Expl Agric. (2000), volume 36, pp. 423–434
Printed in Great Britain

PIGEONPEA RHIZOBIA PREVALENCE AND CROP RESPONSE TO INOCULATION IN ZIMBABWEAN SMALLHOLDER-MANAGED SOILS

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(*Accepted 8 February 2000*)

SUMMARY

A study was conducted to determine the population sizes of indigenous pigeonpea (*Cajanus cajan*)-nodulating rhizobia and responses of the crop to rhizobial inoculation in soils under smallholder management. Rhizobia populations were determined in 21 soils from three different agro-ecological regions of Zimbabwe using the plant infection most-probable-number technique. Pigeonpea response to rhizobial inoculation was tested in five soils representative of low, medium and high rhizobia populations. Pigeonpea rhizobia ranged from undetectable to 121 cells per g soil compared with 16 to 159 cells per g soil for cowpea (*Vigna unguiculata*) which was used for reference. Soils with high cowpea rhizobia counts had relatively low counts of pigeonpea rhizobia and vice versa, showing that the two legumes associate with different subgroups of rhizobia. Poor soil organic matter, low soil moisture at sampling, low pH and low clay content of the soils had a significant negative effect on rhizobial counts. Organic matter appeared critical for maintenance of high populations of indigenous rhizobia in the mostly sandy soils sampled. Lack of pigeonpea response to inoculation in all the soils tested despite the low initial rhizobial populations could be the result of within-season proliferation of indigenous populations which are competitive and effective. There was evidence of rapid build-up of pigeonpea-compatible rhizobia within one growing season when the crop was first introduced. It was concluded that effective pigeonpea rhizobia occur in many arable soils of Zimbabwe. However, to fully exploit biological nitrogen fixation and maximize yields of pigeonpea, highly efficient, adapted and competitive indigenous rhizobial isolates must be identified and evaluated.

INTRODUCTION

Pigeonpea (*Cajanus cajan*) is a nitrogen-fixing legume with potential to improve soil fertility and human nutrition in smallholder farming systems in tropical environments. The crop is drought-tolerant, and the existence of short, medium and long season varieties enhances its suitability in different cropping systems (Reddy, 1990). Moisture is a major limiting factor for crop production in many sub-Saharan countries including Zimbabwe where 55% of the country is semi-arid (Central Statistics Office, 1985). The soils are predominantly granitic sands which are deficient in nitrogen (Grant, 1981). While pigeonpea is an integral

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component of cropping systems in East African countries including Kenya, Uganda and Malawi (Nene and Sheila, 1990), it is relatively new in Zimbabwe and efforts are being made to promote it in the resource-poor smallholder agricultural sector. The production of pigeonpea, and its potential for soil fertility improvement in these systems will, therefore, largely depend on effective nodulation and nitrogen fixation by indigenous or introduced rhizobia.

Pigeonpea is nodulated by slow-growing *Bradyrhizobium* species of the cowpea (*Vigna unguiculata*) miscellany group (Somasegaran and Hoben, 1985; Kumar Rao, 1990), as well as some fast-growing *Rhizobium* species (Bromfield and Kumar Rao, 1983). Rhizobial inoculation is generally recommended when a legume is first introduced into an area on the assumption that local soils may not harbour effective compatible strains (Meisner and Gross, 1980). However, little is known about the effectiveness of indigenous rhizobia on pigeonpea in Zimbabwean soils. In a study of the host range of indigenous cowpea-nodulating rhizobia from Zimbabwean soils, Mpepereki *et al.*, (1996a) found that only 14% and 12% of fast- and slow-growing isolates respectively were effective on pigeonpea. Other studies on rhizobium ecology in Zimbabwe have revealed small indigenous rhizobia populations for cowpea and soyabean (*Glycine max*) (Mpepereki and Makonese, 1994; 1995). Abundance of indigenous rhizobia in soil greatly influences nodulation and inoculation response of the host legume (Singleton and Tavares, 1986; Dudeja and Khurana, 1988). Low native rhizobial populations may necessitate use of commercial inoculants, while high populations of effective rhizobia may obviate the need for inoculation. Soyabean and lupin (*Lupinus* spp.) often respond to inoculation during the first year of introduction into new areas, but not in subsequent years on the same piece of land (Dunigan *et al.*, 1984; Pate *et al.*, 1985). In tropical soils, relatively high population sizes of indigenous rhizobia have been considered to be responsible for the lack of inoculation response observed for cowpea (Danso and Owiredu, 1988).

