*Research article*

# Growth, Productivity, Competitive Ratio, Maize Equivalent Yield, Land Equivalent Ratio, and Profitability of Hybrid Maize as Influenced by Relay Cropping with Mukhikachu (*Colocasia esculenta* Schott.) during Rabi Season

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## Abstract

**Keywords**

*Zea mays* L.;
light energy interception;
growth;
yield;
competitive ratio;
economics;
*Colocasia esculenta*;
relay

Relay cropping is a method that increases total productivity through maximum utilization of resources. In this study, we planned a field experiment, which was conducted at the Regional Agricultural Research Station, Ishwardi, Pabna during 2016-2017 and 2017-2018 to find out the most suitable way of relaying mukhikachu (MU) with hybrid maize to get the maximum benefit. Seven treatments: $T_1$= Relay at silking stage (100 DAS), $T_2$ = Relay at the blister stage (110 DAS), $T_3$ = Relay at the milk stage (120 DAS), $T_4$ = Relay at the dough stage (130 DAS), $T_5$ = Relay at the dent stage (140 DAS), $T_6$ = Sole hybrid maize, $T_7$ = Sole mukhikachu, were compared in the study. It was found that among the treatments (relay cropping and sole stand), there was no significant difference in terms of yield and attributes of both base (maize) and relay crop (mukhikachu). In the entire treatment, maize yielded 10.54-11.30 t ha$^{-1}$ with results of 3.28-3.66 MJ m$^{-2}$day$^{-1}$ light energy interception (120 DAS), 2.68-2.84 LAI (120 DAS) and 1534.63-1592.69 g m$^{-2}$ TDM (140DAS). The mukhikachu yielded 26.88-27.28 t ha$^{-1}$ among the relay cropping system. Maize equivalent yield (MEY) and BCR ranged from

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28.48-29.18 t $ha^{-1}$ and 2.33-2.39, respectively, amongst the relay cropping treatments. The land equivalent ratio (LER) of the relay cropping treatment produced almost double (1.934-1.996) that of the sole crops. Farmers can benefit by adopting this relay cropping technology when they grow long-duration crops, and this technology can lead to improved system productivity.

## 1. Introduction

Global food security is going to be a big challenge for the coming generations [1]. The demand for food needed for the rising world population will be increased by a changing climate that negatively affects crop growth and development. Furthermore, cultivable land will become scarce because of urbanization and industry. Thus, increasing crop productivity in response to declining farmland poses a significant challenge. So, it is essential to develop techniques that will increase crop productivity. One such technique is relay cropping which involves sowing a crop a few days before the harvest of another crop [2]. It can increase productivity and family financial gain through the proper utilization per unit of arable areas. This application is additionally helpful because it can facilitate effective use of the residual wetness from the previous crop and can reduce cultivation cost [3-5]. Many crop areas are competitive in an exceedingly bound season, whereas relay cropping can help farmers to avoid direct competition with different crops, and farmers have become more familiar with its potential [6].

At present, maize has become very popular with farmers because of its high yield potential and because it is a feedstock for the poultry and food business. It can be grown each winter and during the summer season. In winter, it is typically planted in November and the harvest occurs in May. On the other hand, mukhikachu is a long cycle length crop with corn that is rich in minerals and vitamins. It is planted from February to March and remains inr the field for 280-290 days. The speed of emergence and subsequent growth of mukhikachu is very slow at the start. The emergence starts at 20-25 days after planting, and it continues for up to 50 to 55 days for 100% emergence. Its growth becomes speedy at a later stage when soil wetness is boosted by rain. Maize and mukhikachu have completely different growth habits and demands for growth resources. Farmers grow each crop in optimum time by adopting relay cropping where maize is the major crop.

In South Asian countries including Bangladesh, maize is a staple cereal food crop after rice, and its cultivation occupies a great portion of cultivated land. So, there is a need to move to novel applications and more economical production systems that can improve the utilization of resources per unit space. Relay cropping is one such step. Moreover, in developing countries, small farmers make up a big portion of the farming community, but their cultivable areas are shrinking day by day. Furthermore, available arable land is very restricted in comparison to the population. Relay cropping assists by extending productivity. Besides, the cultivation of long cycle length crops like mukhikachu have been discouraged due to recently restricted farmer cultivation areas units while the cultivation of short cycle length crops, mixed crops and relay crops area units have been encouraged to boost national food security for an outsized range of the population. Hence, relay cropping has emerged as a time conserving technology for the cultivation of long cycle length crops. A relay of mukhikachu with maize can facilitate the retention of aroids and cereal crops in existing cropping patterns. The relay can play a very important role in ensuring the best productivity per unit space and can also provide minerals and victuals in people's diets. Another issue is that sole crop cultivation of maize is difficult for farmers due to the low crop return and high management value. Relay cropping of mukhikachu with maize may play a significant role to recover the full loss. Inter/relay cropping offers yield improvement relative to mono-cropping through improved yield stability and production per unit space in tropical and sub-tropical areas [7]. Maize-based relay cropping proved to be a timely new technology as it facilitated high economic returns that improved food security for the rising population in several developing countries [2, 8, 9]. Marginal farmers can benefit economically by adopting the technology. Besides, if farmers can cope with growing maize with this method, cropping intensity and productivity may potentially be double with no loss of maize production. The timing of relay cropping is a very important issue for improving yield and profit of each component crop. Therefore, the challenge is to grow mukhikachu as a relay crop while not losing maize production. There seems to be few studies on the appropriate time of relaying mukhikachu with hybrid maize. However, there is a lot of research opportunity to determine the productivity of relaying of mukhikachu with maize through different growth stages, yield contributing traits and competitive indices. In addition, relevant research work on the subject area of crop intensification is scanty. Thus, this experiment was conducted to discover the most suitable method of relaying mukhikachu with hybrid maize in order to obtain the greatest profit.

