Analysis of competition between pigeonpea and maize in semi-arid Tanzania

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Introduction

Pigeonpea (*Cajanus cajan* L. Millsp.) is traditionally intercropped or grown in rotation with cereal crops (Fig. 1) in semi-arid tropics (Snapp et al. 2002; Ghosh et al. 2006). Productivity of these pigeonpea-based cropping systems is dependent on facilitative and competitive interactive effects on resource availability. Controlling these interactions will optimize yields of both cereal and legume crops; hence benefit farmers through increased productivity and diversification of income and food sources. Unlike the Indian sub-continent (Ghosh et al. 2006), previous research on intercropping legumes with cereals in Sub-Saharan Africa focused on improving soil fertility and crop yield (Snapp et al. 2002; Myaka et al. 2006), but provided inadequate information on the mechanisms of interspecific competition. Therefore, this study evaluated facilitative and competitive interactions under pigeonpea-maize cropping systems in semi-arid Tanzania in order to elucidate mechanisms for optimizing productivity. Specific objectives were to assess effects of cropping systems (Fig. 1), cattle manure, and combined N and P fertilizers on crop yield and nutrient uptake, soil N and P replenishment, and competition for nutrients.

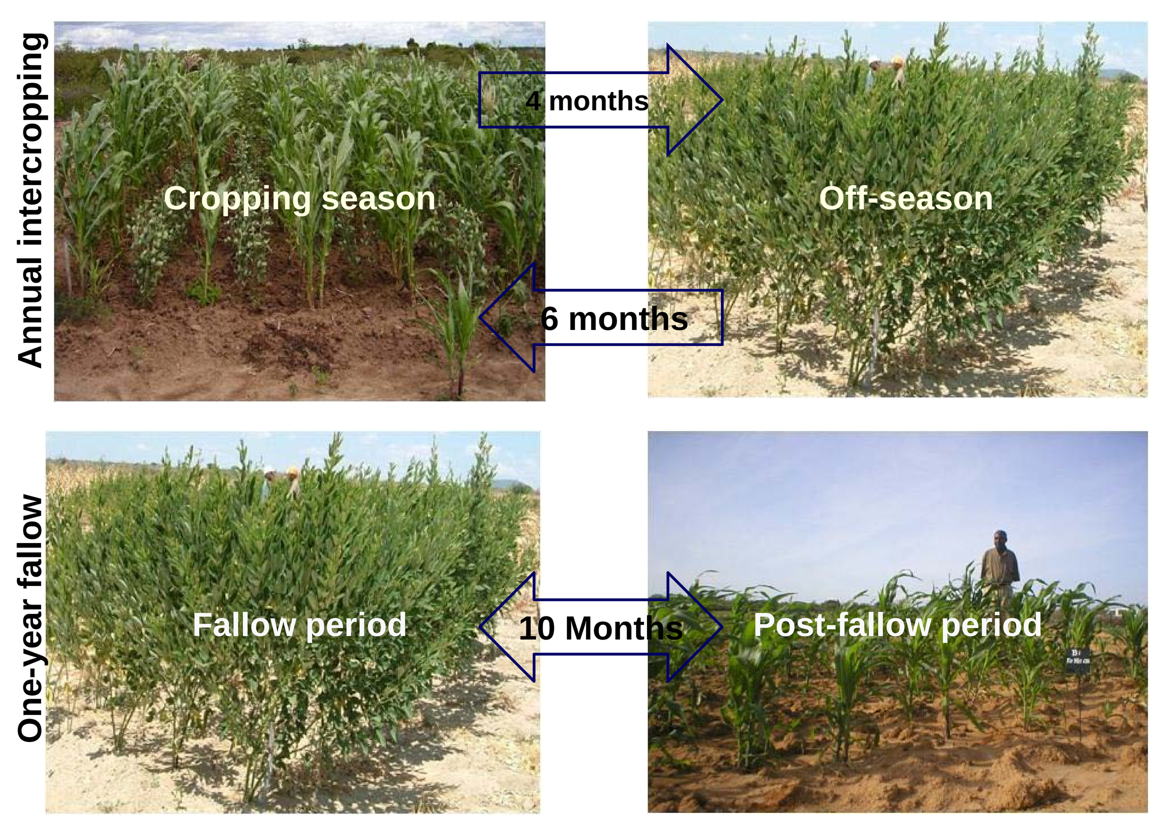

Figure 1. Intercropping and improved fallows of pigeonpea and maize at Ihumwa, Dodoma, Tanzania. In both systems pigeonpea occupies the land approximately the same amount of time, but its impacts on productivity depend on the nature and magnitude of interactions with associated maize crop. Such information is scanty in sub-Saharan Africa.

