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## MULTIVARIATE ANALYSIS OF GROWTH DYNAMICS OF MAIZE UNDER DIVERSIFIED CROPPING AND PRODUCTION SYSTEMS

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### ABSTRACT

A field experiment was carried out at College Farm, Navsari Agricultural University, Navsari during the *rabi* season of the year 2023-24 and 2024-25. The experiment was laid out in Split Plot Design comprising of three replications. The main plot (production system) include: T<sub>1</sub>: Control (no nutrient input), T<sub>2</sub>: INM (25% organic + 75% chemical), T<sub>3</sub>: Organic Farming (5t ha<sup>-1</sup> Biocompost + Bio-fertilizers (seed treatment of *Azotobacter/ Rhizobium* (as per crop) + PSB)) and T<sub>4</sub>: Natural Farming (*Jeevamrut* (500 lit ha<sup>-1</sup> at every irrigation) + *Bijamrut* (seed treatment) + *Ghan Jeevamrut* @ 500 kg ha<sup>-1</sup>). The sub plot (Cropping system) include: C<sub>1</sub>- Maize Sole, C<sub>2</sub>- Maize + Spinach (2:2), C<sub>3</sub>- Maize + Fenugreek (2:2), C<sub>4</sub>- Maize + Cabbage (2:1) and C<sub>5</sub>-Maize + Indian Bean (2:1). INM recorded significantly higher plant height at 60 DAS and at harvest and maximum AGR up to 60 DAS and from 60 DAS up to harvest. While, RGR and RHE of maize plants were maximum under natural farming. Among the different cropping systems, the height of maize at 60 DAS and at harvest was significantly higher in sole maize and was at par with the system C<sub>5</sub>. In case of growth indices AGR up to 60 DAS was higher in sole maize while, AGR and RGR from 60 DAS up to harvest and RHE was higher in the system C<sub>2</sub> (Maize + Spinach (2:2)).

**Key words :** Absolute Growth Rate, Cropping Systems, Maize, INM, Intercropping, Organic Farming, Natural Farming, Relative Growth Rate, Relative Height Expansion.

### Introduction

Maize (*Zea mays* L.) being one of the world's most important cereal crops is a major source of food, feed, fodder, and industrial raw material. Maize plays a pivotal role in ensuring food and nutritional security owing to its high yield potential, adaptability to diverse agro-climatic conditions and increasing demand. However, continuous cultivation under monocropping systems and excessive dependence on chemical fertilizers have resulted in declining soil fertility and environmental degradation (Fiorini *et al.*, 2020). These challenges have compelled the adoption of sustainable production systems that aids in maintenance of crop productivity while improving soil

health and resource-use efficiency. Integrated Nutrient Management (INM) consisting of both chemical and organic nutrient input aids in better crop growth and development. Moreover, organic farming and natural farming have emerged as promising systems by improving soil biological activity and promoting sustainable crop production. Simultaneously, crop diversification through maize-based intercropping systems is an effective strategy to improve resource utilization, reduce production risks, and enhance returns. Maize geometry has sufficient inter-row space, which can be utilized profitably for raising a short duration crop (Jat *et al.*, 2014). Inter-cropping maize with short-duration vegetables and legumes such as

spinach, fenugreek, cabbage, and Indian bean can improve nutrient cycling, increase land-use efficiency and create support crop growth. Plant height is a fundamental indicator of vegetative growth and it showcases the cumulative effects of genetic potential, nutrient availability and management practices. It represents sunlight interception, competitive vigor and mechanical strength (Westoby, 1998 and Diaz *et al.*, 2016). Measurement of maize plant height at critical growth stages viz., 60 days after sowing (DAS) and at harvest, are vital to study crop vigour and growth dynamics. Growth indices including Absolute Growth Rate (AGR), Relative Growth Rate (RGR), and Relative Height Expansion (RHE) offer a comprehensive understanding of crop growth by quantification of the rate and efficiency of increase in plant height during different growth phases. These indices give an insight to the influence of production systems and cropping systems on crop development.

