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## Influence of crop geometry on nutrient concentration and uptake in maize-legume intercropping in eastern India

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### Abstract

A field study on intercropping maize with legumes namely, green gram and cowpea was conducted with the objective to determine the effect of different stands arrangements on nutrient concentration and nutrient uptake at the ICAR-Indian Agricultural Research Institute, Jharkhand during the rainy (*khari*) season of 2022. Nine ‘Treatments’ viz., pure stands of maize, green gram and cowpea, and intercrop stands with green gram or cowpea at Additive stand (AS), Replacement stand-I (RS-I) and Replacement stand-II (RS-II) was laid out in a randomized complete block design in 5 replications. Results showed the grain nutrient concentration of maize was recorded highest in Maize + Cowpea (RS-II) stands analysing nitrogen concentration in grain (1.03%) and stover (0.35%); phosphorus concentration in grain (0.342%) and stover (0.201%); potassium concentration in grain (0.367%) and stover (1.068%); sulphur concentration in grain (0.098%) and stover (0.152%); zinc concentration in grain (22.8 mg/kg) and stover (38.8 mg/kg); iron concentration in grain (27.4 mg/kg) and stover (183.7 mg/kg); copper concentration in grain (2.2 mg/kg) and stover (8.7 mg/kg); manganese concentration in grain (3.3 mg/kg) and stover (33.9 mg/kg) and similar trend was also followed in nutrient uptake. Thus, intercropping maize with cowpea at Replacement stands-II could ensure higher nutrient concentration and residual nutrients than traditionally growing pure stand of maize alone.

**Keywords:** Nutrient concentration, nutrient uptake, Intercropping stands

### Introduction

Maize (*Zea mays* L.) is one of the world's most important cereal crops, serving as a major source of food, feed and industrial raw material. However, sustaining maize productivity in the eastern Indo-Gangetic Plains remains challenging because of declining soil fertility, imbalanced fertilizer use, low nutrient-use efficiency and smallholder-dominated production systems (Begam *et al.*, 2024) <sup>[1]</sup>. These challenges are further intensified by increasing climatic variability and rising input costs, necessitating the adoption of resource-efficient and sustainable cropping systems (Rani *et al.*, 2022) <sup>[7]</sup>. Cereal-legume intercropping has emerged as an ecologically sound strategy for improving productivity while maintaining soil fertility (Talukdar *et al.*, 2023) <sup>[10]</sup>. Complementary use of growth resources by cereals and legumes enhances the efficiency of light interception, water utilization and nutrient acquisition compared with sole cropping (Zheng *et al.*, 2022) <sup>[13]</sup>. Legumes contribute biologically fixed nitrogen, improve rhizosphere processes and mobilize relatively less available nutrients, thereby increasing nutrient availability to the associated cereal crop (Schwerdtner and Spohn, 2021) <sup>[9]</sup>. These positive interactions frequently result in greater system productivity and improved nutrient-use efficiency while reducing dependence on synthetic fertilizers (Dong *et al.*, 2022) <sup>[2]</sup>. Among the factors determining the success of maize–legume intercropping, crop geometry plays a pivotal role by regulating the spatial arrangement of component crops. Appropriate row arrangements modify canopy architecture, root distribution, interspecific competition for growth resources and efficient acquisition and utilization of nutrients (Raza *et al.*, 2019) <sup>[8]</sup>. Nutrient concentration and nutrient uptake are key indicators for assessing the efficiency of resource utilization in intercropping systems (Yadav *et al.*, 2022) <sup>[11]</sup>. Enhanced soil enzyme activities and greater nutrient cycling under maize-legume systems further contribute to improved nutrient availability

and uptake (Zhao *et al.*, 2022) <sup>[12]</sup>. Despite considerable research on maize-based intercropping, information on the influence of crop geometry on nutrient concentration and uptake in Eastern India remains limited. Understanding how different crop geometries influence nutrient accumulation in maize-legume systems is therefore essential for improving nutrient-use efficiency and sustainable crop production. The findings provide valuable insights for designing efficient maize-legume intercropping systems with optimized crop geometry that enhance nutrient-use efficiency under resource-constrained conditions in Eastern India.

