Productivity, Weed Dynamics, Nutrient Mining, and Monetary Advantage of Maize-Legume Intercropping in the Eastern Himalayan Region of India

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Abstract: Despite the lack of scientific knowledge on plant density and its influence on component crops in intercropping, risk-averse smallholder farmers unabatedly continue growing crops in a mixture, which finally lowers the productivity of the system. Studies were conducted to evaluate the productivity, weed dynamics, nutrient mining, and monetary advantages in the maize-legume intercropping systems. The highest yield, maize equivalent yield (MEY), and per day productivity were recorded in the plot of sole cowpea (CP) and plots of maize (M) intercropped with CP at row proportions of 1:2 (1M:2CP) and 1M:5CP. Density and biomass of grasses, sedges, and broadleaved weeds were lowest in the plot of sole CP followed by 1M:5CP. Weed smothering efficiency was highest (88%) in the plot of sole CP followed by 1M:5CP, and lowest in the plot of 1M:1frenchbean (FB) (8%). Nitrogen, phosphorus, and potassium were removed less by weeds by intercropping M with CP than with any other legume at row proportions of 1:5. Uptake of nitrogen and potassium was high in the plot of 1M:5 blackgram (BG). The net return, net return per dollar of investment, and marginal returns were high in the plot of 1M:2CP followed by 1M:5CP. Intercropping M with CP at a row proportion of 1:2 gave a higher yield and nutrient uptake, and lowered nutrient mining by weeds with higher returns. In an area where weeds are the major competitor with M for site-specific resources, intercropping M with CP at a row proportion of 1:2 or 1:5 will help to suppress weeds and also to obtain higher MEY. Higher yield gave better returns. Inclusion of legumes increased the uptake of nutrients by maize. This intercropping system may be found efficient in similar situations or land use elsewhere, especially in Southeast Asia.

Key words: Intercropping, Maize equivalent yield, Monetary advantage, Nutrient mining, Productivity, Weed smothering efficiency.

Cultivable area for food production in the eastern Himalayan region of India is static, and it is becoming more important to raise crop productivity in order to meet the food requirements of a rising population (Munda et al., 2009). The region is running deficit of food requirements and is dependent on neighboring state to fulfill their food requirements (Saha and Ghosh, 2010). The three types of land forms, namely slash and burn cultivation locally called “jhum khet”, wet land rice, and terrace land are available and major chunk of the area is under slash and burn cultivation, which are rainfall and uplands in nature (Choudhary et al., 2013). The productivity of this land varies as per the fallow periods. Due to population pressure, there is a huge demand to shorten the fallow period, which is reducing productivity (Darlong, 2008; Choudhary et al., 2012a). Growers fulfill their entire household requirements from these lands (Tawnenga and Tripathi, 1997; Murtem et al., 2008). Although growers are planting many crops on these lands to fulfill their household requirements (Ramakrishnan, 1993; Anonymous, 2005), the productivity of these crops is very low due to severe competition (for space, light, nutrient, and water) among crops due to improper row spacing and overcrowding (Choudhary et al., 2012b). In this situation, intercropping could be a possible answer to meet the household requirements (Shah et al., 2011). Intercropping of legumes with cereals has been recognized as a common practice in India and is one of the most promising options for diversification of sustainable agricultural production systems (Shah et al., 2011). Research on intercropping has revealed how niche differences in crop species can escort to resource capture and conversion of available resources leading to augmented biological efficiency and yield.
improvement (Hussain et al., 2003).

Cereal-legume intercropping is an important agronomic practice, in which the efficiency of the system as a whole is usually better than that of each component independently (Saha et al., 2011). Maize (Zea mays L.), being a rainy season and wide-spaced crop (Shah et al., 2011; Choudhary et al., 2012), gets infested with numerous weeds and is subjected to intense weed competition (Shah et al., 2011). Growers in the eastern Himalayan region rarely use herbicides for controlling weeds, especially in uplands, due to lack of knowledge on the use of herbicides in polyculture. However, the space available between wider rows in maize can be used to grow short-duration legumes, which may smother weeds as well as provide additional yield.

Weeds during the growing period of a crop lower productivity. Weed infestation poses competition for natural and applied inputs, such as space and nutrients. Maize-based intercropping systems are often subjected to severe stress by weeds. Weeds in maize result in an average of 30 – 70% yield loss (Thakur, 1994; Blackshaw et al., 2002; Chikoye et al., 2004). Soil health can be improved by reducing the uptake of nutrients with increased sustainability of productivity (Hugar and Palled, 2008). Large numbers of field studies have been undertaken to compare the monetary advantages of the sole crop yield when grown along with other crops in the system (Banik et al., 2000; Ghosh, 2004; Chalka and Nepal, 2006; Agegnehu et al., 2006). Improper spatial arrangement in intercropping not only reduces the yield components but also induces a high degree of rolling topography (Choudhary et al., 2012b). Productivity per unit area could be increased with suitable crops having higher yield stability and adoption of appropriate intercropping patterns (Pandita et al., 2000). Intercropping will always have an edge over the sole cropping pattern, given that the crops will efficiently use the existing resources (Singh et al., 2005). Legumes in an intercropping system, for example, not only fix atmospheric nitrogen for its use but could offer a part of nitrogen to the companion crop (Blackshaw et al., 2004). A suitable intercropping provides a yield advantage over a sole cropping, because the component crops utilize the natural resources in such a way that they are able to complement each other (Ghosh, 2004; Agegnehu et al., 2006; Choudhary et al., 2012b).