### Materials and Methods

The field experiment was carried out at College Farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat during the *rabi* season of the year 2023-24 and 2024-25. The experiment was carried out in Split Plot Design consisting of three replications and 20 treatment combinations. The main plot (production system) include: T<sub>1</sub>: Control (no nutrient input), T<sub>2</sub>: INM (25% organic + 75% chemical), T<sub>3</sub>: Organic Farming (5t ha<sup>-1</sup> Biocompost + Bio-fertilizers (seed treatment of *Azotobacter/ Rhizobium* (as per crop) + PSB)) and T<sub>4</sub>: Natural Farming (*Jeevamrut* (500 lit ha<sup>-1</sup> at every irrigation) + *Bijamrut* (seed treatment) + *Ghan Jeevamrut* @ 500 kg ha<sup>-1</sup>). The sub plot (Cropping system) include: C<sub>1</sub>- Maize Sole, C<sub>2</sub>- Maize + Spinach (2:2), C<sub>3</sub>- Maize + Fenugreek (2:2), C<sub>4</sub>- Maize + Cabbage (2:1) and C<sub>5</sub>-Maize + Indian Bean (2:1). Hybrid maize variety 'GAYMH-3' was grown at 45/75\*20 cm in all plots. The recommended dose of fertilizer for hybrid maize is 150:60:00 N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O kg per hectare In INM 25% nitrogen was applied from biocompost and 75% from urea. The soil of the experimental units in both the years were slightly alkaline, with normal electrical conductivity, medium in organic carbon, available nitrogen and phosphorus and high in available potassium. The plant height of maize was recorded at 60 DAS and at harvest. The growth indices of maize based on vertical growth of plant were calculated using the formula (Ghule *et al.*, 2013):

$$\text{Absolute Growth Rate (cm/day)} = \frac{H_2 - H_1}{T_2 - T_1}$$

$$\text{Relative Growth Rate (cm/cm/day)} = \frac{\ln(H_2) - \ln(H_1)}{T_2 - T_1}$$

$$\text{Relative Height Expansion (\%)} = \frac{H_2 - H_1}{H_1} \times 100$$

where, H<sub>1</sub>: Height of maize plant at time T<sub>1</sub>

H<sub>2</sub>: Height of maize plant at time T<sub>2</sub>

## Results and Discussion

### Plant height

Periodical measurement of plant height of maize was carried out at 60 DAS and at harvest. Table 1 shows the data pertaining to plant height of maize at 60 DAS and at harvest varying across different production systems and cropping systems. In the context of production systems, it was observed that the maize plant height was maximum when grown under the INM system (T<sub>2</sub>) at 60 DAS (126.78 cm, 121.89 cm and 124.33 cm) and at harvest (179.72 cm, 174.55 cm and 177.14 cm) during 1<sup>st</sup> year, 2<sup>nd</sup> year and pooled data, respectively. It was at par with organic farming (T<sub>3</sub>) during the year 2023-24 and 2024-25. Moreover, the plant height at 60 DAS and at harvest recorded in organic farming and in natural farming did not differ significantly during both the experimental years and pooled data. While, no application of nutrient input i.e. control (treatment T<sub>1</sub>) resulted in significantly lower plant height of maize in both the individual years and pooled analysis. Among the different cropping systems, sole maize (C<sub>1</sub>) recorded significantly higher plant height at 60 DAS (123.41 cm, 119.36 cm and 121.38 cm) and at harvest (173.50 cm, 169.15 cm and 171.33 cm). It was at par with the systems C<sub>5</sub> and C<sub>3</sub> during both the experimental years and pooled analysis, respectively and with the system C<sub>2</sub> during individual years in case of plant height at 60 DAS. Moreover, sole maize was at par with the systems C<sub>5</sub> and C<sub>2</sub> during both the individual years and pooled data and with C<sub>3</sub> only in 2023-24 and 2024-25 in case of plant height at harvest. The interaction of different production systems and cropping systems did not exert any significant influence on height of maize plants at 60 DAS and at harvest.