## 2. Materials and Methods

### 2.1 Experimental site

The experiment was conducted over two consecutive periods (2016-2017 and 2017-2018) at the Regional Agricultural Research Station, Ishwardi, Pabna (24.03°N and 89.05°E), Bangladesh. The target of the study is to seek out the suitability of relaying mukhikachu with hybrid maize to obtain the most profit. The experimental site belongs to the agro-ecological zone of the High Ganges River Flood plain (AEZ#11) and has an elevation of 16 m above sea level. The environment of this area is subtropical in nature. The annual rainfall ranges from 1000-1200 mm. The land is of medium elevation and the soil is clay loam in texture. The physical, morphological, and chemical properties of AEZ#11's soil area units are depicted in Tables 1 and 2 [10, 11]. Seasonal weather information together with maximum temperature, minimum temperature and rainfall for the study period were recorded at the meteorological station of Bangladesh Sugarcrop Research Institute, situated about 400 m from the experimental site.

**Table 1.** Soil physical and chemical characteristics of the experimental sites in the AEZ-11 and adjoining regions [10]

| Soil Profile (cm) | Sand (%) | Silt (%) | Clay (%) | Stone | pH | CEC (meq/100g) | EC (ds/m) | OC (%) | Total N (%) | Moisture (%) | $NO_3$ (mg/kg) | $NH_4$ (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 30 | 40 | 30 | 0 | 7.5 | 17.5 | 0.2 | 1.5 | 0.12 | 0.22 | 10 | 5 |
| 40 | 25 | 43 | 32 | 0 | 7.2 | 15.3 | 0.17 | 1.2 | 0.09 | 0.24 | 9 | 6 |
| 80 | 20 | 45 | 35 | 0 | 6.8 | 11.2 | 0.11 | 0.9 | 0.07 | 0.26 | 7 | 7 |
| 150 | 18 | 50 | 32 | 0 | 6.2 | 8.00 | 0.06 | 0.3 | 0.02 | 0.28 | 5 | 5 |

CEC, cation exchange capacity; EC, electric conductivity; OC, organic carbon

**Table 2.** Physical and morphological characteristics of the types of soil in experimental sites [11]

| AEZ-11 | Extent ($Km^2$) | Land type (%) | Organic matter | Fertility status | Physiological characteristics of the soil |
|---|---|---|---|---|---|
| High Ganges River Flood Plain | 13205 | High - 43%,<br>Medium-high -32%<br>Medium-low -12%<br>Others -13% | Low | Low | General soil type - Calcareous dark grey<br>Topography - Medium high land<br>Drainage - Well Drained<br>Flood level - Above flood level<br>Color - Dark Grey |

## 2.2 Soil analysis

Experimental soil properties were analyzed before starting the research. Soil pH was measured in soil/water (1:2, w/v) employing a glass electrode pH meter. Organic carbon was determined by the Walkley and Black oxidation method [12], total nitrogen (N) by the micro Kjeldhal method [13], phosphorus (P), potassium (K), sulphur(S) and zinc (Zn) by a modified Hunter's method [14], and element boron (B) was estimated colorimetrically by the Azomethine-H method [15].

## 2.3 Plant material

The seeds of Maize (var. BARI hybrid maize-9) and mukhukachu (var. Bilashi) were collected from Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh. The yield potentiality and properties of these crops are given in Table 3.

**Table 3.** The yield potentiality of existing tested component crops and their characters

| Component crops | Characteristics |
|---|---|
| Maize (var. BARI hybrid maize-9) | This is a high-yielding maize variety. Days to silking: 94-107 (winter). Plant height ranged: from 208-239 cm. Ear height: 100-115 cm. Grain colour: Orange-yellow. Thousand seed weight: 340-360 gm. Developed by the Bangladesh Agricultural Research Institute, Year of release: 2007. Crop duration: 145-150 days. Yield (t $ha^{-1}$): 10.20-12.00 (winter). |
| Mukhikachu{var. BARI Mukhikachu 1 (Bilashi)} | It is a high-yielding and good-quality mukhikachu variety. The plant is green, erect and of medium height. The corm is very smooth and oval. Soft, tasty, and easily boiled equally during cooking. It contains very little amount of calcium oxalate, which means it does not cause a sore throat. It was developed by the Bangladesh Agricultural Research Institute, Year of release: 1988. Crop duration: 210-280 days. Yield (t $ha^{-1}$): 25-30. Cultivable area: All over the country except the saline zone. Sowing time: 15-30 February. |

## 2.4 Experimental design and treatments

The experiment was laid out in a randomized complete block design following three replications. Mukhukachu were relayed in various growth stages of maize. The treatments viz; $T_1$= Relay at the silking stage (100 DAS), $T_2$ = Relay at the blister stage (110 DAS), $T_3$ = Relay at the milk stage (120 DAS), $T_4$ = Relay at the dough stage (130 DAS), $T_5$ = Relay at the dent stage (140 DAS), $T_6$ = Sole hybrid maize, $T_7$ = Sole mukhikachu, were compared in the study.

## 2.5 Crop management

In the study, maize was the base crop and mukhikachu was grown as the relay crop. The planting system was traditional rows of maize (75 cm × 25 cm) + relay of a double row of MU between the maize rows. There was a 55 cm spacing between adjacent pairs of mukhikachu, and a 20 cm spacing between each row in an mukhikachu pairs (Figure 1).