Very limited studies have been conducted in the eastern Himalayan region to improve efficiency in maize-based intercropping systems (Choudhary et al., 2012b). For instance, optimum relative populations in maize-based intercropping systems, especially with legumes, are not known. The choice of crop and row combinations or densities of companion crops is critical for the achievement of high yield and income in intercropping because they offer inter and intra-specific competition (Saka et al., 1993). Studies on the effect of relative component proportions on yield performance of maize-based intercropping have been conducted elsewhere by several researchers (Subasinghe and Senaratne, 2000; Polthanee and Treloges, 2003; Izumi et al., 2004; Rusinamhodzi et al., 2012). However, such information is very limited in the eastern Himalayan region of India. In an appropriate intercropping system, advantages, such as less weed infestation, may also accrue (Blackshaw et al., 2004; Shah et al., 2011).

The ever-escalating costs of inputs in crop production present the need to explore opportunities for reliable and less costly crop production systems. This particularly applies to production of maize and legumes, in which excess rainfall and high humidity create conditions conducive for weed prevalence, which demands high inputs including agrochemicals (Maereka et al., 2009). The high rainfall in the region offers a high degree of weed competition for space and nutrients between the crop and weeds. Such competition with weeds for various available resources resulted in yield reduction of maize. Improper planting geometry of crops offers competition among the crops and finally lowered the yield. The major objective of this study was to improve our understanding in incorporating different legumes with suitable row proportions to obtain a higher system yield with monetary advantage. Therefore, the present study was conducted to evaluate the influence of intercropping of maize with legumes on yield, weed dynamics, nutrient mining, and monetary advantages.

Materials and Methods

1. Experimental site

The field experiment was conducted in April-August 2009 and 2010 at the experimental farm of the Indian Council of Agricultural Research, Research Complex for North Eastern Hilly Region, Basar, West Siang, Arunachal Pradesh, India (27°95’ N latitude and 94°76’ E longitude, 631 m above mean sea level).

2. Climate

The region falls under a humid subtropical climate. The daily temperature during the year varies widely between a minimum of 4°C and a maximum of 35°C. The experimental site receives an average annual rainfall of 2930 mm with a high degree of temporal and spatial variations. The details of the rainfall and temperatures are given in Fig. 1.

3. Soil characteristics

Soil was sampled randomly at 15 cm depths from the experimental block and a composite sample was made for analysis of various parameters. The soil at the experimental site was silty loam in texture, acidic in reaction (pH 5.3), and high in organic carbon (13.2 g kg⁻¹), available nitrogen (N) (alkaline permanganate N, 96.9 mg kg⁻¹), available phosphorus (P) (Bray P, 5.2 mg kg⁻¹), and available potassium (K) (ammonium acetate K, 105.3 mg kg⁻¹).
4. Experimental design

The experiment was laid out in a randomized complete block design with three replications. Thirteen experimental treatments were applied for two successive years (2009 and 2010). The treatments included sole maize (cv. Allrounder) planted at 55,500 plants ha\(^{-1}\) (90 × 30 cm); sole cowpea [Vigna unguiculata (L.) cv. CP04], sole frenchbean [Phaseolus vulgaris (L.) cv. Anupum], and sole blackgram [Vigna mungo (L.) cv. PU31] planted at a density of 333,300 plants ha\(^{-1}\) (30 × 10 cm); and maize (M) intercropped with the legumes, cowpea (CP), frenchbean (FB) and blackgram (BG) at row proportions of 1:1, 1:2 and 1:5. Determining the optimal plant density is the major problem in intercropping to achieve high production. Therefore, the crops were tested with additive and replacement series. Row proportions of 1:1 and 1:2 were used in additive series with 100\% plant density of sole M and 30 and 60\% plant density of the sole legume, respectively. The 1:5 row proportions had 60\% plant density of sole M and 77\% plant density of the sole legume (Fig. 2).

5. Field preparation and cultivation details

The seedbed was prepared using cultivation operations of two disc harrows and one cultivator. Two times more seeds than the expected plant density were planted manually and the emerged plants were thinned to the desired density. M was intercropped with each legume at row proportions of 1:1, 1:2, and 1:5. The space between two rows of M was 90 cm in the plot with a M:legume row proportion of 1:1 and 1:2, and 180 cm with a plant-to-plant spacing of 20 cm in the plot with M:legume row proportion of 1:5 (Fig. 2).

The recommended basal dose of fertilizer was applied at the time of sowing of M (40:60:40 kg N, P, and K ha\(^{-1}\)), CP (25:75:60 kg N, P, and K ha\(^{-1}\)), FB (62.5:100:75 kg N, P, and K ha\(^{-1}\)), and BG (25:60:50 kg N, P, and K ha\(^{-1}\)); and in the M plot, the remaining nitrogen (40 kg N ha\(^{-1}\)) was applied 40 days after sowing (DAS). In intercropping treatments, fertilizers were applied proportionate to the sole optimum population for main and intercrop separately. Maize equivalent yields (MEY) in different treatments were calculated by taking into consideration the price of M and the legume components at the time of their harvest. MEY was calculated as described below:

\[
\text{MEY (kg ha}\^{-1}\text{)} = \text{Maize yield in intercropping system + [intercrop yield × market price of intercrop (US$ kg}\^{-1}\text{)] / price of maize (US$ kg}\^{-1}\text{)}
\]