Overall, there is a paucity of information on the ecology of indigenous pigeonpea-nodulating rhizobia in African soils and the crop's response to rhizobial inoculation. Investigation of inoculation requirements for newly introduced legumes is a vital component of agronomic evaluations (Patrick and Lowther, 1995). To support the efforts for introduction of pigeonpea into the characteristically low-N-input smallholder cropping systems, a study was conducted to estimate the population levels of indigenous pigeonpea-nodulating rhizobia in Zimbabwean soils and response of the crop to rhizobial inoculation.

MATERIALS AND METHODS

Soil sampling sites

Soil samples were collected from 17 smallholder farm locations covering the country's agro-ecological regions II to V. The regions are defined primarily on the basis of mean annual rainfall. Region II receives 750–1000 mm while Region V receives less than 450 mm rainfall. Four additional soil samples were collected

from two research stations, both of which are located in Region II. All except one site had no known history of pigeonpea cropping.

At each farm location at least 10 subsamples of approximately 500 g soil were collected from depths of 0–25 cm, thoroughly mixed in a plastic bucket and 1 kg of the composite sample packed in a polythene bag. Before sampling was done at each site, tools were disinfected by soaking them in 1.0% sodium hypochlorite for five minutes followed by three rinses in sterile distilled water. To avoid moisture loss and direct sunlight (Wollum, 1994), samples were transported in a cooler box and stored in a cold-room at 4 °C. All samples were processed within 5 d of collection except for soils from Mhondoro, Kezi and Chiweshe which were stored for 23 d due to logistic problems. The bulk samples for the pot experiment on inoculation response could not be cooled during transportation. They were transported from the field in polypropylene bags and shaded from direct sunlight with a canvas screen. Soil sampling for rhizobia enumeration was carried out in July 1996, while soils for the inoculation response experiment were collected during the third week of December 1996. Part of each composite sample was analysed for texture, pH, total and mineral nitrogen (N), available phosphorus (P), exchangeable bases and organic carbon (C) using methods described by Anderson and Ingram (1993).

Determination of rhizobial populations

Rhizobia cells were enumerated using the plant infection most-probable-number (MPN) technique (Woomer, 1994). Soil moisture content for each soil sample was determined by oven-drying a 40-g subsample of soil at 105 °C for 24 h. A 5:1 base dilution was used, where a 100-g soil sample, on a dry weight basis, was suspended in 400 ml sterile water and shaken mechanically for 10 min to ensure soil dispersion. A preliminary experiment with a 10:1 dilution series had resulted in very low or undetectable rhizobia counts in several soils. The step-wise dilutions were continued to 5^6 by transferring 5 ml of the preceding dilution to 20 ml of sterile water contained in a separate bottle.

Plastic pots (0.4 L), supported on wire-mesh platforms in a glasshouse, were filled with sterile horticultural vermiculite. All pots were first saturated with sterile distilled water, left to soak overnight and then saturated with N-free nutrient solution (McClure and Israel, 1979). A sterile end of a pipette was used to make out three planting holes in each pot. A single seed was planted in each hole. The seeds were first surface-disinfected by immersing in 95% ethanol for 30 s and then rinsing five times in sterile distilled water. Preliminary tests showed that this treatment was adequate to remove any rhizobia. Each pot received 1.0 ml of a given soil dilution, equally divided among the three seeds. There were four replications per dilution level. Pigeonpea cv. ICLP 87109 was used as trap host on all 21 soils. For comparison, cowpea-nodulating rhizobia, known to occur widely in Zimbabwean soils (Mpepereki and Makonese, 1995) were also counted in eight of the soils with cowpea variety 'Local-mixed' as trap host. Positive control pots were inoculated using a *Bradyrhizobium* (spp. *Macrotyloma*) strain

MAR1510 obtained from the Grasslands Rhizobium Collection, Marondera, Zimbabwe.