## Materials and Methods

The field experiment was conducted during the rainy (*khari*) season of 2022 at the research farm ICAR-Indian Agricultural Research Institute, Jharkhand. The soil was sandy loam, acidic in reaction (pH 5.4) analysing less contents of organic carbon (0.29%), microbial biomass carbon (138.32 µg MBC/g soil), dehydrogenase activity (27.57 µg TPF/g soil/ day), available nitrogen (128.4 kg/ha), available phosphorus (6.62 kg/ha), available potassium (135.8 kg/ ha), available sulphur (21.84 kg/ha), available zinc (0.73 kg/ha), available iron (11.29 mg/kg), available copper (0.26 mg/kg) and available manganese (6.51 mg/kg). Nine 'Treatments' viz., T<sub>1</sub>: Pure stands of maize, T<sub>2</sub>: Pure stands of green gram, T<sub>3</sub>: Pure stands of cowpea, T<sub>4</sub>: Additive stand (AS) of Maize + Green gram, T<sub>5</sub>: Replacement stand-I (RS-I) of Maize + Green gram, T<sub>6</sub>: Replacement stand-II (RS-II) of Maize + Green gram, T<sub>7</sub>: Additive stand (AS) of Maize + Cowpea, T<sub>8</sub>: Replacement stand-I (RS-I) of Maize + Cowpea and T<sub>9</sub>: Replacement stand-II (RS-II) of Maize + Cowpea was laid out in a randomized complete block design in 5 replications. Treatment differences were compared at 5% level of significance ( $P < 0.05$ ) for deriving a logical inference of the study. Concentration and uptake of nitrogen, phosphorus, potassium, sulphur, iron, zinc, copper and manganese were also analyzed in grain and stover.

## Nutrient concentration and uptake by crop

### Plant nutrient analysis

#### Collection and preparation of plant samples

Grain and straw samples of individual treatment were dried in an oven at 60 to 70 °C till constant weight was obtained and ground to fine powder in stainless steel Willey mill. The powdered plant samples were used for nutrient analysis.

### Nitrogen concentration and uptake

Nitrogen concentration in grain and straw was expressed in percentage and determined by modified Kjeldahl method (Prasad *et al.*, 2006) <sup>[6]</sup>. Nitrogen uptake was calculated by using the following equations:

$$\text{N uptake (kg/ha) in grain/straw} = [\text{N\% in grain or straw} \times \text{grain or straw yield (kg/ha)}]$$

$$\text{Total uptake of N (kg/ha)} = \text{N uptake in grain} + \text{N uptake in straw}$$

### Phosphorus concentration and uptake

Phosphorus concentration in grain and straw was determined by using the vanadomolybdophosphoric acid yellow colour method at 420 nm wavelength on a UV-VIS spectrophotometer (Jackson, 1973) <sup>[4]</sup>. Total phosphorus uptake (kg/ha) was calculated by multiplying P content with the dry matter yield.

$$\text{P uptake (kg/ha) in grain/straw} = [\text{P\% in grain or straw} \times \text{grain or straw yield (kg/ha)}]$$

$$\text{Total uptake of P (kg/ha)} = \text{P uptake in grain} + \text{P uptake in straw}$$

### Potassium concentration and uptake

Potassium concentration in grain and straw was determined by flame photometer (Prasad *et al.*, 2006) <sup>[6]</sup>. Potassium uptake was calculated by using the following expression:

$$\text{K uptake (kg/ha) in grain/straw} = [\text{K\% in grain or straw} \times \text{grain or straw yield (kg/ha)}]$$

$$\text{Total uptake of K (kg/ha)} = \text{K uptake in grain} + \text{K uptake in straw}$$

### Sulphur concentration and uptake

Sulphur concentration in grain and straw was determined by spectrophotometer (Prasad *et al.*, 2006) <sup>[6]</sup>. Sulphur uptake was calculated by using the following expression:

$$\text{S uptake (kg/ha) in grain/straw} = [\text{S\% in grain or straw} \times \text{grain or straw yield (kg/ha)}]$$

$$\text{Total uptake of S (kg/ha)} = \text{S uptake in grain} + \text{S uptake in straw}$$

### Zinc concentration and uptake

Zinc concentration in grain and straw was determined by Atomic absorption spectrophotometer (Prasad *et al.*, 2006) <sup>[6]</sup>. Zinc uptake was calculated by using the following expression:

$$\text{Zn uptake (kg/ha) in grain/straw} = [\text{Zn (mg/kg) in grain or straw} \times \text{grain or straw yield (kg/ha)}]$$

$$\text{Total uptake of Zn (kg/ha)} = \text{Zn uptake in grain} + \text{Zn uptake in straw}$$

### Iron concentration and uptake

Iron concentration in grain and straw was determined by Atomic absorption spectrophotometer (Prasad *et al.*, 2006) <sup>[6]</sup>. Iron uptake was calculated by using the following expression:

$$\text{Fe uptake (kg/ha) in grain/straw} = [\text{Fe (mg/kg) in grain or straw} \times \text{grain or straw yield (kg/ha)}]$$

$$\text{Total uptake of Fe (kg/ha)} = \text{Fe uptake in grain} + \text{Fe uptake in straw}$$