6. Weed parameters

Weeds were counted from a randomly selected area of 1.0 m\(^2\) in each plot at 60 DAS and grouped into grasses, sedges, and broadleaved weeds. Then, weed roots were separated from the rest of the plants and aboveground parts were dried in an oven at 70\(^\circ\)C for 48 hr and weighed to record dry biomass. Total dry biomass was determined by summing up the dry biomass of each plant. The data on weeds were subjected to square root transformation (\(\sqrt{x} + 0.5\)) to normalize their distribution. Weed smothering efficiency was calculated using weed dry biomass in intercropping plots in comparison to sole M at 60 DAS (Shah et al., 2011). The weed index of different intercropping systems was calculated on the basis of reduction in yield in intercropping systems in comparison to best of the treatment (Shah et al., 2011). Weed smothering efficiency (WSE) and weed index were calculated as described below:

\[
\text{WSE} (%) = \frac{\text{Weed biomass in sole maize - weed biomass in intercrop}}{\text{Weed biomass in sole maize}}
\]

\[
\text{Weed index} = \frac{\text{MEY of sole maize - MEY in intercrop}}{\text{MEY of sole maize}}
\]

7. Nutrient removal

Nutrient content of weeds and nutrient uptake by M plants were estimated by standard laboratory procedures. Vanadomolybdo-phosphoric yellow color method (Richards, 1968) and flame photometric method (Chapman and Pratta, 1961) were used to determine N, P, and K contents. The uptake of each nutrient, N, P and K was computed from the content in the dry biomass of weeds, and that of the grain and stover of crop. The total NPK uptake of each component crop was calculated by
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summing the values for each nutrient, and the values for all the components were summed up to obtain the total uptake of the intercropping system.

8. Monetary advantages

Cost of cultivation, including all the fixed and variable costs, of individual intercropping system was calculated on the basis of price of different inputs used during the experiments. The production of the intercropping system was converted into gross realization ($ ha$^{-1}$) on the basis of prevailing market price (1 US$ = 50 Indian Rupees). The prevalent market price of the produce was considered in calculating gross and net realizations and finally, net returns per dollar of investment were calculated. The additional cost involved in production and additional return gained from the experiment was considered as marginal cost (MC) and marginal return (MR), respectively.

9. Statistical analyses

Different parameters were statistically analyzed using the SAS 9.2 program. The significance of treatment effects was determined by the $F$-test. The significance of the difference between means of two treatments was tested using least significant difference (LSD) at 5% probability level. In

| Row proportion | Details | Line diagram |
|----------------|---------|-------------|
| Sole planting  | Sole maize density (90 × 20 cm): 55,500 plants ha$^{-1}$ | ![Diagram](#) |
| 1:1 row proportion (additive series) | Maize was planted at 90 × 20 cm geometry throughout the experiment, and maize density was maintained at 100%. However, one row of legumes was planted in the space available between maize rows, which was 50% of their sole planting | ![Diagram](#) |
| 1:2 row proportions (additive series) | Maize was planted at 90 × 20 cm geometry throughout the experiment, and maize density was maintained at 100%. However, two rows of a legume were planted in the space available between maize rows, which was 60% of their sole planting | ![Diagram](#) |
| 1:3 row proportions (replacement series) | Maize was planted at 180 × 20 cm geometry throughout the experiment, and maize density was maintained up to 60% of its sole planting due to replacement of one row in between two rows of maize. However, five rows of a legume were planted in the space available between maize rows, which was 77% of their sole planting | ![Diagram](#) |

Fig. 2. Details on row arrangements of intercropping.
most of the cases, the effect of year and/or year × intercropping was significant; therefore, the results were presented separately for years.

Results and Discussion

The effects of year and year by intercropping interaction were significant on grain, stover, and intercrop yield, MEY, land equivalent ratio (LER) and, production efficiency. During the experiments, a higher yield was obtained in 2010 for all and row proportions for better growth and yield. Different letters indicate significant difference according to LSD (0.05).

Table 1. Yield, maize equivalent yield, land equivalent ratio and productivity as influenced by maize-legume intercropping.