Among the production systems, higher plant height in the INM system at 60 DAS (12.89% higher than control) and at harvest (15.32 % higher than control) is attributed to the balanced supply of nutrients through a combined application of fertilizers and biocompost which resulted readily available nutrients to satisfy immediate demand as well as sustained release of nutrients. The adequate availability nitrogen resulted in enhanced cell division, cell elongation and to higher chlorophyll resulting

**Table 1 :** Effect of production systems and cropping systems on plant height of maize at 60 DAS and at harvest.

| Treatments                                 | Plant height (cm) |         |        |            |         |        |
|--------------------------------------------|-------------------|---------|--------|------------|---------|--------|
|                                            | At 60 DAS         |         |        | At harvest |         |        |
|                                            | 2023-24           | 2024-25 | Pooled | 2023-24    | 2024-25 | Pooled |
| <b>Main Plot: Production systems (T)</b>   |                   |         |        |            |         |        |
| T <sub>1</sub> - Control                   | 112.15            | 108.12  | 110.13 | 155.85     | 151.35  | 153.60 |
| T <sub>2</sub> - INM                       | 126.78            | 121.89  | 124.33 | 179.72     | 174.55  | 177.14 |
| T <sub>3</sub> - Organic Farming           | 119.38            | 115.95  | 117.66 | 170.40     | 165.29  | 167.85 |
| T <sub>4</sub> - Natural Farming           | 115.00            | 110.61  | 112.80 | 163.68     | 159.75  | 161.71 |
| SEm ±                                      | 2.92              | 2.63    | 1.96   | 3.90       | 3.59    | 2.65   |
| CD (P=0.05)                                | 10.09             | 9.10    | 6.05   | 13.50      | 12.45   | 8.18   |
| CV (%)                                     | 9.55              | 8.92    | 9.25   | 9.03       | 8.56    | 8.81   |
| <b>Sub Plot: Cropping systems (C)</b>      |                   |         |        |            |         |        |
| C <sub>1</sub> - Maize Sole                | 123.41            | 119.36  | 121.38 | 173.50     | 169.15  | 171.33 |
| C <sub>2</sub> - Maize + Spinach (2:2)     | 117.49            | 113.23  | 115.36 | 169.29     | 163.97  | 166.63 |
| C <sub>3</sub> - Maize + Fenugreek (2:2)   | 119.47            | 115.51  | 117.49 | 166.63     | 161.26  | 163.95 |
| C <sub>4</sub> - Maize + Cabbage (2:1)     | 111.12            | 106.84  | 108.98 | 158.07     | 153.52  | 155.80 |
| C <sub>5</sub> - Maize + Indian Bean (2:1) | 120.13            | 115.76  | 117.95 | 169.57     | 165.79  | 167.68 |
| SEm ±                                      | 2.76              | 2.68    | 1.92   | 3.48       | 3.58    | 2.50   |
| CD (P=0.05)                                | 7.95              | 7.71    | 5.43   | 10.04      | 10.34   | 7.07   |
| CV (%)                                     | 8.08              | 8.13    | 8.10   | 7.21       | 7.64    | 7.42   |
| <b>Interaction: T × C</b>                  |                   |         |        |            |         |        |
| SEm ±                                      | 5.52              | 5.36    | 3.85   | 6.97       | 7.18    | 5.00   |
| CD (P=0.05)                                | NS                | NS      | NS     | NS         | NS      | NS     |
| <b>Year</b>                                |                   |         |        |            |         |        |
| Y × T                                      | NS                | NS      | NS     | NS         | NS      | NS     |
| Y × C                                      | NS                | NS      | NS     | NS         | NS      | NS     |
| Y × T × C                                  | NS                | NS      | NS     | NS         | NS      | NS     |

in higher photosynthesis resulting in higher vegetative growth and taller plants (Rathod *et al.*, 2024). Moreover, phosphorus stimulated root proliferation and ATP synthesis which enhanced uptake of nutrients and water and assimilation of photosynthates. Furthermore, 6.84% and 9.28% increase over control in case of plant height at 60 DAS and at harvest, respectively in Organic Farming (T<sub>3</sub>) is attributed to gradual release of nutrients throughout the growth period of maize from basally applied biocompost and the availability of nutrients due to seed treatment *viz.*, nitrogen due to nitrogen fixers like *Rhizobium* and *Azotobacter* and phosphorus due to phosphorus solubilizing bacteria. However, Natural Farming (T<sub>4</sub>) resulted in an increase of 2.43% and 5.28% in plant height at 60 DAS and at harvest, respectively