### Copper concentration and uptake

Copper concentration in grain and straw was determined by Atomic absorption spectrophotometer (Prasad *et al.*, 2006) <sup>[6]</sup>. Copper uptake was calculated by using the following expression:

$$\text{Cu uptake (kg/ha) in grain/straw} = [\text{Cu (mg/kg) in grain or straw} \times \text{grain or straw yield (kg/ha)}]$$

$$\text{Total uptake of Cu (kg/ha)} = \text{Cu uptake in grain} + \text{Cu uptake in straw}$$

### Manganese concentration and uptake

Manganese concentration in grain and straw was determined by flame Atomic absorption spectrophotometer (Prasad *et al.*, 2006)

[6]. Manganese uptake was calculated by using the following expression:

Mn uptake (kg/ha) in grain/straw = [Mn (mg/kg) in grain or straw × grain or straw yield (kg/ha)]

Total uptake of Mn (kg/ha) = Mn uptake in grain + Mn uptake in straw

## Results and Discussion

### Effect on Nutrient concentration

#### Maize

Results showed the grain nutrient concentration of maize was recorded highest in Maize + Cowpea (RS-II) stands analysing nitrogen concentration in grain (1.03%) and stover (0.35%); phosphorus concentration in grain (0.342%) and stover (0.201%); potassium concentration in grain (0.367%) and stover (1.068%); sulphur concentration in grain (0.098%) and stover (0.152%); zinc concentration in grain (22.8 mg/kg) and stover (38.8 mg/kg); iron concentration in grain (27.4 mg/kg) and stover (183.7 mg/kg); copper concentration in grain (2.2 mg/kg) and stover (8.7 mg/kg); manganese concentration in grain (3.3 mg/kg) and stover (33.9 mg/kg). The lowest values were estimated with pure stand of maize analysing nitrogen concentration in grain (0.94%) and stover (0.29%); phosphorus concentration in grain (0.319%) and stover (0.132%); potassium concentration in grain (0.331%) and stover (0.982%); sulphur concentration in grain (0.081%) and stover (0.133%); zinc concentration in grain (22.0 mg/ kg) and stover (36.8 mg/ kg); iron concentration in grain (26.2 mg/ kg) and stover (161.5 mg/ kg); copper concentration in grain (1.8 mg/ kg) and stover (7.9 mg/kg); manganese concentration in grain (2.9 mg/kg) and stover (32.9 mg/kg). No significant differences were observed in nutrient concentrations between maize stover and grain, except for phosphorus concentration, which was significantly different in the maize stover (Table 1.). Maize-cowpea intercropping increased the amount of nutrients compared to monocrop of maize. Fan *et al.* (2020) [3] reported that cereal-legume intercropping could also constitute a natural biofortification method that may improve the nutritional composition of the component crops.

#### Green gram

Results showed the grain nutrient concentration of green gram was recorded highest in pure stand of green gram stands analysing nitrogen concentration in grain (3.49%) and stover (0.77%); phosphorus concentration in grain (0.75%) and stover (0.28%); potassium concentration in grain (1.37%) and stover (0.82%); sulphur concentration in grain (0.24%) and stover (0.55%); zinc concentration in grain (22.9 mg/kg) and stover (58.7 mg/kg); iron concentration in grain (55.4 mg/ kg) and stover (119.0 mg/ kg); copper concentration in grain (9.6 mg/ kg) and stover (34.0 mg/ kg); manganese concentration in grain (12.5 mg/kg) and stover (28.8 mg/kg). The lowest values were estimated with additive stand of maize + green gram analysing nitrogen concentration in grain (3.27%) and stover (0.66%); phosphorus concentration in grain (0.68%) and stover (0.22%); potassium concentration in grain (1.30%) and stover (0.74%); sulphur concentration in grain (0.22%) and stover (0.53%); zinc concentration in grain (21.5 mg/kg) and stover (57.2 mg/kg); iron concentration in grain (52.2 mg/ kg) and stover (116.4 mg/ kg); copper concentration in grain (9.3 mg/ kg) and stover (33.6 mg/ kg); manganese concentration in grain (11.7 mg/kg) and stover (27.5 mg/kg). No significant differences were observed in

nutrient concentrations between green gram stover and grain, except for phosphorus concentration in grain and stover (Table 2.). Jensen *et al.* (2020) [5] reported that the higher uptake of nutrients in legume intercropping systems might be due to the better availability and supply of N by the leguminous crops intercropped with maize. The incorporation of legumes in cropping systems improves the physico-chemico-biological properties, soil fertility and ameliorate the resource use efficiency.