| Treatment       | Grain yield (kg ha⁻¹) | Stover yield (kg ha⁻¹) | Intercrop yield (kg ha⁻¹) | Maize equivalent grain yield (kg ha⁻¹) | Land equivalent ratio | Productivity (kg ha⁻¹ day⁻¹) |
|-----------------|-----------------------|------------------------|---------------------------|----------------------------------------|-----------------------|-------------------------------|
|                 | 2009      | 2010      | 2009      | 2010      | 2009      | 2010      | 2009      | 2010      | 2009      | 2010      | 2009      | 2010      | 2009      | 2010      | 2009      | 2010      |
| Sole M          | 4468 ± a  | 4800 ± a  | 8058 ± b  | 8100 ± c  | – ±        | – ±        | 4468 ± c  | 4800 ± e  | 1.00 ± a  | 1.00 ± b  | 30.82 ± c  | 33.57 ± c  |
| Sole CP         | – ±       | – ±       | – ±       | – ±       | 5259 ± d  | 4567 ± c  | 5811 ± c  | 6074 ± e  | 1.00 ± c  | 1.00 ± e  | 68.37 ± c  | 73.18 ± c  |
| Sole FB         | – ±       | – ±       | – ±       | – ±       | 4520 ± b  | 4033 ± c  | 4018 ± c  | 3585 ± e  | 1.00 ± d  | 1.00 ± e  | 51.51 ± c  | 47.80 ± c  |
| Sole BG         | – ±       | – ±       | – ±       | – ±       | 1510 ± b  | 1300 ± c  | 4027 ± c  | 3467 ± e  | 1.00 ± c  | 1.00 ± e  | 36.61 ± c  | 32.40 ± c  |
| 1M:1CP          | 4285 ± b  | 4650 ± b  | 7902 ± b  | 7900 ± c  | 1356 ± b  | 2267 ± c  | 5792 ± c  | 7192 ± e  | 1.22 ± d  | 1.38 ± e  | 39.40 ± c  | 49.44 ± c  |
| 1M:2CP          | 4170 ± b  | 4583 ± b  | 7764 ± b  | 8467 ± c  | 2110 ± d  | 3700 ± c  | 6514 ± c  | 8694 ± e  | 1.34 ± d  | 1.63 ± e  | 43.43 ± c  | 58.75 ± c  |
| 1M:5CP          | 2252 ± d  | 2800 ± d  | 3675 ± d  | 4800 ± f  | 4358 ± b  | 4367 ± c  | 7094 ± c  | 7652 ± e  | 1.34 ± c  | 1.38 ± e  | 46.37 ± c  | 50.67 ± c  |
| 1M:1FB          | 4113 ± b  | 4267 ± d  | 7837 ± b  | 7700 ± d  | 1156 ± c  | 2513 ± c  | 5143 ± c  | 6323 ± e  | 1.18 ± c  | 1.46 ± e  | 34.75 ± c  | 43.61 ± c  |
| 1M:2FB          | 3842 ± c  | 4567 ± c  | 7545 ± a  | 8000 ± a  | 1780 ± c  | 3233 ± c  | 5425 ± c  | 7441 ± e  | 1.26 ± c  | 1.75 ± e  | 36.41 ± c  | 50.62 ± c  |
| 1M:5FB          | 2267 ± d  | 2700 ± d  | 3437 ± d  | 5000 ± f  | 3566 ± c  | 3517 ± c  | 5347 ± c  | 5826 ± e  | 1.30 ± d  | 1.44 ± e  | 36.01 ± c  | 38.58 ± c  |
| 1M:1BG          | 4138 ± b  | 4485 ± b  | 7628 ± a  | 8133 ± a  | 410 ± b  | 470 ± c  | 5281 ± c  | 5377 ± f  | 1.20 ± e  | 1.30 ± f  | 35.35 ± c  | 39.29 ± c  |
| 1M:2BG          | 3733 ± c  | 4600 ± c  | 7380 ± c  | 8290 ± d  | 620 ± b  | 917 ± c  | 5387 ± c  | 7404 ± e  | 1.25 ± d  | 1.66 ± e  | 35.91 ± c  | 47.28 ± c  |
| 1M:5BG          | 2148 ± d  | 2700 ± d  | 3325 ± d  | 5933 ± c  | 1152 ± c  | 1117 ± c  | 5220 ± c  | 5678 ± e  | 1.24 ± d  | 1.42 ± f  | 33.90 ± c  | 37.11 ± b  |
| LSD 0.05        | 195 ± c   | 137 ± c   | 375 ± 13s | 413 ± 12s | 246 ± 12s | 128 ± 12s | 321 ± 12s | 235 ± 12s | 0.06 ± 03 | 2.88 ± 1.92 |

M: maize; CP: cowpea; FB: frenchbean; BG: blackgram; LSD: least significant difference; same letters in same column are not significant and different letters indicate significant difference according to LSD (0.05).

Price of the produce (Indian Rupees c⁻¹): M: 9000; CP: 10000; FB: 8000; BG: 24000; [1US$=50 Indian Rupees].

The effects of year and year by intercropping interaction were significant on grain, stover, and intercrop yield, MEY, land equivalent ratio (LER) and, production efficiency. During the experiments, a higher yield was obtained in 2010 for all the crops with their respective row proportions in comparison with 2009. This was mainly because of the considerably higher rainfall received in 2010, which might have favored the crops and row proportions for better growth and yield.

1. Yield, maize equivalent yield, and productivity

The individual yield of M was higher under the sole M system, and the yield was similar to that obtained by intercropping M with a legume at row proportions of 1:1 and 1:2 (Table 1). Increase in yield under sole M was due to the fact that the wider available space in sole M reduced the competition for light and nutrients, which probably provided favorable physical environments to produce higher yield. However, yield of M was reduced in the plot of M intercropped with a legume at a row proportion of 1:5. This might be due to the reduction in plant population of M in these row combinations. Increase in yield under sole M was also observed in earlier studies (Ullah et al., 2007; Hugar and Palled, 2008).

The grain yield of M intercropped with FB or BG at a row proportion of 1:2 was higher in 2010 than in 2009. This might be due to the lower density and dry biomass of weeds in these treatments in 2009 (Tables 2–4). The grain yield in these treatments may also have been higher in 2010 because of lower density of N, P, and K by weeds. This was mainly due to the lower density and dry biomass of weeds, which resulted in lower nutrient mining in 2010 than in 2009, and also resulted in higher uptake of nutrients by crops (Table 5). Two-row proportions of legumes can fix more atmospheric N than a single row proportion, and also higher row proportions of legumes might transform and mobilize the inherent nutrients from the rhizosphere, which resulted in higher availability of nutrients for crop plants. In 2009, the effect of higher row proportions was less pertinent but in 2010, due to combined effects of both the years, the availability of nutrients became more (Table 5). Maize is an exhaustive crop and with the availability of higher nutrients, nutrient uptakes increased (Table 5), which, increased growth and yield attributes, and led to higher grain yield (Table 1).