compared to control. This is attributed to lesser nutrient input from the applied sources, which might not be sufficient for the high nutrient requiring maize crop. The complete absence of nutrient inputs resulted in the lowest plant height in control due to restricted cell division, chlorophyll formation and photosynthetic activity. Similar results were reported by Vinay (2018), Tanotra *et al.* (2021), Thakur (2022) and Sidhu *et al.* (2025). In the context of cropping systems, maize when grown as a sole crop recorded higher plant height owing to the absence of competition for space and nutrients. Moreover, maize when grown with Indian bean in 2:1 proportion (C<sub>5</sub>) resulted in comparable plant height due to lesser competition and improved nitrogen availability by biological nitrogen fixation. The height reduced only

by 2.83% at 60 DAS and 2.13% at harvest compared to sole maize in the system  $C_5$ . Furthermore, the system  $C_3$  recorded higher plant height at 60 DAS compared to  $C_2$  owing to the greater competition by spinach for nitrogen due to its fast growth in the initial stage of maize growth. However, after the harvest of spinach the height of maize increases due to lack of competition. While, the height of maize at harvest in the system  $C_3$  is lower than  $C_2$  due to the extended period of competition with crowded fenugreek plants for resources. Moreover, cabbage being a heavy feeder of nitrogen and potassium resulted in a higher competition with maize throughout its growth period which resulted in lower plant height of maize in the system  $C_4$  (10.2% less at 60 DAS and 9.86% less at harvest compared to sole maize). These results were in accordance with Veeranna *et al.* (2023), Gaikwad *et al.* (2022) and Nandini *et al.* (2024).

### Absolute Growth rate

Table 2 shows the data pertaining to the absolute growth rate (AGR) of maize on the basis of height from sowing to 60 DAS and from 60 DAS to harvest. Among the different production systems, the absolute growth rate was maximum in the treatment  $T_2$  (INM) both up to 60 DAS (2.113, 2.031 and 2.072 cm/day) and from 60 DAS to harvest (0.854, 0.836 and 0.845 cm/day) during both the experimental years and pooled data, respectively. It was followed by the treatment  $T_3$  (Organic Farming) and  $T_4$  (Natural Farming). Maize plants grown without any nutrient input had the lowest AGR in both the individual years and pooled analysis. The AGR of maize varied among different cropping systems. It was maximum when maize was grown as a sole crop ( $C_1$ ) up to 60 DAS (2.057, 1.989 and 2.023 cm/day) and in the system  $C_2$  (Maize + Spinach (2:2)) from 60 DAS to harvest (0.835, 0.805 and 0.820 cm/day). The AGR of maize was found in the order  $C_1 > C_5 > C_3 > C_2 > C_4$  up to 60 DAS and in the order  $C_2 > C_1 > C_5 > C_3 > C_4$  from 60 DAS up to harvest during both the individual years and pooled data, respectively.

Higher AGR in INM is attributed to higher immediate as well as sustained release of nutrients from both chemical and organic sources. While, gradual release of nutrients in  $T_3$  and  $T_4$  leads to lower AGR compared to INM and higher AGR compared to control. The maximum AGR of sole maize up to 60 DAS is mainly due to lack of competition for resources viz., light, nutrients, water and space during early growth stages. While, after 60 DAS the AGR is higher in  $C_2$ , as harvesting of spinach leads to lowered competition and thus higher growth rate of maize in later growth stage. The lower AGR of maize when

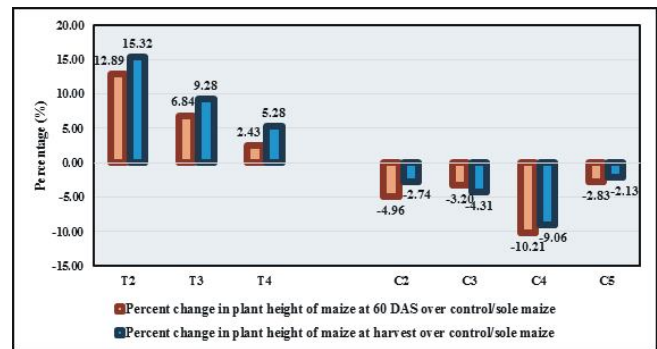


**Fig. 1 :** Percent change in plant height of maize at 60 DAS and at harvest over control/ sole maize.

intercropped with cabbage is due to high competition of maize and cabbage for nutrients and other resources for a prolonged period of maize growth.