#### Cowpea

Results showed the grain nutrient concentration of cowpea was recorded highest in pure stand of green gram stands analysing nitrogen concentration in grain (3.44%) and stover (0.44%); phosphorus concentration in grain (0.64%) and stover (0.27%); potassium concentration in grain (0.37%) and stover (0.18%); sulphur concentration in grain (0.24%) and stover (0.45%); zinc concentration in grain (22.9 mg/kg) and stover (48.7 mg/kg); iron concentration in grain (55.4 mg/ kg) and stover (88.9 mg/ kg); copper concentration in grain (9.6 mg/ kg) and stover (23.9 mg/ kg); manganese concentration in grain (12.5 mg/kg) and stover (18.8 mg/kg). The lowest values were estimated with additive stand of maize + green gram analysing nitrogen concentration in grain (3.18%) and stover (0.29%); phosphorus concentration in grain (0.49%) and stover (0.17%); potassium concentration in grain (0.26%) and stover (0.16%); sulphur concentration in grain (0.22%) and stover (0.43%); zinc concentration in grain (21.5 mg/kg) and stover (47.2 mg/kg); iron concentration in grain (52.2 mg/ kg) and stover (86.4 mg/ kg); copper concentration in grain (9.3 mg/ kg) and stover (22.6 mg/ kg); manganese concentration in grain (11.7mg/kg) and stover (17.5 mg/kg). No significant differences were observed in nutrient concentrations between cowpea stover and grain, except for phosphorus concentration in grain and stover (Table 3.). Enhanced nutrient uptake in maize-legume intercropping systems is primarily associated with complementary nutrient acquisition, biological nitrogen fixation, and improved rhizosphere interactions. The inclusion of legumes also promotes soil fertility by improving soil physical, chemical, and biological characteristics, resulting in greater nutrient-use efficiency and sustainable crop production (Yadav *et al.*, 2022) [11].

### Effect on Nutrient uptake

#### Maize

Significant variation in grain and stover yields were also different in nutrient acquisition among different stands. Grain and stover nitrogen (94.4 kg/ha), phosphorus (37.3 kg/ha), potassium (114.3 kg/ha), sulphur (18.7 kg/ha), zinc (495.7 g/ha), iron (1733.8 g/ha), copper (86.5 g/ha) and manganese (317.5 g/ha) uptakes were significantly higher in T<sub>7</sub> (Table 4.). The higher uptake of nutrients in legume intercropping systems might be attributed to the leguminous crops intercropped with maize. That might have activated microbial population in microbes of plant rhizosphere to mobilize the inherent P and K and nutrients increasing their availability and uptake by plants and by addition of organic matter in the form of leaf litter by legume components. But the uptake of these nutrients varied significantly. It was mainly due to variation in yield (grain and stover) in different intercropping systems in maize crop. Similar findings were reported by Raza *et al.* (2019) [8].

#### Green gram

Grain and stover nitrogen (67.3 kg/ha), phosphorus (17.8 kg/ha), potassium (21.8 kg/ha), sulphur (15.4 kg/ha), zinc (194.2 g/ha),

iron (405.0 g/ha), copper (107.5 g/ha) and manganese (97.0 g/ha) uptakes were significantly higher in T<sub>2</sub> (Table 5.). The variation in uptake was mainly due to variation in yield (grain and stover) in different intercropping systems in green gram crop. Similar findings were reported by Zheng *et al.* (2022) <sup>[13]</sup>.

### Cowpea

Grain and stover nitrogen (57.4 kg/ha), phosphorus (16.1kg/ha),

potassium (10.1 kg/ha), sulphur (16.5 kg/ha), zinc (174.4 g/ha), iron (335.6 g/ha), copper (83.4 g/ha) and manganese (72.1 g/ha) uptakes were significantly higher in T<sub>3</sub> (Table 6.). The variation in uptake was mainly due to variation in yield (grain and stover) in different intercropping systems in cowpea crop. Similar findings were reported by Yadav *et al.* (2022) <sup>[11]</sup>.