Plants were thinned to two per pot six days after emergence. Glasshouse air temperatures ranged from 10 to 17 °C for minimum and 24 to 32 °C for maximum. Distilled water and N-free nutrient solution were used alternately during watering. Plants were harvested six weeks after planting, and the root systems examined and scored for nodulation. A pot was awarded a positive score when any one of the two plants had at least one nodule on the root system. The rhizobia numbers were determined using the MPNES computer program (Woomer, Bennett and Yost, 1990).

Determination of response to rhizobial inoculation

Based on the MPN results, two soils with low (<20 cells per g soil), one with medium (20-80 cells per g soil) and two with high (>80 cells per g soil) populations were collected from the field in bulk and pigeonpea response to inoculation was tested in a pot experiment. Each soil was passed through a 2-mm sieve to remove root materials, organic debris and gravel particles. Four-litre plastic pots were filled with each soil. In each pot four pigeonpea seeds (cv. ICPL 87109) were planted. There were three inoculation treatments: non-inoculated; inoculated with MAR1510, a commercial inoculant for cowpea and groundnut in Zimbabwe; and inoculated with IC3100, a pigeonpea inoculant strain obtained from ICRISAT. Both strains are slow-growing and alkali-producing. There were four replications per inoculation × soil combination. The two inoculants, MAR1510 and IC3100, were supplied in a bagasillo and peat carrier respectively. Inoculation rates were according to manufacturers' instructions. For pigeonpea a 1-g sample of inoculant was mixed with 0.5 ml 5% sucrose solution. Seventy-five grams of seed were thoroughly mixed with the inoculant suspension before sowing. The mixing container was washed with 500 ml sterile water and the washings distributed equally among all inoculated pots. This gave approximately 2.1×10^7 rhizobia cells per seed.

Pots were arranged in a randomized complete block design on raised wire mesh platforms to prevent contamination from soil. The pots were occasionally put in a glasshouse to protect plants from excessive rains. Plants were thinned to two per pot one week after emergence and watered with N-free nutrient solution once every week. Harvesting was done at the flowering stage (99 d after planting). The root system was inspected for nodule number, N-fixing activity (pink/red colour when nodule sectioned) and nodule dry mass. Mean nodule mass was used as a measure of nodule size. Plant root and shoot biomass yields were measured. Shoot biomass was analysed for N content using the semi-micro Kjeldahl method (Anderson and Ingram, 1993). Plant material was digested through wet-oxidation, and N determined colorimetrically.

Data were subjected to analysis of variance of treatment means for a randomized complete block design, using a MINITAB Release 8.2 statistical program. Simple and multiple regression analyses were performed on MPN counts against

soil properties, paying particular attention to the correlation coefficients derived from the functions.

RESULTS

Soil characteristics

Soils from the smallholder areas contained 89% sand on average (Table 1). Exceptions were the soils from Guruve and Mutoko with lower sand contents of 30 and 44% respectively. The soils were very low in available N and P except for the one from Gokwe which had very high concentrations of both N and P. Organic C averaged 0.50%, ranging from 0.24 to 1.19%. Research station sites showed relatively better soil properties except for Domboshawa1 which typified some of the poorest soils from smallholder areas.

Rhizobia populations

The pigeonpea-nodulating rhizobia populations were small in all soils except for Shamva 1 soil which had been under pigeonpea in the preceding season (Table 2). About 67% of the tested soils had less than 6 cells per g soil. Cowpea-nodulating rhizobia in contrast occurred in relatively greater abundance (Table 2). There was one contrasting feature between the Shamva 1 and Kezi soils. Shamva 1 soil had a large population of pigeonpea rhizobia and a small population of cowpea rhizobia, while the opposite was true for Kezi soil (Table 2).

