR 185 and NGR 457, respectively. The good performance of KWN 35 was expected as it has been selected as the most effective strain for nodulating calliandra (Pottinger and Lesuer, 2003). It is interesting to note the nodule weight of NGR 185, NGR 457 and TAL 1145 out performed KWN 35 and should therefore be considered for future screening work with calliandra.

Leucaena results showed that three strains KWN 35, NGR 185 and NGR 457 recorded the highest height growth though shoot dry weight was low for NGR 185 (Table 8). The highest number of nodules was recorded in CP 354 (47 nodules) and TAL 1145 (48 nodules) though TAL 1145 had significantly higher nodule weight than all other strains. The control treatments gave, as expected, the lowest plant height, shoot and root dry weight and did not develop any nodules. The Canadian strains recorded medium performance.

Highest number of nodules in *Crotalaria ochroleuca* was recorded in with CP 354 and NGR 451 with 55 and 59 nodules per plant, respectively (Table 9). These two strains also recorded the highest plant height, shoot and root dry weight, and nodule weight. The two strains therefore have potential for use in inoculating crotalaria.

This initial screening of rhizobia strains showed that their effectiveness to nodulate the different species varied. This agrees with results of other authors (Turk and Keyser, 1992) who found differences in nodulation of tree legumes. They reported that calliandra and leucaena were nodulating effectively with rhizobia isolated from 3 genera while Sesbania effectively nodulated only with rhizobia isolates of members of that genus. Such information is important in selecting strains that would be more effective in different species. There is need to continue this work and assess how the species will respond to inoculation with the same rhizobia strains in soils collected from the trial sites.

*Table 8.* Effect of rhizobium strains on plant height, shoot dry weight, root dry weight, nodule numbers per plant, nodule dry weight of *Leucaena trichandra* after 12 weeks of growth in Leonard jars

| Strain | Plant height (cm) | Shoot dry weight plant$^{-1}$(g) | Root dry weight plant$^{-1}$ (g) | No. of nodule plant$^{-1}$ | Nodule dry weight plant$^{-1}$ (g) |
|---|---|---|---|---|---|
| CP354 | 20.3 | 0.57 | 0.31 | 47 | 0.034 |
| KWN 35 | 26.7 | 1.79 | 0.8 | 39 | 0.039 |
| NGR 185 | 26.7 | 0.25 | 0.13 | 20 | 0.016 |
| NGR 457 | 17.4 | 0.76 | 0.63 | 28 | 0.179 |
| TAL 1145 | 21.6 | 1.88 | 1.45 | 48 | 0.033 |
| Control +N | 13.5 | 0.55 | 0.42 | 0 | n.a. |
| Control -N | 11.8 | 0.17 | 0.01 | 0 | n.a. |
| **SED** | **1.4** | **0.14** | **0.13** | **8** | **0.032** |

Each value is the mean of 4 replicates.

*Table 9.* Effect of rhizobium strains on plant height, shoot dry weight, root dry weight, nodule numbers per plant, nodule dry weight of *Crotalaria ochroleuca* after 12 weeks of growth in Leonard jars

| Strain | Plant height (cm) | Shoot dry weight plant$^{-1}$(g) | Root dry weight plant$^{-1}$ (g) | No. of nodule plant$^{-1}$ | Nodule dry weight plant$^{-1}$ (g) |
|---|---|---|---|---|---|
| CP354 | 35.8 | 3.38 | 1.6 | 56 | 0.82 |
| KWN 35 | 18.7 | 0.88 | 0.60 | 43 | 0.02 |
| NGR 185 | 9.7 | 0.52 | 0.35 | 29 | 0.19 |
| NGR 457 | 35.4 | 3.14 | 1.91 | 59 | 0.57 |
| TAL 1145 | 10.2 | 0.44 | 0.38 | 0 | n.a. |
| Control +N | 22.8 | 1.52 | 0.79 | 0 | n.a. |
| Control -N | 9.7 | 0.26 | 0.08 | 0 | n.a. |
| **SED** | **1.3** | **0.14** | **0.06** | **14** | **0.07** |

Each value is the mean of 4 replicates.

## Conclusions and Recommendations

This study revealed that the soils in Chuka farms are generally acidic, were low in total nitrogen and organic carbon. The soils were also deficient in available phosphorus. These soil conditions could adversely affect performance of legumes. Nodulation of herbaceous legumes on farms was found to be variable with some of the farms having very low numbers of nodules per plant especially for mucuna. Poor nodulation could be due to soil acidity, low soil P levels and possibly lack of adequate indigenous rhizobia. Screening of rhizobia strains under glasshouse conditions showed variation in the effectiveness of the rhizobia on the different legumes. Indications are that crotalaria could benefit from inoculation with rhizobia from Canada (NGR 457). Further screening of the legumes using soils collected from the trial sites is recommended. Evaluation on whether the tested legumes would respond to P application and inoculation in the field is also recommended.

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