The yield was high in the plot of M intercropped with CP, FB, and BG in the row proportions of 1:5 followed by 1:2 and 1:1. The higher economic yield of intercrop obtained in the plot of M to legume row proportion of 1:5 was mainly attributed to the lower plant stand of M and larger population of legumes. The highest M grain yield and intercrop yield were obtained by intercropping M with CP followed by BG. However, MEY was higher in the plot with M intercropped with CP at the row proportion of 1:2 (1M:2CP) followed by 1M:5CP and 1M:1CP, and 1M:2FB. However, the average increment in MEY was higher in the plots with CP followed by BG and FB. The plot 1M:2CP followed by 1M:5CP and 1M:1CP, and
Table 2. Density and biomass of grass, sedge, and broadleaved weeds at 60 days after sowing as influenced by maize-legume intercropping (original values).

| Treatment     | Weed density (no. m<sup>−2</sup>) | Weed biomass (g m<sup>−2</sup>) |
|---------------|-----------------------------------|---------------------------------|
|               | Grass   | Sedge  | Broadleaved | Grass   | Sedge  | Broadleaved |
|               | 2009    | 2010   | 2009  | 2010   | 2009    | 2010 |
| Sole M        | 43.67   | 35.33  | 22.33 | 15.00  | 82.67   | 82.00 |
| Sole CP       | 6.33    | 6.00   | 4.00  | 4.00   | 11.33   | 7.33 |
| Sole FB       | 14.67   | 13.00  | 7.67  | 11.00  | 42.67   | 36.67 |
| Sole BG       | 13.00   | 8.67   | 6.00  | 6.00   | 18.67   | 16.33 |
| 1M:1CP        | 30.00   | 31.33  | 20.67 | 10.67  | 62.33   | 63.67 |
| 1M:2CP        | 8.00    | 7.33   | 4.00  | 5.33   | 18.00   | 12.33 |
| 1M:5CP        | 5.67    | 5.33   | 3.00  | 4.00   | 14.33   | 11.00 |
| 1M:1BG        | 41.67   | 33.33  | 15.67 | 22.00  | 78.67   | 70.67 |
| 1M:2BG        | 28.00   | 21.00  | 21.33 | 9.00   | 47.33   | 59.33 |
| 1M:5BG        | 20.67   | 17.00  | 11.33 | 7.67   | 42.33   | 49.67 |
| 1M:1CP        | 29.33   | 31.00  | 15.00 | 12.00  | 82.00   | 80.67 |
| 1M:2BG        | 20.67   | 20.67  | 10.33 | 8.67   | 50.00   | 56.00 |
| 1M:5BG        | 16.67   | 13.00  | 8.00  | 6.67   | 27.33   | 26.67 |

M: maize; CP: cowpea; FB: frenchbean; BG: blackgram; LSD: least significant difference; same letters in same column are not significant and different letters indicate significant difference according to LSD (0.05); Values of weed density and weed dry weight are subjected to square root transformation (√{x + 0.5}).

Table 3. Density and biomass of grass, sedge and broadleaved weeds at 60 days after sowing as influenced by maize-legume intercropping (transformed values).

| Treatment     | Weed density (no. m<sup>−2</sup>) | Weed biomass (g m<sup>−2</sup>) |
|---------------|-----------------------------------|---------------------------------|
|               | Grass   | Sedge  | Broadleaved | Grass   | Sedge  | Broadleaved |
|               | 2009    | 2010   | 2009  | 2010   | 2009    | 2010 |
| Sole M        | 6.62*   | 5.97*  | 4.78* | 3.93*  | 9.11*   | 9.08* |
| Sole CP       | 2.61*   | 2.54*  | 2.11* | 2.10*  | 3.44*   | 2.78* |
| Sole FB       | 3.88*   | 3.66*  | 2.85* | 3.38*  | 6.55*   | 6.09* |
| Sole BG       | 3.67*   | 3.03*  | 2.53* | 2.53*  | 4.37*   | 4.10* |
| 1M:1CP        | 5.51*   | 5.63*  | 4.63* | 3.33*  | 7.92*   | 8.01* |
| 1M:2CP        | 2.89*   | 2.80*  | 2.11* | 2.40*  | 4.30*   | 3.57* |
| 1M:5CP        | 2.48*   | 2.42*  | 1.86* | 2.11*  | 3.83*   | 3.39* |
| 1M:1BG        | 6.49*   | 5.81*  | 3.76* | 4.73*  | 8.89*   | 8.43* |
| 1M:2BG        | 5.34*   | 4.63*  | 4.66* | 3.08*  | 6.91*   | 7.73* |
| 1M:5BG        | 4.60*   | 4.18*  | 3.44* | 2.85*  | 6.54*   | 7.08* |
| 1M:1BG        | 5.46*   | 5.61*  | 3.93* | 3.53*  | 9.08*   | 9.01* |
| 1M:2BG        | 4.60*   | 4.00*  | 3.29* | 3.02*  | 7.10*   | 7.52* |
| 1M:5BG        | 4.14*   | 3.67*  | 2.91* | 2.67*  | 5.26*   | 5.20* |
| LSD 0.05      | 0.55    | 0.52   | 0.43  | 0.54   | 0.66    | 0.54 |

M: maize; CP: cowpea; FB: frenchbean; BG: blackgram; LSD: least significant difference; values in same column followed by the same letter are not significantly different, whereas different letters indicate significant differences (P<0.05).