The MPN count for pigeonpea rhizobia was significantly and positively correlated with soil moisture content and pH (Table 3). The regression models for both soil moisture content and pH were slightly improved when organic C and clay content were included. Soil organic C alone did not significantly affect rhizobia counts.

Pigeonpea response to inoculation

Inoculation had no significant effect on all tested parameters, namely, number of nodules per pot, nodule dry mass, root biomass, shoot biomass and N content (Table 4). The effect of soils on these parameters, however, was highly significant ($p < 0.001$). Soils with relatively high clay content gave rise to a large number of small nodules while plants on sandier soils had large but few nodules. The differences in nodule sizes were strongly reflected in the mean nodule mass (Table 4). Inoculation gave a 2.3–3.4% overall increase in nodule number which was not significant.

DISCUSSION

The high sand fraction and low N, P and pH levels of soils used in this study are characteristic of most soils in the smallholder farming areas of Zimbabwe (Grant, 1981). The soils are predominantly derived from granitic parent material (Nyamapfene, 1991) and are inherently of low fertility.

Table 1. Physical and chemical properties of soils sampled from smallholder farms for pigeonpea rhizobia enumeration.

Location	Clay (%)	Silt (%)	Sand (%)	pH ($CaCl_2$)	Mineral N (ppm)	Resin P (ppm)	Organic C (%)	Total N (%)	K (meq†)	Ca (meq)	Mg (meq)
Chikwaka	4	6	90	4.7	27	18	0.42	0.015	0.09	1.23	0.30
Chinyika 1	5	6	89	4.5	28	9	0.58	0.018	0.12	1.03	0.42
Chiweshe	9	7	84	4.9	17	14	0.63	0.019	0.08	1.20	0.31
Domboshawa 1	2	6	92	4.2	20	4	0.29	0.019	0.08	0.50	0.36
Domboshawa 2‡	18	6	76	4.4	42	10	0.59	0.024	0.19	0.92	0.53
Mhondoro	3	3	94	4.4	28	13	0.29	0.028	0.15	0.89	0.39
Murewa 1‡	4	7	89	4.2	17	8	0.26	0.013	0.07	0.39	0.15
Murewa 2	6	2	92	4.4	17	8	0.32	0.017	0.10	0.94	0.26
Shamva 1‡	30	18	52	6.1	17	19	0.87	0.021	0.57	6.09	2.30
Shamva 2	30	18	52	6.1	19	19	0.88	0.023	0.61	6.37	2.33
Chikomba‡	16	8	76	4.2	27	4	0.39	0.011	0.08	0.57	0.35
Chinyika 2	4	6	90	4.6	15	10	0.27	0.019	0.09	1.02	0.33
Gokwe	2	2	96	5.9	153	57	1.81	0.020	1.92	2.20	1.24
Guruve‡	40	30	30	5.1	34	9	0.85	0.021	0.30	14.37	5.99
Mutoko	36	20	44	4.8	32	10	1.19	0.021	0.66	7.63	3.39
Buhera	4	4	92	5.3	34	11	0.23	0.030	0.10	1.88	0.52
Mudzi	5	6	89	4.6	25	14	0.27	0.014	0.12	1.04	0.65
Zimuto	3	4	93	4.5	24	11	0.24	0.015	0.09	0.78	0.39
Chivi	6	8	86	5.0	28	22	0.28	0.014	0.33	1.68	0.67
Kezi	5	6	89	5.1	19	11	0.26	0.017	0.22	4.18	0.94
Empandeni	4	4	92	4.5	20	2	0.24	0.017	0.07	0.07	0.38

† meq = milliequivalent per 100 g dry soil; ‡ soils used in the inoculation response study.

https://doi.org/10.1017/S0014479700001009 Published online by Cambridge University Press

Table 2. Pigeonpea (PP)- and cowpea (CP)-nodulating rhizobia populations, moisture content and cropping history of soils from smallholder farm sites.