**Table 1:** Effect on nutrients concentration of grain and stover in maize

| Treatment      | N concentration (%) |        | P concentration (%) |        | K concentration (%) |        | S concentration (%) |        | Zn concentration (mg/kg) |        | Fe concentration (mg/kg) |        | Cu concentration (mg/kg) |        | Mn concentration (mg/kg) |        |
|----------------|---------------------|--------|---------------------|--------|---------------------|--------|---------------------|--------|--------------------------|--------|--------------------------|--------|--------------------------|--------|--------------------------|--------|
|                | Grain               | Stover | Grain               | Stover | Grain               | Stover | Grain               | Stover | Grain                    | Stover | Grain                    | Stover | Grain                    | Stover | Grain                    | Stover |
| T <sub>1</sub> | 0.94                | 0.29   | 0.319               | 0.132  | 0.331               | 0.982  | 0.081               | 0.133  | 22                       | 36.8   | 26.2                     | 161.5  | 1.8                      | 7.9    | 2.9                      | 32.9   |
| T <sub>4</sub> | 0.96                | 0.29   | 0.323               | 0.153  | 0.339               | 1.009  | 0.085               | 0.139  | 22.3                     | 37.2   | 26.3                     | 169.7  | 2                        | 8.1    | 3                        | 33.2   |
| T <sub>3</sub> | 0.97                | 0.31   | 0.328               | 0.179  | 0.349               | 1.028  | 0.091               | 0.146  | 22.5                     | 37.4   | 26.9                     | 176.4  | 2                        | 8.2    | 3                        | 33.4   |
| T <sub>4</sub> | 1.02                | 0.34   | 0.338               | 0.195  | 0.356               | 1.054  | 0.096               | 0.15   | 22.6                     | 38.6   | 27.2                     | 180.9  | 2.1                      | 8.5    | 3.3                      | 33.7   |
| T <sub>5</sub> | 0.96                | 0.31   | 0.326               | 0.164  | 0.343               | 1.017  | 0.089               | 0.141  | 22.4                     | 38.2   | 26.6                     | 174.2  | 2                        | 8.2    | 3                        | 33.4   |
| T <sub>6</sub> | 0.99                | 0.33   | 0.335               | 0.186  | 0.351               | 1.042  | 0.093               | 0.148  | 22.6                     | 38.4   | 27.1                     | 178.7  | 2.1                      | 8.4    | 3.1                      | 33.5   |
| T <sub>7</sub> | 1.03                | 0.35   | 0.342               | 0.201  | 0.367               | 1.068  | 0.098               | 0.152  | 22.8                     | 38.8   | 27.4                     | 183.7  | 2.2                      | 8.7    | 3.3                      | 33.9   |
| S.Em±          | 0.03                | 0.01   | 0.013               | 0.004  | 0.01                | 0.04   | 0.006               | 0.005  | 0.9                      | 1.5    | 0.6                      | 6.3    | 0.2                      | 0.3    | 0.2                      | 1.1    |
| LSD (P=0.05)   | NS                  | NS     | NS                  | 0.012  | NS                  | NS     | NS                  | NS     | NS                       | NS     | NS                       | NS     | NS                       | NS     | NS                       | NS     |

**Table 2:** Effect on nutrients concentration of grain and stover in green gram

| Treatment      | N concentration (%) |        | P concentration (%) |        | K concentration (%) |        | S concentration (%) |        | Zn concentration (mg/kg) |        | Fe concentration (mg/kg) |        | Cu concentration (mg/kg) |        | Mn concentration (mg/kg) |        |
|----------------|---------------------|--------|---------------------|--------|---------------------|--------|---------------------|--------|--------------------------|--------|--------------------------|--------|--------------------------|--------|--------------------------|--------|
|                | Grain               | Stover | Grain               | Stover | Grain               | Stover | Grain               | Stover | Grain                    | Stover | Grain                    | Stover | Grain                    | Stover | Grain                    | Stover |
| T <sub>2</sub> | 3.49                | 0.77   | 0.75                | 0.28   | 1.37                | 0.82   | 0.24                | 0.55   | 22.9                     | 58.7   | 55.4                     | 119    | 9.6                      | 34     | 12.5                     | 28.8   |
| T <sub>4</sub> | 3.27                | 0.66   | 0.68                | 0.22   | 1.3                 | 0.74   | 0.22                | 0.53   | 21.5                     | 57.2   | 52.2                     | 116.4  | 9.3                      | 33.6   | 11.7                     | 27.5   |
| T <sub>5</sub> | 3.34                | 0.68   | 0.71                | 0.24   | 1.32                | 0.76   | 0.23                | 0.53   | 21.9                     | 57.3   | 52.6                     | 117.2  | 9.3                      | 33.7   | 11.9                     | 27.9   |
| T <sub>6</sub> | 3.4                 | 0.73   | 0.74                | 0.25   | 1.35                | 0.78   | 0.23                | 0.54   | 22.6                     | 57.8   | 53.2                     | 117.4  | 9.4                      | 33.7   | 12.1                     | 28.2   |
| SEm±           | 0.11                | 0.02   | 0.01                | 0.01   | 0.05                | 0.03   | 0.01                | 0.02   | 0.8                      | 1      | 1.4                      | 2.3    | 0.3                      | 1      | 0.5                      | 1.0    |
| LSD (P=0.05)   | NS                  | NS     | 0.05                | 0.02   | NS                  | NS     | NS                  | NS     | NS                       | NS     | NS                       | NS     | NS                       | NS     | NS                       | NS     |