### Relative Growth rate

The relative growth rate (RGR) of maize calculated based on the vertical plant growth *i.e.*; increase in plant height from 60 DAS up to harvest was analysed and the data are furnished in Table 2. The RGR of maize plant was maximum in the treatment  $T_4$  on pooled basis (0.00576 cm/cm/day) among the different production systems. It was followed by  $T_3$  and  $T_2$ , which did not vary much while, the treatment  $T_1$  (control) recorded the lowest RGR. Among the various cropping systems, the system  $C_2$  (Maize + Spinach (2:2)) recorded maximum RGR during both the years and pooled analysis. The RGR of maize was found in the order  $C_2 > C_4 > C_5 > C_1 > C_3$  from 60 DAS up to harvest during both the experimental years and pooled analysis.

Natural farming ( $T_4$ ) registered maximum RGR as the maize plants grown under natural farming were growing more efficiently per unit of their existing height due to continuous application of *Jeevamrut* with every irrigation despite having lower height at harvest than INM and organic farming. However, control had the lowest RGR which shows that without proper nutrition the plants ability to develop from its own existing growth is hampered. Furthermore, maize when grown with spinach in 2:2 row proportion had higher growth rate after 60 DAS up to harvest in relation to its height at 60 DAS which is attributed to growth of maize at higher rate relative to its existing height after the harvest of spinach. Moreover, the relative increase in plant height at later stages is lower when grown with fenugreek in 2:2 proportion which is attributed to higher space competition as fenugreek plants grown between maize plants also compete for space and nutrients with maize due to its branching habit and extended period of growth compared to spinach and Indian bean.

**Table 2 :** Absolute growth rate and relative growth rate of maize as influenced by different treatments.

| Treatments                                 | Absolute Growth Rate<br>(cm/day)<br>(up to 60 DAS) |         |        | Absolute Growth Rate<br>(cm/day)<br>(60 DAS- harvest) |         |        | Relative Growth Rate<br>(cm/cm/day)<br>(60 DAS- harvest) |         |         |
|--------------------------------------------|----------------------------------------------------|---------|--------|-------------------------------------------------------|---------|--------|----------------------------------------------------------|---------|---------|
|                                            | 2023-24                                            | 2024-25 | Pooled | 2023-24                                               | 2024-25 | Pooled | 2023-24                                                  | 2024-25 | Pooled  |
| <b>Main Plot: Production systems (T)</b>   |                                                    |         |        |                                                       |         |        |                                                          |         |         |
| T <sub>1</sub> - Control                   | 1.869                                              | 1.802   | 1.836  | 0.705                                                 | 0.686   | 0.696  | 0.00532                                                  | 0.00536 | 0.00534 |
| T <sub>2</sub> - INM                       | 2.113                                              | 2.031   | 2.072  | 0.854                                                 | 0.836   | 0.845  | 0.00565                                                  | 0.00572 | 0.00568 |
| T <sub>3</sub> - Organic Farming           | 1.990                                              | 1.932   | 1.961  | 0.823                                                 | 0.783   | 0.803  | 0.00575                                                  | 0.00562 | 0.00569 |
| T <sub>4</sub> - Natural Farming           | 1.917                                              | 1.844   | 1.880  | 0.785                                                 | 0.780   | 0.783  | 0.00568                                                  | 0.00585 | 0.00576 |
| <b>Sub Plot: Cropping systems (C)</b>      |                                                    |         |        |                                                       |         |        |                                                          |         |         |
| C <sub>1</sub> - Maize Sole                | 2.057                                              | 1.989   | 2.023  | 0.808                                                 | 0.790   | 0.799  | 0.00551                                                  | 0.00554 | 0.00553 |
| C <sub>2</sub> - Maize + Spinach (2:2)     | 1.958                                              | 1.887   | 1.923  | 0.835                                                 | 0.805   | 0.820  | 0.00591                                                  | 0.00590 | 0.00590 |
| C <sub>3</sub> - Maize + Fenugreek (2:2)   | 1.991                                              | 1.925   | 1.958  | 0.761                                                 | 0.726   | 0.743  | 0.00535                                                  | 0.00528 | 0.00532 |
| C <sub>4</sub> - Maize + Cabbage (2:1)     | 1.852                                              | 1.781   | 1.816  | 0.757                                                 | 0.741   | 0.749  | 0.00567                                                  | 0.00575 | 0.00571 |
| C <sub>5</sub> - Maize + Indian Bean (2:1) | 2.002                                              | 1.929   | 1.966  | 0.797                                                 | 0.794   | 0.796  | 0.00557                                                  | 0.00571 | 0.00564 |