Location	Cropping history 94/95–95/96 season	Most probable number (cells per g soil) PP	95% CI§	CP	95% CI	Moisture content (%w/w)
		Region II†				
Chikwaka	maize–maize	1	0–3	nd¶	—	3.0
Chinyika 1	maize–maize	6	2–23	36	9–137	0.9
Chiweshe	maize–maize	16	6–47	61	16–233	4.3
Domboshawa 1	fallow-fallow	1	0–3	33	11–95	0.4
Domboshawa 2‡	maize–maize	5	2–13	nd	—	1.3
Mhondoro	maize–maize	1	0–3	nd	—	2.6
Murewa 1‡	maize–maize	1	0–3	36	9–137	0.5
Murewa 2	maize–maize	5	2–13	nd	—	1.4
Shamva 1‡	maize–pigeonpea	614	161–2333	159	42–606	8.3
Shamva 2	maize–maize	121	42–342	nd	—	8.1
		Region III				
Chikomba‡	maize–maize	40	14–116	nd	—	6.5
Chinyika 2	maize–maize	1	0–3	16	4–61	0.5
Gokwe	maize–maize	22	7–62	nd	—	6.4
Guruve‡	maize–maize	81	28–234	nd	—	6.7
Mutoko	maize–maize	16	6–47	nd	—	7.0
		Region IV				
Buhera	maize–maize	1	0–3	nd	—	0.5
Mudzi	maize–maize	5	2–13	21	6–81	2.3
Zimuto	maize–maize	5	2–13	nd	—	1.8
		Region V				
Chivi	maize–maize	1	0–3	nd	—	0.8
Kezi	cowpea/maize–maize	1	0–3	112	30–428	0.5
Empandeni	maize–maize	0	—	nd	—	0.4

† Region = agro-ecological region; ‡ Soils used in the inoculation response study; § CI = confidence interval; ¶ nd = not determined.

The results confirmed the presence of pigeonpea-nodulating rhizobia in the soils tested. Their populations, however, were very small and this may be partly because pigeonpea has never been grown in these areas. However, populations of indigenous cowpea and soyabean rhizobia also have been reported to be low in several Zimbabwean soils (Davis and Mpepereki, 1995; Mpepereki and Makonese, 1995). In this study the Kezi soil with large populations of cowpea rhizobia had small pigeonpea rhizobia populations while the Shamva 1 soil with large populations of pigeonpea rhizobia had smaller counts for cowpea (Table 2). This suggests that cowpea and pigeonpea are nodulated by different subgroups of rhizobia, confirming the findings by Mpepereki *et al.* (1996b) on the diversity in symbiotic specificity of cowpea rhizobia. Such subgroups differ in their physiological characteristics and stress tolerances (Mpepereki *et al.*, 1997). The relatively larger rhizobia counts on cowpea compared with pigeonpea further indicates that the two legumes probably associate with different subgroups of the indigenous

Table 3. Correlations between soil properties and *Bradyrhizobia* counts for pigeonpea.

Soil property	Correlation coefficient (r)
Clay content (%)	0.49*
Moisture content (%w/w)	0.57**
Organic C (%)	0.28 (ns)
Total N (%)	0.13 (ns)
Resin P (ppm)	0.14 (ns)
pH ($CaCl_2$)	0.59**
Moisture content + Organic C	0.60*
Moisture content + Clay content	0.58*
Moisture content + pH	0.65**
Organic C + pH	0.61*
Clay content + pH	0.66**
Moisture content + Clay content + pH	0.66*
Moisture content + Clay content + Organic C + pH	0.72*

* and ** significant at $p < 0.05$ and $p < 0.01$ respectively; ns = not significant.

Table 4. Effect of different soils on nitrogen-fixing indices measured (per pot) from pigeonpea.