The seed-to-seed distance of maize and mukhikachu was maintained at 20 cm and 60 cm, respectively. The maize variety BARI hybrid maize-9 was seeded on 15 November in both years (2016 and 2017). The mukhikachu variety BARI Mukhikachu-1 (Bilashi) was planted according to the treatment in the respective years. The seed rates of maize and mukhikachu were 30 and 600 kg $ha^{-1}$, respectively. The sole crop of maize and relay crop treatment plots were fertilized with 260-55-110-40-4-1 kg $ha^{-1}$ of N-P-K-S-Zn-B, respectively. The full quantities of P-K-S-Zn-B and $^{1}/_{3}$ N

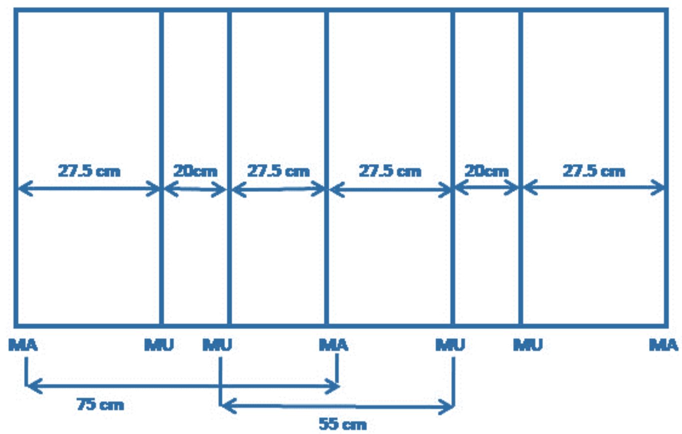



**Figure 1.** Model of planting system for each crop (MA: Maize; MU: Mukhikachu)

were applied basally during the final land preparation. The remaining N was applied in two equal splits as a top dressing at 35 and 60 days after the sowing of maize. Further, an additional 100 kg $ha^{-1}$ N was applied in two equal splits as top dressing at 45 and 100 days after emergence (DAE) of relay mukhikachu plots. The sole crop of mukhikachu was fertilized with 152-40-175-25-6-2 kg $ha^{-1}$ of N-P-K-S-Zn-B, respectively; however, ½ N and other nutrients were applied basally. The rest of N was top dressed at 45 and 100 days after emergence (DAE). Three irrigations were done at 30, 60 and 90 days after sowing/planting of the crops. Weeding and other intercultural operations were done as per the demand of the crops. Earthing up was done two times for mukhikachu after the harvest of maize (i.e., one at 45 DAE and another at 100 DAE). At the maize reached physiological maturity, all the leaves behind the ear height were removed. The base crop (maize) was harvested on 15 and 18 April in 2017 and 2018, respectively. Mukhikachu was harvested on 4-7 November 2017 and 2018, respectively.

## 2.6 Estimates different competitive functions and growth indices under the study

1. The competitive ratio (CR)

CR among different combinations was calculated using the following formulae [16]
CRmi = (RYmi/RYmu)/(Zmi/Zmu)
CRmu = (RYmu/RYmi)/(Zmu/Zmi)
where, CRmi = competitive ratio of maize; CRmu = competitive ratio of MU(relay crop)
RYmi = Relative yield of maize; RYmu = Relative yield of mukhikachu
Zmiand Zmuare the sown/planting proportions of maize and mukhikachu, respectively, in the mixture.

2. Maize equivalent yield (MEY)

MEY was converted by converting the yield of relay crops based on the current market price of the individual crop following the formula:

$$\text{MEY} = \text{Yield of relay crop maize} + \frac{[\text{yield of relay crop mukhikachu} \times \text{price of mukhikachu}]}{[\text{Price of maize}]}$$

3. The land equivalent ratio (LER)

LER was computed according to Jalilian *et al.* [17] and Parwada and Chinyama [18] as follows:

$$\text{LER} = \frac{\text{Relay cropped yield of maize}}{\text{Sole crop yield of maize}} + \frac{\text{Relay cropped yield of mukhikachu}}{\text{sole crop yield of mukhikachu}}$$

4. Crop growth rate (CGR)

CGR was calculated using the formula given by Beadle [19]

$$\text{CGR} = \frac{W_2 - W_1}{T_2 - T_1}$$

Where, $W_2$ = dry weight $m^{-2}$ land area at second harvest, $W_1$ = dry weight $m^{-2}$ land area at first harvest, $t_2$ = time corresponding to second harvest and $t_1$ = time corresponding to the first harvest

5. Measurement of leaf area index (LAI)

The length and width of the leaves of plants were measured with a ruler to determine the LAI. The LAI was determined as per the following formula:

$$\text{Leaf area index (LAI)} = k\,(L \times W)$$

Where, $k = 0.75$, which is constant for all cereals, $L$ = Leaf length and $W$ = Leaf width

6. Determination of light energy interception (LEI)

LEI by the crop (maize) was calculated according to Charles-Edwards [20]

$$\text{LEI} = \frac{\sum_{n}^{1} \text{DM}}{\text{LUE}}$$

Where, DM = daily dry matter production (g $m^{-2}$), LUE = Light use efficiency ($gMJ^{-1}$), which is constant (3.4 g dry matter $MJ^{-1}$) for maize, and LEI= Light energy intercepted by the crop (MJ $m^{-2}$)

7. Observation of total dry matter (TDM) and yield components of maize and Mukhikachu

For measuring the TDM, plant samples from one linear metre were collected and dried in an electric oven at 80ºC for 72 h. Then, the data collected was converted to g/$m^2$. Ten plants were randomly tagged in each treatment plot for measurement of the yield components of maize as well as mukhikachu. The yield data was measured as a whole plot basis and converted to ton per hectare.

## 2.7 Statistical analysis

The data were compiled and subjected to statistical analysis with the assistance of a computer using 'R' platform [21] following the basic procedure outlined by Gomez and Gomez [22]. Significant effects of treatments were determined by analysis of variance (ANOVA) and the mean separation test was done according to the least significant difference (LSD) test at p=0.05. Graphs were established with the Excel program.