### Relative Height expansion

The relative height expansion (RHE) is the extent of elongation of plants after 60 DAS relative to the height at 60 DAS and is expressed in percentage of increase in height after 60 DAS over height at 60 DAS. From Table 3, it can be observed that the relative height expansion of maize plants varied across different production systems. It was maximum in T<sub>3</sub> in 2023-24, while in 2024-25 it was maximum in T<sub>4</sub>. Though on pooled basis, maximum RHE was registered in natural farming (T<sub>4</sub>) (43.36%) and it was followed by T<sub>3</sub> and T<sub>2</sub>. While, control recorded the lowest RHE. Among the different cropping systems, the system C<sub>2</sub> (Maize + Spinach (2:2)) (44.09, 44.81 and 44.44 %) recorded maximum RHE during both the years and pooled analysis, respectively. It was followed by C<sub>4</sub>, C<sub>5</sub>, C<sub>1</sub> and C<sub>3</sub>. Maximum RHE in natural farming (T<sub>4</sub>) is likely attributed to the slow and steady release of nutrients from natural inputs which increases height at later stages of plant growth. The lower RHE in INM is mainly because of already taller plants at 60 DAS and more diversion of photosynthates to reproductive parts which leads to lower addition to the already higher plant height. Furthermore, higher RGR in the system C<sub>2</sub> among the various cropping systems is due to the surge in resource availability and lack of competition in later crop growth stages after removal of spinach.

### Growth of maize plants in initial and later growth stages

Fig. 2 shows that majority of vertical plant growth is achieved in initial 60 days of crop growth. Of the total

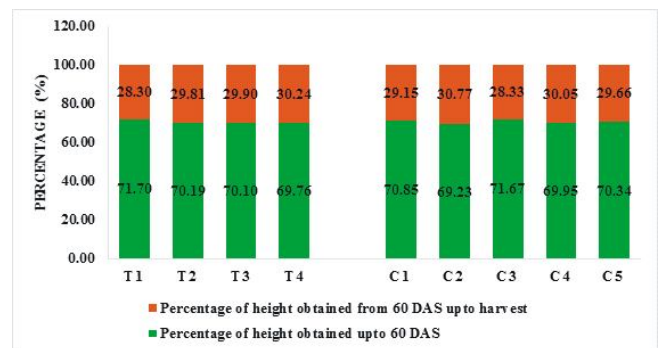


**Fig. 2 :** Percentage of height of maize obtained up to 60 DAS and from 60 DAS to harvest under different treatments.

plant height, 69.23% to 71.70% was gained during the initial 60 days. While, the remaining 28.30 to 30.77 was achieved during later growth stage. Among the production systems, higher growth of 71.70% is achieved within 60 days while the growth reduces later as the limited nutrients available are used for quick establishment and the growth rate reduces during the later stages gaining only 28.30% of the total height achieved. The maize grown under natural farming gained 69.76% of its height in initial 60 days and 30.24% in later stages which was maximum among all the production systems. Also, in the context of cropping systems, the early growth of maize was higher when maize is grown with fenugreek in 2:2 ratio (71.67%) and it reduced during the later growth stage (28.33%). While, the maize grown with spinach in 2:2 ratio gained only 69.23% of total height which was lower compared to other cropping systems. This system resulted in a boost of 30.77% in later part of growth, which was maximum among all the cropping systems.