Soil source	Nodule number	Mean nodule mass (g)	Nodule dry mass (mg)	Root dry mass (g)	Shoot dry mass (g)	Nitrogen content (mg)
Chikomba	78	7.72	0.60	2.67	6.28	137.58
Domboshawa 2	64	18.32	1.09	3.68	10.12	301.87
Guruve	257	5.31	1.26	3.89	14.96	356.13
Murewa 1	96	14.27	1.21	3.64	10.78	236.17
Shamva 1	155	5.87	0.84	3.23	14.99	431.87
s.e.d.	29	1.25	0.08	0.26	0.78	23.08

rhizobia population. Besides cowpea, the only other commonly grown legume in Zimbabwe's smallholder farming systems is groundnut (*Arachis hypogaea*). It is unlikely that groundnut rhizobia which occur abundantly in Zimbabwean soils are compatible with pigeonpea (Mpepereki *et al.*, 1996b).

Comparison of MPN counts between Shamva 1 and Shamva 2 soils (Table 2) shows a five-fold increase in rhizobia populations after one season of pigeonpea growth, indicating a rapid build-up of rhizobia populations within one growing season. This observation is consistent with other reports showing that cropping of homologous host legumes leads to increases in soil populations of compatible rhizobia (Thies *et al.*, 1995). Large counts in Shamva 1 soil could have resulted from rhizobia released from decayed nodules of the previous crop or rapid multiplication in the pigeonpea rhizosphere or both (Chatel and Parker, 1973; Thies *et al.*, 1995). Host legumes have been reported to stimulate multiplication of rhizobia numbers in their (hosts') rhizospheres (Brockwell *et al.*, 1987; Dudeja and Khurana, 1988).

Results showed that rhizobia population levels were most affected by soil factors

that included moisture, organic matter, pH and clay content (Table 3). Given that sampling was done during the dry season on mostly sandy soils of poor water-holding capacity and low organic matter content, the low populations were not unexpected. The observed significant correlation between MPN counts and soil moisture content, also previously reported by Mpepereki and Makonese (1995), suggests that a sharp decline in rhizobia numbers accompanies the drying out of these sandy soils. Rapid soil moisture depletion at the end of the rainy season has been reported in most smallholder area soils (Mapfumo, 1995). The effect of temperature on population size could be a factor. While part of the dry season in Zimbabwe is considerably cooler than the rainy season, temperatures are unlikely to be lethal, so that survival of rhizobia over the dry season can be considered to depend more on soil moisture than temperature. Indeed, some indigenous rhizobia have been shown to be adapted to hot soil environments (Mpepereki *et al.*, 1996a).

Organic matter plays a pivotal role in the soil–water relations of sandy soils. There was a significant linear relationship between organic C and soil moisture content ($r = 0.73, p < 0.05$), and this probably explains why the regression model involving MPN and soil moisture was improved by inclusion of organic C (Table 3). Mahler and Wollum (1981) reported maximum rhizobia populations at moisture contents close to field capacity, while Howieson (1995) reported rapid rhizobia mortality as soil dries. Mpepereki and Makonese (1995) also reported low counts of cowpea-nodulating rhizobia in soils sampled during the dry season.

Low soil pH was associated with a reduction in rhizobia numbers, especially in soils with a low clay content (Table 3). High nodule numbers in soils with relatively high clay contents may be indicative of large initial rhizobia populations in these soils. Soil moisture content, pH, clay content and organic C accounted for most of the relationship between rhizobia counts and soil properties ($r = 0.72$, $p < 0.05$), confirming that organic matter could play a more positive role in soils with very low clay content. Soil management practices which build soil organic matter and arrest decline in pH (for example, liming) are likely to create soil environments that encourage survival, persistence and possibly increase in N-fixing rhizobia populations. Soil organic matter build-up in these sandy soils, however, may be practically difficult to achieve due to its rapid turnover (Giller *et al.*, 1997). The problem of how to build up soil organic matter levels poses a major challenge to those working to develop sustainable soil management systems in African smallholder agriculture.