# 3. Results and Discussion

## 3.1 Physical and chemical properties of experimental soil

The textural category of the experimental soil was clay loam, and the soil had 28.5% field capacity. The soil pH was 7.2, organic matter was 1.05%, total N was 0.06%, available phosphorus was 11 µg $g^{-1}$, available potassium was 0.12 meq $100^{-1}$g soil, and available sulfur, boron and zinc were 13, 0.19 and 2.0 µg$g^{-1}$, respectively. All the nutrient values were above the critical levels except for total N, K and B. The total N was low, and level of K was at the critical level. The B level was slightly below the critical level. Overall, the nutrient standing values indicated that the fertility of experimental soil was moderately good (Table 4).

**Table 4.** Initial soil physical and chemical properties of experimental soil

| Items | Soil Texture (clay loamy) | | | Field Capacity (%) | pH | OM (%) | N (%) | P (µg $g^{-1}$) | K (meq$100^{-1}$g soil) | S (µg $g^{-1}$) | Zn (µg $g^{-1}$) | B (µg $g^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial soil | Sand (18.6%) | Silt (32.0%) | Clay (49.4%) | 28.5 | 7.2 | 1.05 | 0.06 | 11.00 | 0.12 | 13.00 | 2.0 | 0.19 |
| Critical level | - | - | - | | - | - | 0.12 | 10.00 | 0.12 | 10.00 | 0.60 | 0.20 |

## 3.2 Climatic scenario during the crop periods

According to Figure 2, it was shown that the average maximum temperature in the vegetative stage of the maize (seedling to before tassel initiation stage, i.e., first to tenth decades) was in the range of 25.9 to 27°C and the average minimum temperature was in the range of 13.6 to14°C in each the year. At the grain-filling stage (milking to dent stage, i.e., $12^{th}$ to $14^{th}$ decades), the average maximum temperature was between 30.5 to 32.2°C and the minimum was between 16.5 to 17.6°C, respectively, in each year. As a whole (sowing to harvest, i.e., $1^{st}$ to $15^{th}$ decade), the maize plant had the average maximum temperature between 27.8 to 28.2°C and the minimum was between 14.9 to 15.0°C in each year, which showed to be appropriate for good yield in maize crop. In addition, the common minimum and maximum temperatures were 12°C and 29°C, respectively. The optimum growth in maize crops happens in climates with mid-summer temperatures between 21°C and 27°C as reported by García-Lara and Serna-Saldivar [23] and Tiwari and Yadav [24]. Furthermore, the optimum temperature for maximum maize grain yield is approx 25°C [24-26]. In the present study, the maize plant had a total of 397 mm and 114 mm of rainfall throughout the total growing period of 2016-2017 and 2017-2018, respectively. Depending on the relay time, the mukhikachu plant (planting to harvest) had an average maximum temperature of 33.0 to 33.6°C and a minimum was at 23.4 to 25.3°C in each year together with 1214 mm to 2087 mm total rainfall.

## 3.3 Performance of maize

### 3.3.1 Leaf area index (LAI)

LAI increased with advancement of crop growth that showed insignificant variation among the relay cropping system as well as sole stand (Table 5). This meant that the relay of mukhikachu with maize did not inhibit the gains in LAI of maize. The LAI ranged from 2.24-2.39, 2.68-2.84 and 2.51-2.67, respectively, for 100, 120 and 140 days after sowing (DAS). The development of LAI

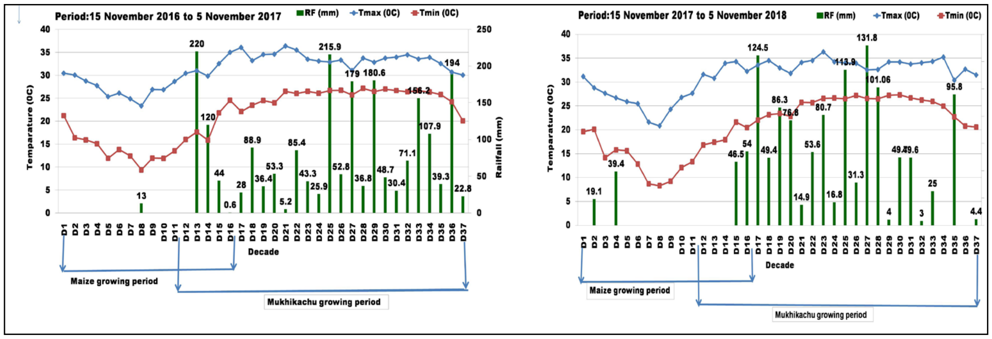



**Figure 2.** Decade-wise (days) mean temperature and total rainfall prevailing during the maize and mukhikachu growing periods (2016-2017 and 2017-2018)

**Table 5.** Leaf area index and light energy interception of maize influenced by the relay of mukhikachu (pooled average of 2016 and 2017)

| Treatments | Leaf area index | | | Light energy interception ($MJ/m^2/day$) | | |
|---|---|---|---|---|---|---|
| | 100DAS | 120DAS | 140DAS | 100DAS | 120DAS | 140DAS |
| $T_1$ | 2.29 | 2.74 | 2.58 | 1.48 | 3.58 | 2.72 |
| $T_2$ | 2.39 | 2.70 | 2.51 | 1.50 | 3.40 | 2.76 |
| $T_3$ | 2.28 | 2.69 | 2.64 | 1.46 | 3.28 | 2.84 |
| $T_4$ | 2.24 | 2.68 | 2.62 | 1.44 | 3.34 | 2.88 |
| $T_5$ | 2.30 | 2.80 | 2.67 | 1.47 | 3.65 | 2.87 |
| $T_6$ | 2.38 | 2.84 | 2.63 | 1.48 | 3.66 | 2.88 |
| Mean | 2.31 | 2.74 | 2.61 | 1.47 | 3.49 | 2.83 |
| $V_T$ | $0.041^{ns}$ | $0.010^{ns}$ | $0.012^{ns}$ | $0.004^{ns}$ | $0.155^{ns}$ | $0.010^{ns}$ |
| LSD (0.05) | 0.37 | 0.18 | 0.20 | 0.11 | 0.72 | 0.18 |
| CV (%) | 8.79 | 3.59 | 4.26 | 4.23 | 11.31 | 3.49 |