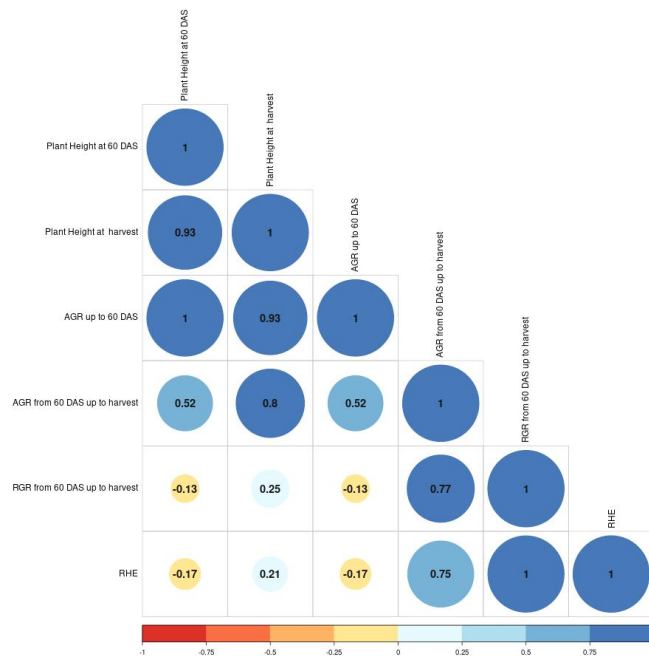


**Fig. 3 :** Correlation matrix showing the degree of correlation between the growth indices of maize.

The higher growth percentage of maize in natural and organic farming is due to the gradual release of nutrients throughout the season. Harvest of spinach increases plant height compared to its height achieved in initial 60 days in  $C_2$ . The sole maize and maize grown with Indian bean as well as that with cabbage recorded stable increase in plant height up to 60 DAS and up to harvest while, maize grown with fenugreek recorded maximum gain in total height up to 60 DAS and lower in later stages due to higher competition.

#### Correlation Matrix of different Growth indices

The correlation matrix in Fig. 4 shows the distinct relationships among plant height and growth indices of maize. A very strong positive correlation was observed between plant height at 60 DAS and plant height at harvest ( $r = 0.93$ ), indicating that vigorous early vertical growth substantially contributed to higher final plant height.

Similarly, AGR up to 60 DAS shows perfect positive association with plant height at 60 DAS ( $r = 1.00$ ) and a strong positive correlation with plant height at harvest ( $r = 0.93$ ), suggesting that rapid early growth was closely related with higher vertical plant growth throughout the crop growth period. AGR from 60 DAS to harvest displayed a strong positive correlation with plant height at harvest ( $r = 0.80$ ), with RGR ( $r = 0.77$ ) and with RHE ( $r = 0.75$ ), indicating that a sustained growth during the reproductive phase contributed significantly to final plant height. Relative growth rate (RGR) and relative height expansion (RHE) were perfectly correlated ( $r = 1.00$ ),