Methodology

The research was carried out at Ihumwa village, Dodoma, Tanzania with mean annual rainfall of 560mm and highly weathered acidic soils (ferric acrisol). A 3 x 3 x 3 factorial experiment in a randomized complete block design was adopted to test the effects of:

- Cropping systems (Maize monoculture, Intercropping, and Fallow)
- Combined N and P fertilizers (Control, 40 and 20 kg ha^{-1}, 80 and 40 kg ha^{-1})
- Cattle manure (Control, 5 and 10 kg ha^{-1})

Results and discussion

Maize and pigeonpea yields

Intercropping enhanced maize yield over sole maize only when fertilized, reflecting probable nutrient competition (Fig. 2). However, improved fallows alone or with fertilizer doubled maize yield (1.2 – 1.6 Mg ha^{-1}) relative to unfertilized sole maize (0.6 Mg ha^{-1}). As expected, these increases were attributed to pigeonpea facilitation mainly through soil N replenishment, reduced competition associated with sequential cropping arrangements, and added nutrients from fertilization. Non-significance differences among cropping systems at full fertilizer rate, implied a fertilizer induced response on maize and pigeonpea yields. Seasonal yield declines in the 2005 were due to low and sporadic rainfall patterns.

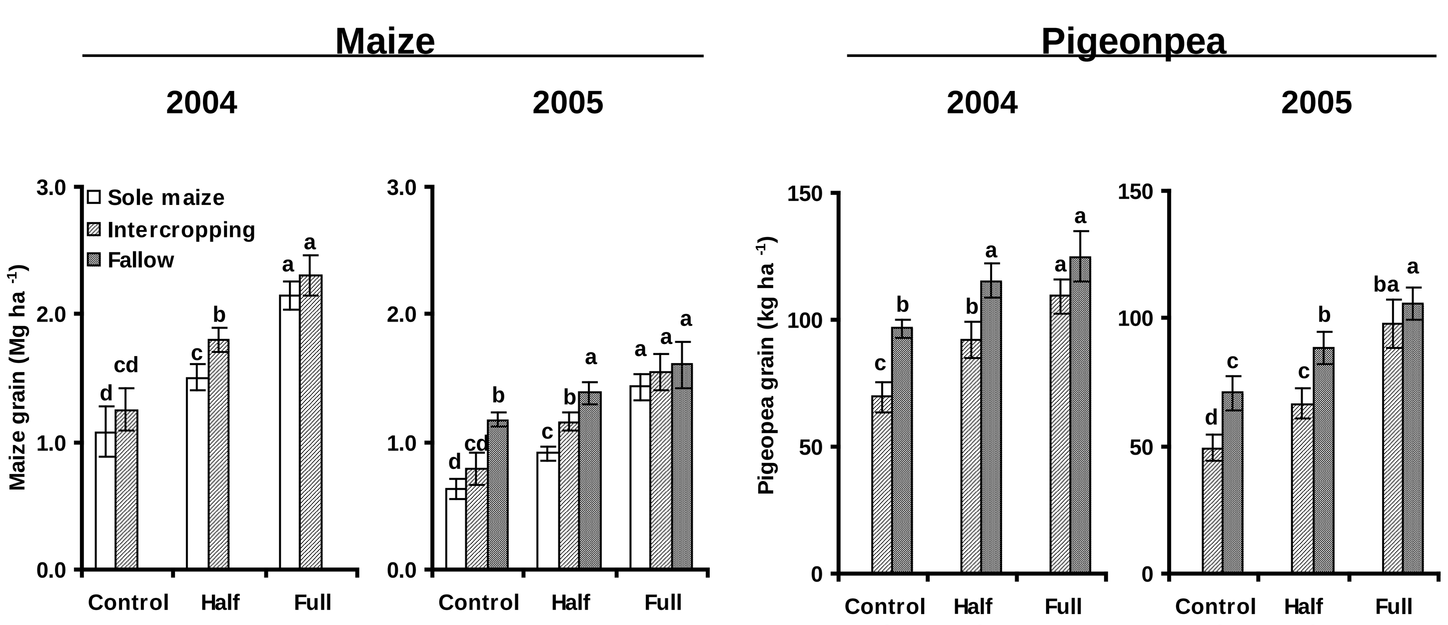

Figure 2. Maize and pigeonpea grain yields for the interactions between combined N and P fertilizers and cropping systems [sole maize, intercropping, and one-year improved fallow at Ihumwa, Dodoma, Tanzania. Application rates were: Control = No fertilizer, Half = 40 kg N ha-1 and 20 kg P ha-1, Full = 80 kg N ha-1 and 40 kg P ha-1. For each Figure, values represent least squares means of treatment combinations and those marked by the same letter are not statistically different at $p < 0.05$ according to Tukey's HSD test. Vertical bars indicate standard error of means (n = 3).

Nutrient competition

Yield and uptake of both maize and pigeonpea were reduced by 20 – 60% under annual intercropping compared to improved fallows when little or no fertilizer was applied (Fig 3a and b), indicating competition for nutrients (Imo and Timmer, 1998). Controlling this interacting would require additions of half and full fertilizer rates to the intercropping and fallow systems, respectively (Fig. 3c and d). At maize harvest, the decline of pigeonpea biomass (60 %) was higher than a 30 % decrease in that of maize (Fig 3a). This signifies a stronger competitive effect of the latter and/or slower growth rates of pigeonpea plants (Fig. 1). Apparently, impacts of this interaction persisted even after maize harvest since pigeonpea grain yield in the unfertilized intercropping treatment was 33 % lower than that of improved fallows without fertilization (Fig. 3). Recovery of growth and nutrient uptake after harvest of an early maturing component has been reported for soybean plants in wheat-soybean intercropping (Zhang and Li 2003). Consistent with this study, such recovery was not observed for unfertilized pigeonpea plants in the pigeonpea-soybean intercropping system due to the high competitive effect of soybean (Ghosh et al. 2006).