ns=non-significant at $P \leq 0.05$; $V_T$=Variance due to treatment, LSD=Least significant difference, CV=Coefficient of variation; $T_1$= Relay at silking stage (100 DAS); $T_2$ = Relay at blister stage (110 DAS); $T_3$ = Relay at milk stage (120 DAS); $T_4$ = Relay at dough stage (130 DAS); $T_5$ = Relay at dent stage (140 DAS); $T_6$ = Sole hybrid maize; DAS =Days after sowing

can be a key issue that increases the capture of sunshine inside the canopy and the production of dry matter. Hence, dry matter decreases with decrease of LAI. LAI extended to a maximum level at 120 DAS and showed a downward trend at 140 DAS in all the treatments due to the increasing ageing of leaves. Milas *et al.* [27] and Wang *et al.* [28] reported that an LAI between 3 and 4 is ideal for achieving maximum yield.

### 3.3.2 Light energy interception (LEI) gained by the base crop (maize)

LEI is a function of LAI. As LAI increases, LEI increases. Ahmed *et al.* [29] reported that the effect of LEI depends on the leaf area of the plant population as the leaves form and turn into the canopy. Islam *et al.* [2] reported that LAI increases as the canopy coverage increased, resulting in a lot of LEI for photosynthesis. In the present study, LEI showed a similar value (insignificant difference to the entire relay cropping system and sole stand (Table 5). The result indicated that the relay of mukhikachu did not interfere with the LEI of maize throughout all the expansion stages. The LEI ranged from 1.44-1.50 MJ $m^{-2}$ $day^{-1}$, 3.28-3.66 MJ $m^{-2}$ $day^{-1}$ and 2.72-2.88 MJ $m^{-2}$ $day^{-1}$, respectively at 100, 120 and 140 DAS. The maize plants growing with relaying mukhikachu tend to have open leaf architecture, with leaves that are predominantly in a horizontal form, and thus occupy a greater area in the canopy. Thereby, obtain a similar quantity of LEI was gained when growing with the relay mukhikachu treatments and sole maize stands.

### 3.3.3 Total dry matter (TDM) production

The TDM of maize increased through to the harvest regardless of the whole relay cropping system and sole stand (Table 6).

**Table 6.** Total dry matter (TDM) and crop growth rate (CGR) of maize influenced by the relay of mukhikachu (pooled average of 2016 and 2017)

| Treatments | Total Dry Matter (g $m^{-2}$) | | | Crop Growth Rate (CGR) | | |
|---|---|---|---|---|---|---|
| | 100DAS | 120DAS | 140DAS | 100DAS | 120DAS | 140DAS |
| $T_1$ | 507.57 | 1197.47 | 1557.24 | 5.08 | 34.50 | 17.99 |
| $T_2$ | 511.11 | 1204.03 | 1553.87 | 5.11 | 34.65 | 17.49 |
| $T_3$ | 509.84 | 1208.37 | 1534.63 | 5.10 | 34.93 | 16.31 |
| $T_4$ | 512.75 | 1211.53 | 1543.59 | 5.13 | 34.94 | 16.60 |
| $T_5$ | 510.23 | 1210.68 | 1588.63 | 5.10 | 35.02 | 18.90 |
| $T_6$ | 504.87 | 1211.89 | 1592.69 | 5.05 | 35.35 | 19.04 |
| Mean | 509.40 | 1207.33 | 1561.78 | 5.09 | 34.90 | 17.72 |
| $V_T$ | 248.498$^{ns}$ | 4038.386$^{ns}$ | 2212.675$^{ns}$ | 0.025$^{ns}$ | 12.321$^{ns}$ | 9.911$^{ns}$ |
| LSD (0.05) | 28.69 | 115.61 | 85.58 | 0.29 | 6.39 | 5.73 |
| CV (%) | 3.09 | 5.26 | 3.01 | 3.09 | 10.06 | 17.76 |

ns=non-significant at P=0.05; $V_T$=Variance due to treatment, LSD=Least significant difference, CV=Coefficient of variation; $T_1$= Relay at silking stage (100 DAS); $T_2$ = Relay at blister stage (110 DAS); $T_3$ = Relay at milk stage (120 DAS); $T_4$ = Relay at dough stage (130 DAS); $T_5$ = Relay at dent stage (140 DAS); $T_6$ = Sole hybrid maize; DAS =Days after sowing

Dry matter production by plants depends on the quantity of LEI produced by the leaves and its potency of conversion into energy [2]. It is the key indication of yield, and a dependable parameter when assessing the growth of various crops. Accumulation of dry matter is directly influenced by the total length of time needed to complete the life cycle although there are many environmental factors related to crop growth. Dry matter assimilates into the organs and is ultimately reflected in the final harvest. Higher dry matter production and its appropriate partitioning into organs are the prime requisites for higher productivity of a crop [29]. Finney *et al.* [30] and Mihai and Florin [31] reported that the buildup of biomass for completely different elements of a plant is a very important consideration for achieving a desirable yield. In the present study, dry matter accumulation in terms of TDM was insignificant among the entire treatments at different growth stages. However, TDM ranged from 504.87-512.75 g $m^{-2}$, 1197.47-1211.89 g $m^{-2}$ and 1534.63-1592.69 g $m^{-2}$, respectively at 100, 120 and 140 DAS. Data clearly revealed that during relay with mukhikachu, the TDM of the maize was not influenced considerably.