1M:2FB and increased yield to the extent of 59, 40 and 39%, respectively, over sole M in both years. Sole FB and sole BG had a negative effect on grain yield than the sole M. This might be because the individual performance of these crops did not reach the desired level. A previous study indicated that scientifically, intercropping of pulses with cereals and other non-legume companion crops has certain in-built advantages over sole cropping (Velautham and Somasundaram, 2000). In addition, legumes leave 20 – 25 kg ha<sup>−1</sup> of N in the soil at the time of harvest, which is utilized by the subsequent crop and the tremendous leaf fall forms the best source of organic matter (Yilmaz et al., 2008).
higher LER in these treatments.

In 2010, yields of all crops were comparatively lower than in 2009, but yields of FB and BG at 1M:2 FB 1M:2BG were exceptionally higher, which resulted in higher LER in these treatments.

Table 4. Total weed density, total weed biomass, smothering efficiency at 60 days after sowing and weed index as influenced by maize-legume intercropping.

| Treatment        | Total weed density (no. m\(^{-2}\)) | Total weed biomass (g m\(^{-2}\)) | Weed smothering efficiency (%) | Weed index |
|------------------|-------------------------------------|-----------------------------------|--------------------------------|------------|
|                  | 2009      | 2010      | 2009      | 2010      | 2009      | 2010      | 2009      | 2010      |
| Solo M           | 12.21     | 11.53     | 5.84      | 5.80      | –         | –         | 0.37      | 0.45      |
| Solo CP          | 4.70      | 4.21      | 2.16      | 2.04      | 87.53     | 88.93     | 0.18      | 0.30      |
| Solo FB          | 8.08      | 7.81      | 3.75      | 3.60      | 59.68     | 62.25     | 0.43      | 0.59      |
| Solo BG          | 6.17      | 5.61      | 3.19      | 3.05      | 70.99     | 73.40     | 0.43      | 0.60      |
| 1M:1CP           | 10.65     | 10.30     | 4.99      | 4.80      | 26.73     | 31.80     | 0.18      | 0.18      |
| 1M:2CP           | 5.54      | 5.04      | 2.80      | 2.64      | 77.89     | 80.43     | 0.08      | –         |
| 1M:5CP           | 4.84      | 4.56      | 2.42      | 2.26      | 83.84     | 85.99     | –         | 0.12      |
| 1M:1FB           | 11.59     | 11.25     | 5.64      | 5.53      | 7.05      | 9.04      | 0.28      | 0.27      |
| 1M:2FB           | 9.85      | 9.48      | 4.71      | 4.53      | 35.57     | 39.65     | 0.24      | 0.14      |
| 1M:5FB           | 8.65      | 8.65      | 4.29      | 4.14      | 46.84     | 49.67     | 0.23      | 0.33      |
| 1M:1BG           | 11.26     | 11.14     | 5.37      | 5.18      | 15.45     | 20.26     | 0.26      | 0.34      |
| 1M:2BG           | 9.40      | 9.26      | 4.45      | 4.25      | 42.52     | 46.92     | 0.24      | 0.19      |
| 1M:5BG           | 6.96      | 6.84      | 3.54      | 3.35      | 64.00     | 67.73     | 0.26      | 0.35      |
| LSD at 0.05      | 0.59      | 0.47      | 0.33      | 0.16      | 0.59      | 0.47      | 0.33      | 0.16      |

M: maize; CP: cowpea; FB: frenchbean; BG: blackgram; LSD: least significant difference; same letters in same column are not significant and different letters indicate significant difference according to LSD (0.05); Values of weed density and weed biomass are subjected to square root transformation (√x + 0.5).

Table 5. Nutrient removal by weeds and uptake by maize (kg ha\(^{-1}\)) as influenced by maize-legume intercropping.

| Treatment | Nutrient removal by weeds (kg ha\(^{-1}\)) | Nutrient uptake by crops (kg ha\(^{-1}\)) |
|-----------|-------------------------------------------|------------------------------------------|
|           | Nitrogen | Phosphorus | Potassium | Nitrogen | Phosphorus | Potassium |
|           | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| Solo M    | 9.00  | 7.82  | 3.63  | 3.40  | 9.26  | 8.45  | 121.00 | 116.67 | 24.00 | 26.00 | 138.67 | 135.67 |
| 1M:1CP    | 7.12  | 6.93  | 3.16  | 2.84  | 8.19  | 7.80  | 134.67 | 141.67 | 29.00 | 33.67 | 154.33 | 155.33 |
| 1M:2CP    | 6.76  | 6.77  | 3.08  | 2.72  | 8.00  | 7.47  | 148.33 | 155.67 | 30.00 | 31.00 | 158.67 | 164.33 |
| 1M:5CP    | 6.61  | 6.41  | 2.93  | 2.57  | 7.80  | 7.22  | 164.33 | 167.00 | 33.67 | 38.67 | 166.33 | 167.00 |
| 1M:1FB    | 7.90  | 6.89  | 3.79  | 3.27  | 7.92  | 7.90  | 128.00 | 140.67 | 25.00 | 24.00 | 142.33 | 148.33 |
| 1M:2FB    | 7.31  | 6.69  | 3.60  | 2.88  | 8.38  | 7.80  | 134.67 | 136.00 | 27.00 | 31.00 | 147.00 | 144.00 |
| 1M:5FB    | 6.96  | 6.62  | 3.25  | 2.82  | 8.16  | 7.62  | 149.33 | 157.67 | 30.67 | 32.00 | 155.00 | 156.33 |
| 1M:1BG    | 7.27  | 7.13  | 3.51  | 3.01  | 8.69  | 8.07  | 146.33 | 144.33 | 31.33 | 30.00 | 152.00 | 149.33 |
| 1M:2BG    | 7.12  | 6.96  | 3.38  | 2.86  | 8.17  | 7.73  | 167.00 | 173.67 | 33.33 | 38.00 | 157.00 | 158.00 |
| 1M:5BG    | 6.83  | 6.64  | 2.25  | 2.79  | 7.97  | 7.67  | 177.33 | 179.33 | 33.67 | 39.33 | 164.67 | 174.33 |
| LSD 0.05  | 0.28  | 0.62  | 0.75  | 0.17  | 0.91  | 0.42  | 10.43  | 8.10  | 5.27  | 6.68  | 7.83  | 9.00  |