**Table 3:** Effect on nutrients concentration of grain and stover in cowpea

| Treatment      | N concentration (%) |        | P concentration (%) |        | K concentration (%) |        | S concentration (%) |        | Zn concentration (mg/kg) |        | Fe concentration (mg/kg) |        | Cu concentration (mg/kg) |        | Mn concentration (mg/kg) |        |
|----------------|---------------------|--------|---------------------|--------|---------------------|--------|---------------------|--------|--------------------------|--------|--------------------------|--------|--------------------------|--------|--------------------------|--------|
|                | Grain               | Stover | Grain               | Stover | Grain               | Stover | Grain               | Stover | Grain                    | Stover | Grain                    | Stover | Grain                    | Stover | Grain                    | Stover |
| T <sub>3</sub> | 3.44                | 0.44   | 0.64                | 0.27   | 0.37                | 0.18   | 0.24                | 0.45   | 22.9                     | 48.7   | 55.4                     | 88.9   | 9.6                      | 23.9   | 12.5                     | 18.8   |
| T <sub>7</sub> | 3.18                | 0.29   | 0.49                | 0.17   | 0.26                | 0.16   | 0.22                | 0.43   | 21.5                     | 47.2   | 52.2                     | 86.4   | 9.3                      | 22.6   | 11.7                     | 17.5   |
| T <sub>8</sub> | 3.24                | 0.33   | 0.53                | 0.19   | 0.29                | 0.17   | 0.23                | 0.44   | 21.9                     | 47.3   | 52.6                     | 87.7   | 9.3                      | 23.7   | 11.9                     | 17.9   |
| T <sub>9</sub> | 3.37                | 0.4    | 0.56                | 0.24   | 0.34                | 0.18   | 0.23                | 0.44   | 22.6                     | 47.8   | 53.2                     | 87.4   | 9.4                      | 23.7   | 12.1                     | 18.2   |
| SEm±           | 0.09                | 0.01   | 0.02                | 0.01   | 0.04                | 0.01   | 0.01                | 0.01   | 0.38                     | 1.51   | 1.09                     | 2.8    | 0.23                     | 0.43   | 0.47                     | 0.47   |
| LSD (P=0.05)   | NS                  | NS     | 0.07                | 0.02   | NS                  | NS     | NS                  | NS     | NS                       | NS     | NS                       | NS     | NS                       | NS     | NS                       | NS     |

**Table 4:** Effect on nutrients uptake of grain and stover in maize

| Treatment      | N uptake (kg/ha) |        | P uptake (kg/ha) |        | K uptake (kg/ha) |        | S uptake (kg/ha) |        | Zn uptake (g/ha) |        | Fe uptake (g/ha) |        | Cu uptake (g/ha) |        | Mn uptake (g/ha) |        |
|----------------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|
|                | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover |
| T <sub>1</sub> | 66.3             | 25.6   | 22.4             | 11.8   | 23.3             | 87.6   | 5.7              | 11.9   | 154.4            | 328.4  | 183.8            | 1440.4 | 12.8             | 70.6   | 20.3             | 293.7  |
| T <sub>4</sub> | 66.4             | 26     | 22.4             | 13.6   | 23.5             | 89.5   | 5.9              | 12.3   | 154.2            | 329.8  | 182.4            | 1505.3 | 13.5             | 71.6   | 20.4             | 294.8  |
| T <sub>3</sub> | 35.3             | 18.3   | 11.9             | 10.4   | 12.7             | 59.8   | 3.3              | 8.5    | 81.5             | 217.4  | 97.6             | 1026.4 | 7.4              | 48     | 10.9             | 194.5  |
| T <sub>4</sub> | 35.8             | 18.9   | 11.9             | 11.0   | 12.5             | 59.3   | 3.4              | 8.5    | 79.5             | 217.1  | 95.6             | 1018.3 | 7.4              | 48     | 11.5             | 189.9  |
| T <sub>5</sub> | 67.0             | 27.4   | 22.7             | 14.6   | 23.9             | 90.4   | 6.2              | 12.5   | 155.8            | 339.9  | 184.8            | 1549   | 13.8             | 72.7   | 20.7             | 296.8  |
| T <sub>6</sub> | 37.8             | 19.4   | 12.8             | 11     | 13.4             | 62.0   | 3.6              | 8.8    | 86.4             | 228.7  | 103.7            | 1063.4 | 8.0              | 49.7   | 11.7             | 199.4  |
| T <sub>7</sub> | 38.0             | 20     | 12.6             | 11.6   | 13.5             | 61.4   | 3.6              | 8.7    | 84.1             | 223    | 100.9            | 1056   | 7.9              | 49.9   | 12.2             | 195.0  |
| SEm±           | 1.74             | 0.64   | 0.56             | 0.39   | 0.36             | 2.21   | 0.13             | 0.32   | 3.7              | 9.9    | 3.8              | 30.8   | 0.4              | 1.7    | 0.6              | 6.8    |
| LSD (P=0.05)   | 5.36             | 1.98   | 1.73             | 1.21   | 1.1              | 6.81   | 0.4              | 0.97   | 11.4             | 30.5   | 11.8             | 94.8   | 1.1              | 5.1    | 1.9              | 20.9   |