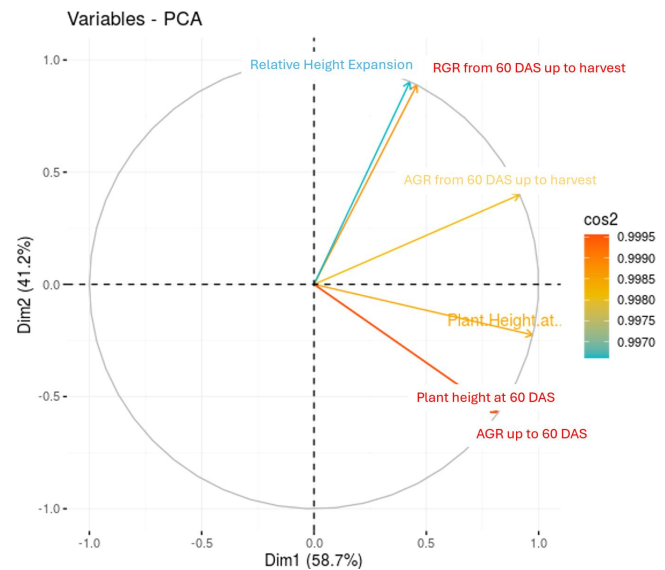


**Fig. 4 :** Principal Component analysis of different growth indices of maize.

demonstrating that both indices described similar aspects of plant growth dynamics over the same period. In contrast, RGR and RHE exhibited weak negative correlations with plant height at 60 DAS ( $r = -0.13$  and  $-0.17$ , respectively) and AGR up to 60 DAS ( $r = -0.13$  and  $-0.17$ , respectively), while maintaining weak positive correlations with plant height at harvest ( $r = 0.25$  and  $0.21$ , respectively). Overall, the correlation analysis suggests that early plant vigour, represented by plant height at 60 DAS, AGR up to 60 DAS and AGR from 60 DAS to harvest was a major determinant of final plant height, whereas RGR and RHE primarily reflected the relative growth behaviour during the later stages of crop development rather than absolute plant size.

#### Principle Component Analysis (PCA) Biplot of Maize growth parameters and indices

As seen in Fig. 4, among the different variables, Absolute Growth Rate (AGR) from 60 DAS to harvest, Relative Growth Rate (RGR) from 60 DAS to harvest and Relative Height Expansion (RHE) were closely grouped with very small angles between their vectors, indicating a strong positive correlation. This suggests that treatments promoting rapid stem elongation during the reproductive phase also enhanced relative and absolute growth rates, reflecting synchronized crop growth after 60 DAS. Similarly, plant height at 60 DAS, plant height at harvest, and AGR up to 60 DAS were close to one another. This indicates a strong positive association among these growth attributes. The proximity of these vectors indicates that plants exhibiting higher vertical growth during the vegetative stage generally maintained greater plant height at harvest. Although positive associations

**Table 3 :** Relative height expansion of maize plants under different production systems and cropping systems.

| Treatments                                 | Relative Height Expansion (%) |         |        |
|--------------------------------------------|-------------------------------|---------|--------|
|                                            | 2023-24                       | 2024-25 | Pooled |
| <b>Main Plot: Production systems (T)</b>   |                               |         |        |
| T <sub>1</sub> - Control                   | 38.97                         | 39.98   | 39.47  |
| T <sub>2</sub> - INM                       | 41.76                         | 43.20   | 42.48  |
| T <sub>3</sub> - Organic Farming           | 42.74                         | 42.55   | 42.66  |
| T <sub>4</sub> - Natural Farming           | 42.33                         | 44.43   | 43.36  |
| <b>Sub Plot: Cropping systems (C)</b>      |                               |         |        |
| C <sub>1</sub> - Maize Sole                | 40.59                         | 41.71   | 41.15  |
| C <sub>2</sub> - Maize + Spinach (2:2)     | 44.09                         | 44.81   | 44.44  |
| C <sub>3</sub> - Maize + Fenugreek (2:2)   | 39.47                         | 39.61   | 39.54  |
| C <sub>4</sub> - Maize + Cabbage (2:1)     | 42.25                         | 43.69   | 42.96  |
| C <sub>5</sub> - Maize + Indian Bean (2:1) | 41.16                         | 43.22   | 42.16  |

were observed among all variables, the separation between the vectors representing early growth parameters (plant height and AGR up to 60 DAS) and those representing post-60 DAS i.e. reproductive stage growth parameters (RGR, RHE, and AGR from 60 DAS to harvest) along the second principal component (PC2) indicates that these two groups of variables contributed differently to the observed variation. This suggests that vegetative growth and reproductive growth dynamics were influenced by distinct physiological processes under different production systems and cropping systems.

### Conclusion

Based on the two-year field experiment growing Maize with Indian bean in 2:1 row proportion or with spinach in 2:2 row proportion or sole maize under the INM system i.e. 112.5 kg nitrogen from urea and 37.5 kg from biocompost resulted in higher vertical growth and higher absolute and relative growth rate of maize.

**Conflict of interest :** The authors do not have any conflicts of interest.

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