M: maize; CP: cowpea; FB: frenchbean; BG: blackgram; LSD: least significant difference; same letters in same column are not significant and different letters indicate significant difference according to LSD (0.05).

which also resulted in higher MEY in 2010 than 2009.

Table 1 clearly illustrated that the LER was higher in 2010 than in 2009 for all the row proportions of intercrops. This was mainly due to the higher yield of sole crop and intercrop. However, in 2009, the LER in the plots of 1M:2CP and 1M:5CP was similar but significantly higher than that in the other combinations. This was due to greater individual yield of M and CP in the 1M:2CP and 1M:5CP. In 2010, yields of all crops were comparatively higher than in 2009, but yields of FB and BG at 1M:2 FB 1M:2BG were exceptionally higher, which resulted in higher LER in these treatments.

Intercropping provided higher productivity (kg ha\(^{-1}\) day\(^{-1}\)) compared to sole M cropping (Table 1). The highest productivity was obtained at the maize to legume row proportion of 1:2 followed by 1:1 and 1:5. Productivity was highest in the plot of M intercropped with CP followed by FB and BG as compared to sole M. Similar findings were also obtained by Hussain et al. (2003), Hugar and Palled (2008), and Haque et al. (2008) in M intercropped with soybean and green gram.

In general, lower yield was obtained in first year (2009). This response was probably because of untimely rain, which made conducive conditions for the growth of...
disease and insect pests and unfavorable conditions for crop growth, yield attributes, and ultimately resulting in poor crop yield than in 2010.

2. Weed dynamics

The weed density was significantly influenced by intercropping of M with different legumes in various row proportions (Tables 2 and 3). The plot of 1M:5CP had the lowest density of grass (5.5 m$^{-2}$) and sedge (3.5 m$^{-2}$) whereas the plot of sole CP (9.3 m$^{-2}$) had the least broadleaved weeds in both years. The highest density of grass (39.5 m$^{-2}$), sedge (18.7 m$^{-2}$), and broadleaved weeds (82.3 m$^{-2}$) were recorded in the sole M plot. Similarly, the weed biomass of grass (0.87 g m$^{-2}$), sedge (0.45 g m$^{-2}$), and broadleaved weeds (2.62 g m$^{-2}$) was the lowest in the plot of sole CP followed by 1M:5CP. The weed biomass of grass (12.68 g m$^{-2}$), sedge (4.72 g m$^{-2}$), and broadleaved weeds (16.02 g m$^{-2}$) was highest in the plot of sole M followed by 1M:1FB. The weed biomass of grass was highest in the plot of sole M. The lower weed biomass in CP plots might be due to their early establishment on the land surface, which resulted in smothering of weeds. The intercrops, which grew vigorously during the early stages and covered the soil with their canopy, resulted in reduced weed growth under intercropped situations (Rajagopal et al., 1998). A large or dense plant canopy has been shown to effectively suppress the germination and growth of weeds through limiting the amount of light that reaches to the ground (Jayakumar et al., 2008). Weed seeds require light for germination (Chauhan and Johnson, 2010; Chauhan et al., 2012). The growth of weeds has been reported to be reduced by filtration of light by a plant canopy (Mallikarjuna et al., 2011).

There was a significant and positive linear relation between weed density and weed biomass with $R^2 = 0.98$ (Fig. 3). This clearly indicates that as weed density increased weed biomass increased linearly. In contrary to this, production efficiency negatively correlated with weed biomass, where coefficient of determination was $R^2 = 0.44$ (Fig. 4).

The average of the values in 2009 and 2010 showed that the sole CP had the highest weed smothering efficiency of 88% followed by the intercropped plot 1M:5CP (85%) (Table 4). The lowest weed smothering was recorded in the 1M:1FB (8%) plot. Intercropping with CP and BG significantly reduced the weed population and weed biomass than intercropping with FB or with sole M (Table 3). Among the different row proportions, 1M:5CP was the most effective in suppressing weeds, which recorded minimum weed density and weed biomass at 60 DAS followed by 1M:2CP and 1M:5BG over sole M. This is only due to the fact that the lower availability of space and light leads to lower density of weeds and ultimately lower weed biomass by intercropping and also suppression of weeds by early canopy cover. These findings are in conformity with those reported by Haque et al. (2008) and Tripathi et al. (2009). The reduction in weed density and weed biomass in intercropping systems using CP and BG may be attributed to the shading effect and competition stress created by the canopy of CP and BP having suppressive effect on associated weeds. Similar results were also reported by Singh et al. (1988) and Pandey et al. (2003).