**Table 5:** Effect on nutrients uptake of grain and stover in green gram

| Treatment      | N uptake (kg/ha) |        | P uptake (kg/ha) |        | K uptake (kg/ha) |        | S uptake (kg/ha) |        | Zn uptake (g/ha) |        | Fe uptake (g/ha) |        | Cu uptake (g/ha) |        | Mn uptake (g/ha) |        |
|----------------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|
|                | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover |
| T <sub>2</sub> | 46               | 21.3   | 10               | 7.8    | 18.4             | 21.8   | 3.2              | 15.4   | 30.3             | 163.9  | 73.1             | 331.9  | 12.7             | 94.8   | 16.5             | 80.5   |
| T <sub>4</sub> | 23.9             | 11.3   | 5                | 3.9    | 9.5              | 12.8   | 1.6              | 3.8    | 16.2             | 98.3   | 38.1             | 200.2  | 6.8              | 57.8   | 8.5              | 47.4   |
| T <sub>5</sub> | 27.4             | 12.1   | 5.9              | 4.3    | 10.8             | 13.5   | 1.9              | 4.1    | 18.4             | 102    | 43.1             | 208.5  | 7.6              | 60     | 9.8              | 49.7   |
| T <sub>6</sub> | 32.6             | 15.4   | 7.1              | 5.5    | 13               | 16.6   | 2.2              | 4.9    | 21.7             | 122.6  | 51.1             | 248.8  | 9.1              | 71.5   | 11.6             | 59.7   |
| SEm±           | 0.66             | 0.58   | 0.33             | 0.2    | 0.33             | 0.22   | 0.07             | 0.35   | 0.7              | 2.8    | 0.7              | 8.6    | 0.2              | 0.8    | 0.3              | 2.1    |
| LSD (P=0.05)   | 2.3              | 2.02   | 1.14             | 0.7    | 1.16             | 0.75   | 0.25             | 1.2    | 2.3              | 9.8    | 2.4              | 29.6   | 0.8              | 2.9    | 1                | 7.4    |

**Table 6:** Effect on nutrients uptake of grain and stover in cowpea

| Treatment      | N uptake (kg/ha) |        | P uptake (kg/ha) |        | K uptake (kg/ha) |        | S uptake (kg/ha) |        | Zn uptake (g/ha) |        | Fe uptake (g/ha) |        | Cu uptake (g/ha) |        | Mn uptake (g/ha) |        |
|----------------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|------------------|--------|
|                | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover | Grain            | Stover |
| T <sub>3</sub> | 44.4             | 13     | 8.2              | 7.9    | 4.7              | 5.4    | 3.1              | 13.4   | 29.6             | 144.6  | 71.4             | 264.2  | 12.4             | 71     | 16.2             | 56     |
| T <sub>7</sub> | 28.9             | 5.6    | 4.5              | 3.4    | 2.4              | 3.3    | 2                | 8.5    | 19.6             | 93.4   | 47.5             | 171.1  | 8.5              | 44.7   | 10.6             | 34.7   |
| T <sub>8</sub> | 30.7             | 6.9    | 5                | 4      | 2.8              | 3.6    | 2.2              | 9.2    | 20.8             | 98.4   | 49.9             | 181.3  | 8.9              | 49.3   | 11.3             | 37.3   |
| T <sub>9</sub> | 37.8             | 10     | 6.3              | 6      | 3.8              | 4.4    | 2.6              | 11.1   | 25.4             | 120.5  | 59.6             | 220.2  | 10.6             | 59.7   | 13.6             | 45.8   |
| SEm±           | 1.21             | 0.05   | 0.17             | 0.14   | 0.07             | 0.08   | 0.09             | 0.34   | 0.52             | 4.25   | 2.56             | 8.28   | 0.38             | 1.9    | 0.35             | 1.11   |
| LSD (P=0.05)   | 4.17             | 0.18   | 0.6              | 0.5    | 0.26             | 0.29   | 0.32             | 1.19   | 1.81             | 14.7   | 8.86             | 28.66  | 1.33             | 6.57   | 1.2              | 3.84   |