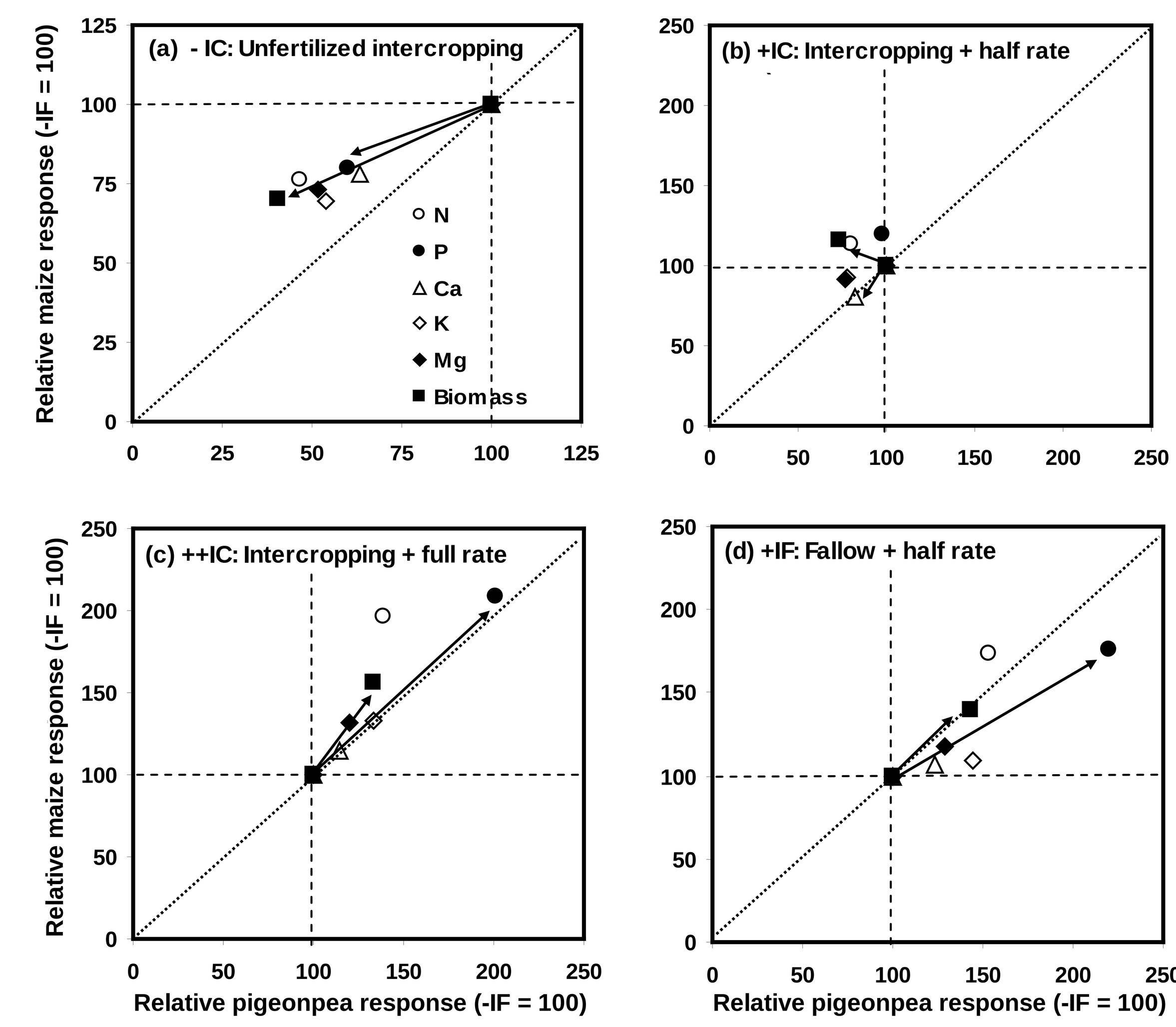

Figure 3. Vector competition diagrams of biomass and nutrient content of maize and pigeonpea under intercropping (a – c) and improved fallow (d) systems without (-), with half (+) or full (++) rates of combined N and P fertilizers at Ihumwa, Dodoma, Tanzania. Responses are expressed relative to the competition-free status (the unfertilized fallow treatment, -IF) that was normalized to 100. Interpretation is based on shifts (direction) and ratio of vectors. Vector shift reflects types of competitive interactions (antagonism, synergism and compensatory) whereas the uptake-to-biomass vector ratio identifies possible mechanisms (antagonistic dilution, growth dilution and deficiency) associated with these interactions. Thus, decreases of uptake and biomass of both crops associated with the longest biomass vector (ratio <1, Fig 3a) represented antagonistic dilution due to nutrient competition. Other shifts illustrated increase in both uptake and biomass (synergism) accompanied with growth dilution of K, Ca, and Mg (vector ratio < 1) and deficiency of N and P (vector ratio > 1) after fertilization (Fig.3c and d).

Nutrient diagnosis

Vector nutrient diagnosis revealed a primary P deficiency as illustrated by the largest increase in biomass yield, content and concentration of P in maize and pigeonpea (Fig. 4). Soil P deficiency on this site was attributed to P fixation due to high soil pH (4.6) and exchangeable aluminum (0.98 cmol kg^{-1}). However, pigeonpea N concentrations remained unchanged even after fertilizer addition, exemplifying self sufficiency through biological fixation. On P deficient sites, pigeonpea plants may access sparingly soluble P through exudation of organic acids and can transfer a large proportion of P from senesced leaves to nodules. These mechanisms may increase P use efficiency to meet the demand for N fixation (Sinclair and Vadez, 2002; Shibata and Katsuya, 2003). As expected, declining concentrations of K, Ca and Mg indicated dilution response due to stimulated growth and uptake after applications of N and P fertilizers. However, growth dilution observed in pigeonpea under the unfertilized fallow treatment possibly reflects non-nutrient limitations such as moisture because soil P was not improved.

