High Yields of Non-fertilized Protein-rich Pigeon Peas on Tropical Soils of Low Inherent Fertility of Puerto Rico: An Explanation of a Paradox[1]

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ABSTRACT

Pigeon peas do not respond to the application of fertilizers on soils of low inherent fertility under conditions in Puerto Rico, although sizeable yields, sometimes over 7800 kg/ha of green pods and seeds, with over 20% protein, are obtained with high-yielding cultivars, sound crop protection practices and adequate soil and crop management techniques. It is estimated that in terms of kg/ha a pigeon pea crop of some 7800 kg/ha removes nutrients at approximately the rates of N, 60; P, 15; K, 20; Ca, 20; and Mg, 10. A plausible explanation for the lack of response to N can be based on the known fact that pigeon peas can fix atomospheric N through rhizobial action at a rate of at least 14.5 mg/day/plant to supplement the N provided from the reserves of soil organic matter and root residues. For a plant population of 17,284/ha this fixation would amount to some 45 to 50 kg for the pigeon pea growing period. Large P applications over the years coupled with P fixation on the soil and gradual release afterwards might explain the observed lack of response to fertilizer P. On the other hand, the relatively high K-supplying power of soils where pigeon peas are grown, together with the small demand of the crop, explains the lack of response to fertilizer K. Many acid soils of the tropics can supply enough Ca as a nutrient to meet the demands of pigeon pea crops. Pigeon peas use relatively small amounts of Mg, which appears to be available in many soils of Puerto Rico.

INTRODUCTION

The mineral nutrition of pigeon peas (*Cajanus cajan* Millsp.), under conditions of Puerto Rico, seems paradoxical since they grow very well on highly leached soils of relatively low inherent fertility, yield an abundant crop of protein-rich seeds without the application of fertilizer and remove substantial amounts of N, P, K, Ca and Mg for each unit of dry matter produced.

The pigeon pea offers a vast potential over a wide range of climatic and soil conditions in the tropics, but performs best on areas where annual rainfall ranges from 500 to 1500 mm/yr and where the soils are well-drained (32). It has a very deep taproot and a profusion of active secondary roots. According to Gooding (15), the pigeon pea is "highly drought and heat resistant." Most pigeon pea cultivars are highly sensitive to day-length; flowering and seed filling occur during short days. Under conditions in Puerto Rico this happens from November through

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February. Therefore, they should be planted from June to August. Dry, ripe seeds contain over 20% protein of good quality, except that they are low in sulfur amino acids and tryptophan, a deficiency common to most grain legumes. Yields of over 7800 kg/ha of green pods, roughly equivalent to 3900 kg/ha of grain, have been obtained from high-yielding cultivars in Puerto Rico (14). Reports from other areas indicate that good dry pigeon pea yields of 500–1000 kg/ha are possible. Favorable growing conditions can lead to high yields of 1600–2500 kg/ha, and exceptionally high yields of 5000 and 7600 kg/ha have been reported.

No response to N, P, K, Ca, Mg, S and micronutrients has been measured under conditions in Puerto Rico (2, 19, 27). Data have been presented, but no attempts have been made to explain the situation. The purpose of this paper is to attempt to explain in a rational way this intriguing, seemingly perplexing situation on the basis of data from outside and local sources.

DOCUMENTED LACK OF RESPONSE TO APPLIED FERTILIZER IN PUERTO RICO

On the basis of the relatively high nutrient removal, including pods, seeds and the whole plant, it could be logically inferred that the demand for plant nutrients of the pigeon pea crop is correspondingly high. Consequently, a crop response to applied fertilizers would be normally expected in soils of low inherent fertility. However, Landrau and Samuels (19), working on an Oxisol at Isabela, reported a lack of response in yield to different levels of N, P and K. Furthermore, Pietri et al. (27), also working on the same soil, further studied the effect of various levels of N, P and K, with and without Ca, and of Mg and Ca silicates on pod yield, date of flowering, plant height, seed weight and protein content. Again, there was no response to fertilizer applications. In 1974, Badillo-Feliciano et al. (2) conducted two experiments on the same Oxisol at Isabela to determine the effect of foliar-applied Nutrileaf[3] at a rate of 2.24 kg/ha at weekly, biweekly, triweekly, and monthly intervals, and biweekly applications of equivalent amounts of N and P separately and combined. The data showed that foliar-applied nutrients did not have significant effects on green pod yield, plant height, seed weight, protein content or seed to pod ratio of cultivars 2B-Bushy and Kaki.

Little or no response to fertilizer additions are reported also from other areas (8,14,16,28). This may be attributed, at least in part, to the fact that pigeon peas have a deep and rather extensive root system which enables

[3] Trade names in this publication are used only to provide specific information. Mention of a trade name does not constitute a warranty of equipment or materials by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

them to utilize available nutrients present deep in the soil. On the other hand, limited responses have been obtained in other areas (5,7,21,31).

In India, applications of N, P and K at rates of 25, 44 and 21 kg/ha, respectively, increased yields from 1600 (0 fertilizer) to 2300 kg/ha (5).