## Conclusion

The present study demonstrated that crop geometry significantly influenced nutrient uptake in maize-legume intercropping systems under the eastern Indian conditions. Intercropping maize with cowpea, particularly under the Replacement Stand-II (RS-II) arrangement, enhanced the concentration and uptake of major nutrients (N, P, K and S) as well as micronutrients (Zn, Fe, Cu and Mn) in maize compared with sole maize. Although the highest nutrient concentration and uptake in green gram and cowpea were recorded under their respective sole cropping systems due to higher plant population, maize-cowpea intercropping exhibited superior nutrient acquisition by the maize component, reflecting efficient complementary resource use and improved rhizosphere interactions. Therefore, the maize + cowpea (RS-II) cropping geometry can be recommended as a sustainable intercropping strategy for improving nutrient-use efficiency and maintaining soil fertility in the resource-constrained regions of Eastern India.

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## References

- Begam A, Pramanick M, Dutta S, Paramanik B, Dutta G, Patra PS, *et al.* Inter-cropping patterns and nutrient management effects on maize growth, yield and quality. *Field Crops Research*. 2024;310:109363.
- Dong Q, Zhao X, Zhou D, Liu Z, Shi X, Yuan Y, *et al.* Maize and peanut intercropping improves the nitrogen accumulation and yield per plant of maize by promoting the secretion of flavonoids and abundance of Bradyrhizobium in rhizosphere. *Frontiers in Plant Science*. 2022;13:957336.
- Fan Y, Wang Z, Liao D, Raza MA, Wang B, Zhang J, *et al.* Uptake and utilization of nitrogen, phosphorus and potassium as related to yield advantage in maize-soybean intercropping under different row configurations. *Scientific Reports*. 2020;10(1):9504.
- Jackson ML. Soil chemical analysis. 2nd ed. New Delhi: Prentice Hall of India Pvt. Ltd.; 1973. p. 498.
- Jensen ES, Carlsson G, Hauggaard-Nielsen H. Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: A global-scale analysis. *Agronomy for Sustainable Development*. 2020;40(1):5.
- Prasad R, Shivay YS, Kumar D, Sharma SN. Learning by doing exercise in soil fertility: A practical manual for soil fertility. New Delhi: Division of Agronomy, Indian Agricultural Research Institute; 2006. p. 8-38.
- Rani SY, Jamuna P, Triveni U, Patro TSSK, Anuradha N. Effect of in situ incorporation of legume green manure crops on nutrient bioavailability, productivity and uptake of maize. *Journal of Plant Nutrition*. 2022;45(7):1004-1016.
- Raza MA, Feng LY, van der Werf W, Iqbal N, Khalid MHB, Chen YK, *et al.* Maize leaf-removal: A new agronomic approach to increase dry matter, flower number and seed yield of soybean in maize-soybean relay intercropping system. *Scientific Reports*. 2019;9(1):13453.
- Schwerdtner U, Spohn M. Interspecific root interactions increase maize yields in intercropping with different companion crops. *Journal of Plant Nutrition and Soil Science*. 2021;184(5):596-606.
- Talukdar TP, Tamuli B, Boruah RR, Richo MK. Growth and yield of maize (*Zea mays*) as influenced by intercropping of French bean and soybean. *Agricultural Reviews*. 2023;44(1).
- Yadav MR, Singh M, Kumar R, Kumar D, Kumar Meena R, Ram H, *et al.* Integrated nutrient management in maize-cowpea intercropping system is an attractive option to improve the fodder productivity and quality. *Communications in Soil Science and Plant Analysis*. 2022;53(22):3045-3059.
- Zhao X, Dong Q, Han Y, Zhang K, Shi X, Yang X, *et al.* Maize/peanut intercropping improves nutrient uptake of side-row maize and system microbial community diversity. *BMC Microbiology*. 2022;22(1):14.
- Zheng B, Zhou Y, Chen P, Zhang X, Yang H, Wang X, *et al.* Maize-legume intercropping promotes N uptake through changing the root spatial distribution, legume nodulation capacity, and soil N availability. *Journal of Integrative Agriculture*. 2022;21:1755-1771.