The lack of response to rhizobial inoculation by pigeonpea despite small populations of indigenous rhizobia populations raises questions on the population dynamics of the indigenous rhizobia across seasons and also the effectiveness of inoculant strains used. It also has implications on the N-fixing efficiency in symbiotic relationships involving tropical rhizobia strains. Lack of response to inoculation against a background of low rhizobia counts was also reported for cowpea (Mpepereki and Makonese, 1995; Thies *et al.*, 1995). Soils used in this study were collected in December, four weeks after the start of the rainy season. By

sampling time considerable growth in rhizobia populations could already have been promoted by the initial mineralization flush associated with the first rains. Rainfall-stimulated plant growth over the sampling sites may also have promoted rhizobia multiplication in the rhizospheres of these plants. In their studies on seasonal fluctuations of cowpea- and soyabean-nodulating rhizobia in Zimbabwean soils, Mpepereki and Makonese (1998) found marked differences in population sizes between dry (April–October) and wet (November–April) seasons. The populations were lowest in August, increasing with the onset of the rainy season between October and December and reaching a maximum in February (peak of rainy season). Dudeja and Khurana (1989) also observed an increase in pigeonpea *Bradyrhizobia* numbers, from 47 cells per g soil during the dry season to 1000 cells per g soil at about a month after the start of the rainy season. Such rapid enrichment of rhizobia populations under the influence of the host legume may account for lack of response to inoculation (Thies *et al.*, 1991).

Cowpea failed to respond to inoculation when indigenous populations were as low as 18 cells per g soil (Thies *et al.*, 1995). It appears that the initial rhizobia population *per se* is not a good indicator of inoculation response. Mere presence of compatible rhizobia may be sufficient to eliminate inoculation response. These findings suggest that, under tropical environments, agronomic management factors promoting rapid build-up in indigenous rhizobia population sizes within a growing season may be more important in nodulation and N_2-fixation of legumes than initial population sizes. The lack of inoculation response by pigeonpea in soils with indigenous rhizobia populations ranging from 1 to 614 cells per g soil may also suggest high plasticity and efficiency in the symbiotic relationships involving these indigenous rhizobia. Although the pigeonpea inoculant strain used is generally recommended for the crop, its potential on local pigeonpea varieties under local conditions has not been investigated. For instance, host–strain interactions in pigeonpea–*Rhizobium* symbiosis have been reported for soil salinity (Subbarao *et al.*, 1990).

CONCLUSION

The occurrence of indigenous pigeonpea rhizobia in Zimbabwean soils has been demonstrated but populations estimated by the MPN were generally low. Population sizes appear to be dependent on organic C, moisture content, texture and pH of the soil. Previous cropping of pigeonpea boosts populations of compatible indigenous rhizobia. Soil management practices that promote the build-up of soil organic matter, hence improving soil water-holding capacity, are likely to result in maintenance of high pigeonpea rhizobia numbers at the beginning of each growing season. Sufficient nodulation of legumes under tropical environments is apparently more dependent on agronomic factors that promote within-season rhizobia proliferation as opposed to the pre-season numbers. This probably explains why the mere presence of compatible rhizobia appears to be sufficient to eliminate pigeonpea response to rhizobial inoculation. The symbiotic

effectiveness of these native populations still needs to be evaluated by comparing with pigeonpea grown under conditions where N is non-limiting. Inoculants are not readily accessible to smallholder farmers in most parts of sub-Saharan Africa including Zimbabwe, and their use introduces an extra labour cost. This study contributes towards a better understanding of indigenous pigeonpea rhizobia population dynamics and their effects on crop response to inoculation under smallholder cropping conditions. If indigenous rhizobia can be shown to be effective, in a wide range of environments, elimination of inoculation requirement would make pigeonpea-based soil fertility management interventions potentially sustainable.

Acknowledgements. This study was funded by the European Union and IDRC through the Institute of Environmental Studies of the University of Zimbabwe. Our sincere thanks go to Dr O. Rupela of ICRISAT for providing the pigeonpea inoculant and Professor K. E. Giller for his constructive comments on the manuscript.

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