NUTRIENT UPTAKE AND REMOVAL

Data from Mehta and Khatri (22) indicate that a pigeon pea crop producing some 1800 kg/ha of dry matter removes the following amounts of nutrients, in kg: N, 13; P, 4; K, 5; Ca, 5; and Mg, 2. Using these data as a framework of reference a crop of Line 69-68, grown on a relatively unfertile, acid Oxisol on northwestern Puerto Rico and yielding 7800 kg/ha of pods and seeds (13) would theoretically remove more than 60 kg of N, 15 of P, 20 of K, 20 of Ca and 10 of Mg.

Sen (31) reports that in India, N uptake by pigeon peas ranged from 310 kg/ha in a non-fertilized crop to 330 in a fertilized crop, variety NP51, a non-significant difference. The difference between the N returned to the soil from N fertilized and non-fertilized plots is not significant. Either fixation and/or mineralization must have been great to provide for such high N crop uptake. Under any standards, these are sizeable amounts of nutrients removed. A crop of corn yielding 6000-8000 kg/ha of grain uses between 67 and 135 kg/ha of N (3,4).

MAGNITUDE OF BIOLOGICAL N FIXATION AND RELEASE

According to Ramaswoni and Nair (30), the same rhizobial complex active in the cowpea group is utilized by the pigeon pea in symbiotic biological fixation of atmospheric N. They report variability in the bacterial strain and in the host × symbiotic relationship. They obtained increases in dry matter yield of inoculated plants ranging from 1.9 to 231% over the uninoculated control. Similarly, the amount of N fixed varied from 1.3 to 342.3% over control. Oke (24) reports that N fixation and transfer of N to other parts of the plant can be very efficient. He measured a maximum fixation of 14.5 mg/day/plant in pigeon peas, grown in washed sand fed with N-free nutrient solution, as compared to 10.3 for *Centrosema* and 4.6 for *Stylosanthes*. Younger plants were more effective in the fixation process than older plants. These data provide an important point of reference to roughly estimate the amount of N fixed biologically by the pigeon pea crop on a field-wide basis. For a population of 17,254 plants/ha this would amount to some 45 or 50 kg/ha for a 6-month growing season if fixation would be constant throughout the crop's life cycle. However, no nodules have been observed in pigeon pea roots after 12 weeks of growth (30). On the other hand, data from Sen (31) suggest that perhaps pigeon peas can fix larger amounts of N and/or that large amounts of N can be made available to the plant from other sources, other than fertilizer N. His data indicate that from the 7177 kg/ha of shed leaf and flower material from an unfertilized pigeon pea crop, some 131 kg/ha of N was incorporated into the soil. This is an unusually high level of N just from the foliage and flower and shows that the amount of N available to the plant must have been substantial. Evidently, in addition to the N fixed, rather large amounts of N must have been made available to the crop, probably through mineralization of soil organic matter, crop residues and roots. These possible sources of additional N in tropical soils have been pointed out by Pérez-Escolar et al. (26).

Harding et al. (17) compared nodulation of several legumes grown on an Oxisol in northwestern Puerto Rico over an 81-day period. Pigeon peas were only second to winged beans (*Psophocarpus tetragonolobus*), a food legume widely recognized for its prolific nodulation. Numerous large active nodules were observed throughout the experimental period. However, the number of nodules decreased with time, but the mean nodule dry weight increased. It does seem certain that growth of individual nodules is the dominant factor in the prolific nodulation of pigeon peas, whereas growth in numbers as well as nodule growth is important in the abundant nodulation of winged beans.

On the same Oxisol at the same location, where pigeon peas are grown, a 1412 kg/ha crop of native white beans (*Phaseolus vulgaris*) needs at least some 80 kg/ha of fertilizer N for near maximum yields over an 81-day growing season (4,20). Beans are considered to be low N fixers and levels of nodulation are low (12). In some cases, small amounts of N, not over 25 kg/ha, have been used to stimulate nodulation of pigeon peas or to increase the protein content of the seeds (21). Higher rates of N will depress biological N fixation (9).

The pigeon pea is considered to be an exhausting crop that uses rather large quantities of N. Through its relatively high biological N fixation rate it can obtain enough N to supplement the N which can be provided from the reserves of soil organic matter and root residues. The deep taproot and the rather extensive fibrous root system of the pigeon pea allow it to tap more successfully a larger soil volume than do some other cultivated crop plants. All together, these can contribute N in substantial amounts. Furthermore, under such conditions, little or no response to N fertilizers is likely to be expected in the soils of Puerto Rico.

RESIDUAL P

Most studies in other areas indicate that P is the first limiting nutrient for pigeon peas under the tropical environment (28,29). Usually, 20–80 kg/ha of P_2O_5 are recommended. Increases of 13.5% were measured by using 5 tons of compost with 22.5 kg/ha of P_2O_5 in Madras (33); at Delhi, increases of 1.29 to 2.76 tons/ha of dry seed were obtained with 100 kg/

ha of P_2O_5 (18). Nichols (23) has shown that Ca, P and Mg deficiencies reduce plant growth and nodulation to a greater extent than N, K and Fe deficiencies. High Mo applications maximized the accumulation of some aminoacids. S, at the rate of 100 p/m, alone or combined with P, increased the N content of pigeon pea nodules (25).