### 3.3.4 Crop growth rate (CGR)

Crop growth rate (CGR) was calculated from the TDM production at completely different growth phases. Insignificant variation was observed in CGR among the various relay cropping systems and sole stand at all growth stages (Table 6). The highest CGR was recorded at 120 DAS and then it exhibited a declining trend till maturity. This was due to the halt of vegetative growth, loss of leaves, leaf senescence, and decrease of LAI at later growth stages which reduced the photosynthetic potency and ultimately reduced the dry matter accumulation rate. In our study, CGR ranged from 5.05-5.13 g $m^{-2}$ $day^{-1}$, 34.50-35.35 g $m^{-2}$ $day^{-1}$ and 16.31-19.04 g $m^{-2}$ $day^{-1}$, respectively in 0-100, 100-120 and 120-140 DAS. It is clear from the results that due to the relay of mukhikachu, the CGR of maize was not hampered when compared to the control (sole maize).

### 3.3.5 Yield attributing traits and yield of maize

The yield and yield-contributing characteristics of maize are given in Table 7. All the parameters for maize in the study did not show any vital distinction between the treatments. Plant height, ear height, cob length, cob breath, grain $cob^{-1}$, 1000-grain weight and grain yield ranged from 201.90-208.10 cm, 98.89-100.48 cm, 18.37-18.98 cm, 5.31-5.48 cm, 533.00-538.57 (no.), 347.30-357.27 g and 10.54-11.30 t $ha^{-1}$, respectively. It was evident that after the relay of mukhikachu with maize as per treatment, the emergence of the mukhikachu stalk started at 20-25 days after planting. Furthermore, they took 45-50 days to reach 80% emergence. Hence, it can be assumed that the yield and yield-contributing characteristics of maize were not influenced by the mukhikachu.

**Table 7.** Effect of time of relaying mukhikachu on the yield and yield contributing characters of hybrid maize (pooled average of 2016 and 2017)

| Treatments | Plant Height | Ear Height (cm) | Cob Length (cm) | Cob Breath | Grain/Cob | 1000-Seed Weight (g) | Grain Yield |
|---|---|---|---|---|---|---|---|
| $T_1$ | 203.60 | 99.30 | 18.37 | 5.31 | 533.00 | 347.60 | 10.87 |
| $T_2$ | 201.90 | 100.37 | 18.55 | 5.32 | 533.35 | 354.30 | 10.77 |
| $T_3$ | 203.80 | 98.89 | 18.48 | 5.31 | 534.90 | 347.30 | 10.90 |
| $T_4$ | 204.00 | 99.75 | 18.81 | 5.42 | 535.00 | 355.30 | 10.54 |
| $T_5$ | 207.70 | 101.40 | 18.96 | 5.46 | 536.84 | 355.30 | 11.25 |
| $T_6$ | 208.10 | 100.48 | 18.98 | 5.48 | 538.57 | 357.27 | 11.30 |
| Mean | 204.85 | 100.03 | 18.69 | 5.38 | 535.28 | 352.84 | 10.94 |
| $V_T$ | $32.30^{ns}$ | $18.651^{ns}$ | $0.666^{ns}$ | $0.342^{ns}$ | $508.1^{ns}$ | $321.6^{ns}$ | $1.1783^{ns}$ |
| LSD (0.05) | 6.84 | 5.20 | 0.98 | 0.70 | 27.15 | 21.60 | 1.31 |
| CV (%) | 2.77 | 4.32 | 4.37 | 10.86 | 4.21 | 5.08 | 9.92 |

ns=non-significant at P=0.05; $V_T$=Variance due to treatment, LSD=Least significant difference, CV=Coefficient of variation; $T_1$= Relay at silking stage (100 DAS); $T_2$ = Relay at blister stage (110 DAS); $T_3$ = Relay at milk stage (120 DAS); $T_4$ = Relay at dough stage (130 DAS); $T_5$ = Relay at dent stage (140 DAS); $T_6$ = Sole hybrid maize; DAS =Days after sowing

## 3.4 Performance of mukhikachu

The yield and yield contributing characteristics of mukhikachu in experimental treatments are shown in Table 8. There were no statistically significant differences for all traits for the relay cropping system and sole mukhikachu. However, the number of secondary corm $plant^{-1}$, number of

**Table 8.** Yield and yield contributing characters of mukhikachu under mukhikachu relay with hybrid maize cropping system (pooled average of 2016 and 2017)

| Treatment | Secondary corm/plant (no.) | Cormels/ plant | Weight of primary corm/plant (gm) | Weight of secondary corm/plant (gm) | Weight of cormels/ plant (gm) | Weight of edible parts/plant (gm) | Yield (t ha$^{-1}$) |
|---|---|---|---|---|---|---|---|
| $T_1$ | 9.32 | 17.40 | 128.08 | 265.37 | 445.35 | 701.45 | 27.25 |
| $T_2$ | 9.36 | 17.34 | 127.61 | 265.30 | 445.17 | 701.43 | 27.13 |
| $T_3$ | 9.14 | 17.05 | 127.65 | 265.14 | 445.19 | 701.34 | 26.96 |
| $T_4$ | 8.95 | 17.07 | 127.54 | 264.51 | 445.13 | 700.52 | 26.91 |
| $T_5$ | 9.11 | 17.28 | 127.55 | 264.73 | 445.07 | 701.15 | 26.90 |
| $T_7$ | 9.37 | 17.07 | 127.63 | 265.26 | 445.06 | 701.37 | 26.88 |
| Mean | 9.21 | 17.20 | 127.68 | 265.05 | 445.16 | 701.21 | 27.01 |
| $V_T$ | 0.488$^{ns}$ | 1.633 $^{ns}$ | 12.564$^{ns}$ | 92.13$^{ns}$ | 510.7$^{ns}$ | 678.5$^{ns}$ | 1.445$^{ns}$ |
| LSD (0.05) | 0.84 | 1.54 | 4.27 | 11.56 | 27.22 | 31.37 | 1.45 |
| CV (%) | 7.58 | 7.43 | 2.78 | 3.62 | 5.08 | 3.71 | 4.45 |