The weed index was higher in the sole FB and BG plots followed by sole M plot. However, the weed index was lowest in the plots of M intercropped with CP followed by FB and BG (Table 4). The growth of weeds was reduced by filtration of light by a plant canopy. Therefore, the intercropping of M with CP and BG could have had a synergistic effect in reducing the amount of light penetrating the canopy, resulting in lower weed density and weed biomass in the plot with M intercropped with legumes compared to the sole M plot (Maereka et al., 2009). These results suggest that the canopy became denser with increasing intercrop density; thus weed density and weed biomass were lowered by intercropping of M with legumes at higher intercrop densities. Shading by the crop canopy has been recognized as the main factor promoting weed suppression in intercrops (Baumann et al., 2001).
3. Nutrient removal by weeds

The amount of N, P, and K removed by weeds was lowest in the plot of M intercropped with a legume at a row proportion of 1:5 followed by 1:2 and 1:1 in this order compared with the sole M plot (Table 5). The amount of nutrients removed by weeds was smallest in the plots of M intercropped with CP followed by BG and FB in this order. The amount of P removed was also in this order. However, the amount of P removed by weeds was largest in the sole M plot. The removal of K showed a trend similar to that of P; CP removed less K than BG or FB. The nutrient removal was directly related to weed density and weed biomass. Low weed density and biomass resulted in less removal of nutrients by weeds. The amount of N removed by weeds was lowest in 1M:5CP (29%) followed by 1M:2CP, and 1M:5FB (25, 24, and 24%, respectively) over sole M. The data clearly depict that the amount of N removed by weeds was the lowest in the plots intercropped with CP followed by BG and FB in this order (Table 5). The amount of N removed by weeds was highest in the plots of M intercropped with a legume at a row proportion of 1:5 followed by 1:2 and 1:1 in this order. The amounts of P and K removed showed a trend similar to that of N. The lowest P removal was recorded in the plot of 1M:5BG (40%) followed by 1M:5CP (28%). However, the plot of 1M:5CP gave 18% lower K removal by weeds followed by 1M:2CP and 1M:5BG (15 and 13%, respectively) over removal by weeds in the sole M plot. A similar finding was reported by Chalka and Nepalia (2006). Eskandari and Ghanbari (2010) reported that as weed biomass increased nutrient removal increased significantly ($P < 0.05$). This might be due to higher nutrient uptake by plants in different parts.

4. Nutrient uptake by crops

N uptake by M was influenced by the combination and proportion of intercropping (Table 5). N uptake was highest in the plot of 1M:5BG (50%) followed by 1M:2BG (43%) and 1M:5CP (39%). Among the intercrops, 1M:1FB gave 13% higher N uptake than the sole M in both 2009 and 2010 (Table 5). Similar to the uptake of N, the uptake of P and K was also higher in the plot of M intercropped with BG followed by CP and lowest with FB. The plot of 1M:2BG gave 46% higher P followed by 1M:5BG (43%) and 1M:5CP (45%). Apart from these proportions, 1M:1FB showed 1.6% lower uptake of P than the sole M. K uptake was 24% higher in 1M:5BG followed by 1M:5CP (22%). Intercropping M with FB gave marginally higher K uptake over sole M in both 2009 and 2010. Such higher uptake might be due to the better availability and supply of N by the legume intercropped with M. Similar to uptake of N, uptake of P and K showed a similar trend. Intercropping with legumes caused the wide range of microbes of plant rhizosphere to mobilize the inherent P and K and nutrients increasing their availability and uptake by plants. An earlier study also revealed greater nutrient absorption in the M-legume intercropping system than the sole M (Chalka and Nepalia, 2006). Intercropping M with legumes had a synergetic effect and suppressed weed growth, which increased the uptake of N, P, and K (Katsaruware and Manyanhaire, 2009; Maereka et al., 2009; Eskandari and Ghanbari, 2010).

5. Monetary advantage

The purpose of intercropping is not only to grow more than one crop together, but also to obtain higher productivity per unit area with better monetary returns. Results indicated that among the row proportions, 1M:5CP gave high returns of CP followed by 1M:2CP and 1M:1CP, but the net return per dollar investment of FB were in the order of 1M:2FB > 1M:1FB > 1M:5FB (Table 6). In contrast to CP and FB, BG gave high net return per dollar in the order of 1:2 > 1:5 > 1:1. The M:legume row proportion of 1:5 and 1:2 was suggested to have economic advantage. This implies that higher plant density and optimum spacing in...
the above crop ratios provided effective utilization of resources, such as land nutrients etc. Hence, efficiency in productivity and profitability can be accounted in these planting patterns (Santalla et al., 2001). The marginal cost of the sole crop of CP, FB, and BG was lower than the cost for production of sole M. All the intercrops showed additional yield advantages and therefore marginal returns were higher than the sole M. Apart from this, intercropping with different crops and their row proportion also required lower cost than the sole M due to drastic reduction of the cost involved in weeding, except in 1M:2CP. This was due to additional cost involved in more labor required for additional plucking and also pesticides required for the control of pests and diseases. However, the highest marginal return was obtained with 1M:2CP followed by 1M:5CP.

**Conclusions**

The results of our study clearly showed the significant impact of different row proportions of legumes intercropped with M on productivity, weed dynamics, nutrient uptake by the crop and weeds, and the monetary advantages. In an area where weeds are the major competitor with M for site-specific resources and where the use of herbicides is not feasible, intercropping of M with CP at the row proportions of 1:2 and 1:5 was found to suppress weeds and also to obtain higher MEY. Higher yield improved the monetary returns and soil health. Intercropping with a legume increased the uptake of nutrients by M. Use of legumes in M-based intercropping can also curtail the use of inorganic nutrients and larger requirements of nutrient may be fulfilled through biological N fixation. Further studies are needed to determine how inorganic nutrient can be minimized by intercropping with a legume.
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