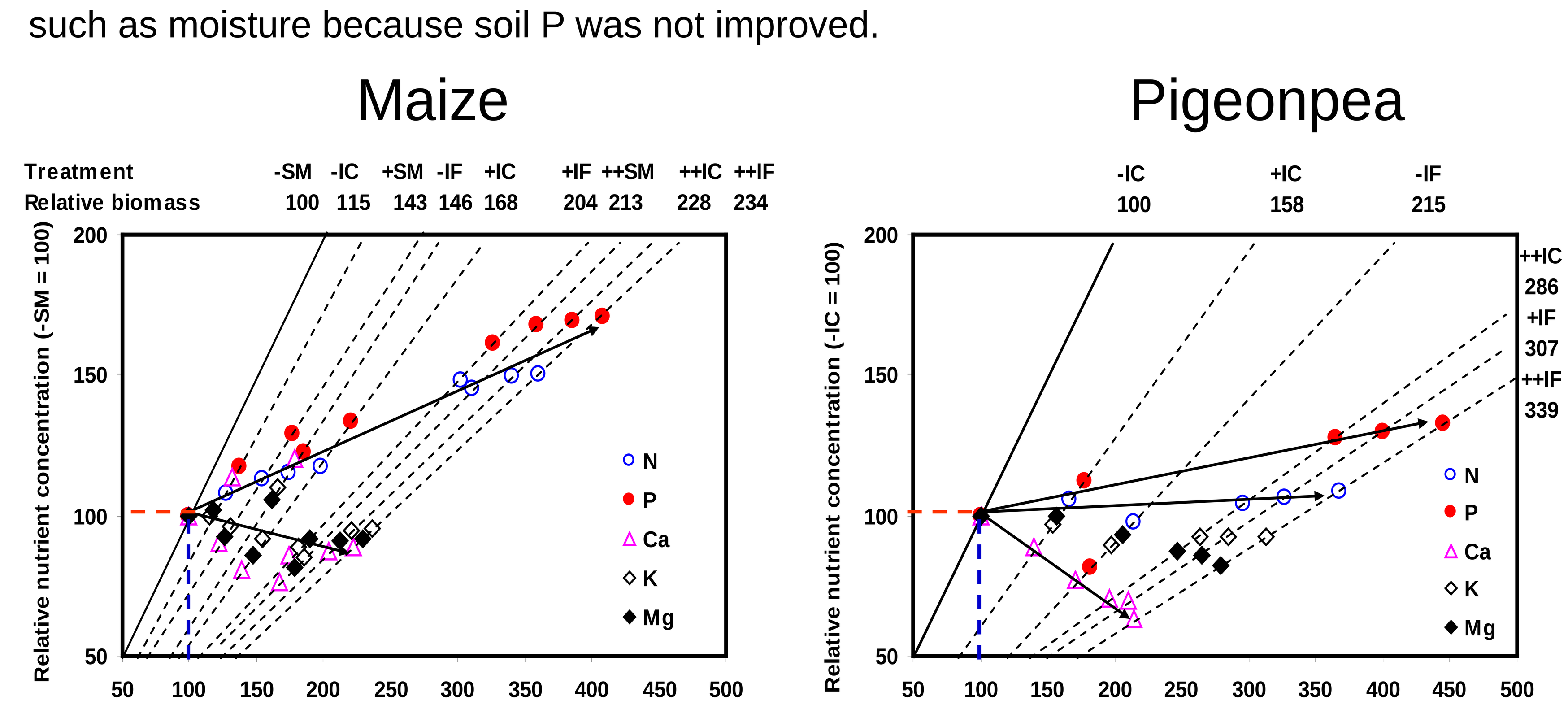

Figure 4. Relative change in biomass, nutrient content , and nutrient concentration of maize and pigeonpea in response to cropping systems (SM = sole maize, IC = intercropping, IF = improved fallow) without (-), with half (+) and with full (++) rates of combined N and P fertilizers. Unfertilized controls (sole maize and improved fallows) are normalized to 100. Nutrient diagnosis is based on shifts (increase, decrease or no change) and magnitude of plant biomass, nutrient concentration, and nutrient content response to treatment effect . Thus, vectors (arrows) depict a primary P deficiency response of maize and pigeonpea (largest increase in concentration, content, and biomass), N sufficiency in pigeonpea (no change in concentration despite increase in content and biomass), and growth of dilution of K, Ca, and Mg (decrease in nutrient concentration due to stimulated growth and uptake).

Conclusions

- Interspecific competition reduced biomass yields of maize and pigeonpea by 30 % and 60 %, respectively.
- A combination of improved fallows and half rates of N and P fertilizers alleviated nutrient competition and optimized crop yield.
- Improved fallows may reduce fertilizer applications by half without compromising crop yield. This would benefit farmers who are concerned with yield loss of maize intercropped with grain legumes, especially in drier seasons, when additional yield from the legume may not offset such losses.

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