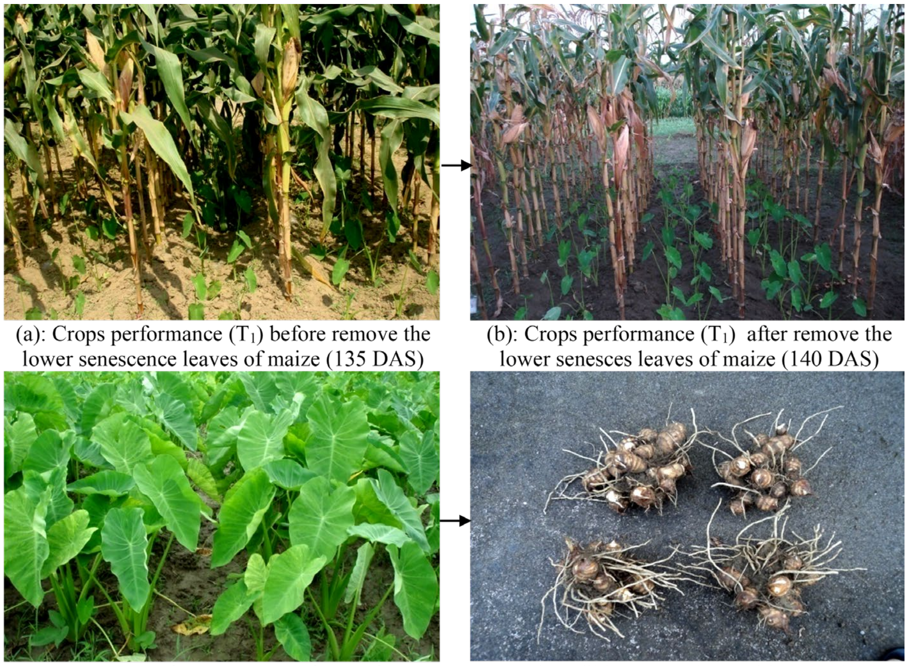
ns=non-significant at P=0.05; $V_T$=Variance due to treatment, LSD=Least significant difference, CV=Coefficient of variation;$T_1$= Relay at silking stage (100 DAS); $T_2$ = Relay at blister stage (110 DAS); $T_3$ = Relay at milk stage (120 DAS); $T_4$ = Relay at dough stage (130 DAS); $T_5$ = Relay at dent stage (140 DAS);$T_7$= Sole mukhikachu; DAS =Days after sowing

cormels plant$^{-1}$, weight of primary corm plant$^{-1}$, weight of secondary corm plant$^{-1}$, weight of cormels plant$^{-1}$, weight of edible parts plant$^{-1}$ and yield of mukhikachu ranged from 9.11-9.37 (no.), 17.05-17.40 (no.), 127.54-128.08 (no.), 264.51-265.37 g, 445.06-445.35 g, 701.15701.45 g and 26.88-27.25 t ha$^{-1}$, respectively.

The results showed that the yield of mukhikachu under sole condition ($T_7$) was numerically lower (26.88 t ha$^{-1}$) than the relay mukhikachu ($T_1$-$T_5$) system (26.90-27.25 t ha$^{-1}$). This may be due to open daylight sole mukhikachu taking more days for emergence than relay technique particularly at 100 and 110 DAS. Additionally, the microclimate was cooler due to partial shading of maize under relay mukhikachu methods that were accountable for the promoted emergence of mukhikachu. Thus, growth and development were quicker for mukhikachu in relay than for sole mukhikachu. Furthermore, the yield was numerically higher in the case of the relayed mukhikachu. The crop performances at various stages of the maize - mukhikachu relay cropping systems are shown in Figure 3.

### 3.5 Competitive ratio (CR)

Competitive ratio (CR) is an important method that measures the degree of competitiveness between one crop and other crops [32]. In this study, there was negligible variation in CR among the relay cropping systems, indicating the non-differential competitive ability of component crops as influenced by the relay of mukhikachu (Table 9). Mukhikachu showed better competitiveness than maize, demonstrating higher CR values (1.149-1.227). Maize had CR values of 0.815-0.870 among the relay cropping systems. The minimum difference in CR values indicated better use of growth resources. However, the relay of mukhikachu at the dent stage ($T_5$) gave a numerically lower CR value (0.278) with higher productivity in terms of maize equivalent yield (MEY) (29.18 t ha$^{-1}$). Lower values of difference in CR indicate similarities in competitiveness but higher values of difference in CR indicate more competitiveness between the species grown in a mixture. A value of CR over 1 (unity) indicates that the species is a good competitor while less than 1 (unity) indicates that the species is a poor competitor when grown in association [33]. During this relay cropping, mukhikachu was the best competitor as compared to maize.