Under conditions in Puerto Rico, no response in pigeon pea yields has been measured attributable to applications of P (2,19,27). A plausible explanation might be found in the work with various crops of Bonnet et al. (6), Del Valle et al. (10,11), Badillo (4), under various soil conditions. Even on Oxisols and Ultisols, tropical soils, which are usually low in fertility, no crop response to fertilizer P could be measured. Del Valle et al. (10) could not obtain any response from soybeans to applications of fertilizer P at varying levels. Under the same soil and climatic conditions they failed to obtain responses from two succeeding crops of native white beans (11).

Many soils in Puerto Rico, whether planted to sugarcane, tobacco, coffee or pastures, have been receiving over the years rather large applications of fertilizer P. Most of this P has probably been fixed by the soil and can be gradually tapped by growing crops over a number of years.

K-SUPPLYING POWER OF MAJOR SOILS

The case for K can perhaps best be argued on the basis of the low K consumption while the K-supplying and releasing power of many of the soils of Puerto Rico can be rather high. Abruña et al. (1) measured the K-supplying power of 23 typical soils by cropping pangola grass on pots for 4 consecutive years. During the first year of cropping, the soils released the following amounts of K:

Soil	*K released, kg/ha*
Oxisols	234
Ultisols of the uplands	260
Ultisols of the coastal plains	230

After the first cropping year, K removal dropped off sharply to about 50 kg/ha for the Oxisols and Ultisols of the coastal plains and 90 for the Ultisols of the uplands.

Considering the low K uptake and K removal in a pigeon pea crop (around 2 kg/ha/1000 kg crop) it can be inferred that most of the soils of Puerto Rico can release yearly more than adequate amounts of K to support growth and production of pigeon pea crops throughout several years. Furthermore, K in soils where micas are abundant in the clay fraction and where the K-bearing minerals in the sand fraction are more abundant and less weathered, can be expected to become available throughout the years. Abruña et al. (1) measured removal of soil K by pangola grass over 4 years of consecutive cropping of the order of 533 kg/ha, a figure that considerably exceeded the so-called "available" soil K content in the soil.

THE CASE FOR Ca AND Mg

Most of the soils where experimental work with pigeon peas has been conducted in Puerto Rico appear to be well-supplied with Ca. Even many of the acid soils with low exchangeable Ca can normally supply enough Ca as a nutrient for adequate crop growth. An Oxisol at Isabela with a CEC of 13 meq/100 g of dry soil will have about 3.6 meq of exchangeable Ca. This is equivalent to some 1440 kg/ha of exchangeable Ca, which is more than enough to support many crops like pigeon peas that use and remove only around 2 kg/ha/1000 kg crop.

The pigeon pea crop appears to use only a relatively small amount of Mg, i.e., 1.3 kg/ha/1000 kg of dry matter. The same Oxisol previously mentioned where pigeon peas are grown in northwestern Puerto Rico, can supply almost 1 meq of available Mg per 100 g soil. This is equivalent to 269 kg/ha of Mg, more than enough to support a number of crops for a rather large period of time.

RESUMEN

El objetivo del análisis que aquí se presenta fue tratar de explicar el hecho de que en Puerto Rico el gandul no responde a las aplicaciones de abonos. Sin embargo, se logran cosechas de altos rendimientos (hasta de 7800 kg/ha de vainas verdes con semillas ricas en proteína, (más de 20%), cuando se utilizan cultivares de buen potencial productivo y se siguen prácticas adecuadas de protección de cosechas y de cultivo aun en suelos de reconocida baja fertilidad. Se ha estimado que una cosecha de 7800 kg/ha de vainas verdes extrae aproximadamente los siguientes nutrimentos, en kg: N, 60; P, 15; K, 20; Ca, 20; y Mg, 10. Una posible explicación de la falta de respuesta a N puede formularse a base del hecho conocido de que el gandul puede fijar N atmosférico en simbiosis con *Rhizobium* a razón de 14.5 mg/dia y planta. En una siembra de 17,284 plantas/ha el N fijado ascendería a 45 ó 50 kg durante su ciclo de crecimiento para suplementar el derivado de la mineralización de la meteria orgánica del suelo y de los residuos de raíces. La falta de respuesta a aplicaciones de P puede explicarse considerando que, a lo largo de muchos años se han hecho aplicaciones de P de gran magnitud a los suelos de Puerto Rico, del cual gran parte se ha fijado en el suelo, y que asimilable gradualmente las cosechas pueden utilizarlo. De otra parte, la capacidad relativamente alta de los suelos de suministrar K, junto a la relativamente baja apetencia del

gandul por este nutrimento, explica la ausencia de respuesta a las aplicaciones de K. También es un hecho reconocido que aun los suelos ácidos pueden suministrar suficiente Ca como nutrimento. El gandul usa relativamente bajas cantidades de Mg que están disponibles en los suelos de Puerto Rico.

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