(a): Crops performance ($T_1$) before remove the lower senescence leaves of maize (135 DAS)

(b): Crops performance ($T_1$) after remove the lower senesces leaves of maize (140 DAS)

(c): Crops performance ($T_1$) of MU after harvesting of maize (100 DAR)

(d): Edible corms along with cormels

**Figure 3.** Performance of mukhikachu (MU) and maize at different stages (DAS= days after sowing; DAR= days after relay)

**Table 9.** Competitive ratio (CR) of maize and mukhikachu under different relay cropping systems

| Treatments | Competitive ratio (CR) of maize | Competitive ratio (CR) of mukhikachu | Difference |
|---|---|---|---|
| $T_1$ | 0.830 | 1.204 | 0.374 |
| $T_2$ | 0.826 | 1.210 | 0.384 |
| $T_3$ | 0.842 | 1.188 | 0.347 |
| $T_4$ | 0.815 | 1.227 | 0.411 |
| $T_5$ | 0.870 | 1.149 | 0.278 |
| $T_6$ | - | - | - |
| T7 | - | - | - |

$T_1$= Relay at silking stage (100 DAS); $T_2$ = Relay at blister stage (110 DAS); $T_3$ = Relay at milk stage (120 DAS); $T_4$ = Relay at dough stage (130 DAS); $T_5$ = Relay at dent stage (140 DAS); $T_6$ = Sole hybrid maize; $T_6$ = Sole hybrid maize; $T_7$ = Sole mukhikachu

## 3.6 Maize equivalent yield (MEY)

Maize equivalent yields were higher in the entire relay cropping system (28.48-29.18 t ha$^{-1}$) than the sole crops of maize (11.30 t ha$^{-1}$) and MU (17.92 t ha$^{-1}$). The variation of MEY was very negligible among the relay cropping system (Table 10). However, numerically higher MEY was observed in $T_5$ (29.18 t ha$^{-1}$). The results indicated that relay cropping of mukhikachu with maize gave higher productivity in terms of MEY as compared to sole crops. The results agree with the findings of Islam *et al.* [6].

**Table 10.** Economic analysis of mukhikachu relay with hybrid maize cropping system (prediction from pooled average yield data of 2016 and 2017)

| Treatment | MEY ($t\ ha^{-1}$) | LER | Gross Return (US$ $ha^{-1}$) | Total Variable Cost (US$ $ha^{-1}$) | Gross Margin (US$ $ha^{-1}$) | BCR |
|---|---|---|---|---|---|---|
| $T_1$ | 29.04 | 1.976 | 5444.38 | 2293.81 | 3150.56 | 2.37 |
| $T_2$ | 28.86 | 1.962 | 5410.63 | 2293.81 | 3116.81 | 2.36 |
| $T_3$ | 28.87 | 1.968 | 5413.75 | 2293.81 | 3119.94 | 2.36 |
| $T_4$ | 28.48 | 1.934 | 5340.00 | 2293.81 | 3046.19 | 2.33 |
| $T_5$ | 29.18 | 1.996 | 5471.88 | 2293.81 | 3178.06 | 2.39 |
| $T_6$ | 11.30 | 1.000 | 2118.75 | 1258.81 | 859.94 | 1.68 |
| $T_7$ | 17.92 | 1.000 | 3360.00 | 1708.38 | 1651.63 | 1.97 |

Market price: Hybrid maize grain US$ 0.19 $kg^{-1}$; Mukhikachu US$ 0.13 $kg^{-1}$; Hybrid maize grain as seed US$ 1.56 $kg^{-1}$; Muchachos as seed US$ 0.25 $kg^{-1}$; MEY=Maize equivalent yield; BCR = Benefit cost ratio; $T_1$ = Relay at silking stage (100 DAS); $T_2$ = Relay at blister stage (110 DAS); $T_3$ = Relay at milk stage (120 DAS); $T_4$ = Relay at dough stage (130 DAS); $T_5$ = Relay at dent stage (140 DAS)$T_6$ = Sole hybrid maize; $T_6$ = Sole hybrid maize; $T_7$ = Sole mukhikachu

### 3.7 Land equivalent ratio (LER)

The land equivalent ratio (LER) of different relay cropping systems was almost 2-fold higher than the sole stand (Table 10). Among the relay cropping systems, LER ranged from 1.934-1.996, indicating that the productivity increased by 93-100% with relay cropping. Numerically, the highest land equivalent ratio (1.996) was obtained from the treatment $T_5$ which involved mukhikachu relay at the dent stage (140 DAS). The LER value of 1.996 indicated that by relay cropping maize and mukhikachu, a farmer could produce 11.25 (av. of two years) tons of maize and 26.90 (av. of two years) tons of mukhikachu from one hectare of land instead of growing them separately in 1.996 hectares of land to obtain the same combined yield. It was noticed that LER of more than 1.00 in the entire relay cropping system showed better productivity than their sole stand. The LER over 1 (unity) also indicated more land utilization capability for relay cropping than actual mono-cropping land [34, 35]. The results are in agreement with the previous findings [32, 36, 37].

### 3.8 Economic performance

Economic analyses of the maize-mukhikachu relay cropping system are presented in Table 10. The results obtained for all the relay cropping systems showed higher monetary returns than monoculture. From the two years mean data, the gross return, gross margin and BCR were very similar under the relay cropping system, and they ranged from 5340.00 to 5471.88 US$ $ha^{-1}$, 3046.19-3178.06 US$ $ha^{-1}$ and 2.33-2.39, respectively. However, the highest gross return (US$ 5471.88 $ha^{-1}$), gross margin (US$ 3178.06 $ha^{-1}$) and benefit-cost ratio (2.39) were observed from $T_5$ treatment, i.e., mukhikachu relay at the dent stage (140 DAS). The sole crop of maize gave the lowest gross returns (US$ 2118.75 $ha^{-1}$), gross margin (US$ 859.94 $ha^{-1}$) and benefit-cost ratio (1.68) of the entire treatments. The results revealed that the relay cropping of mukhikachu with maize was highly productive and profitable compared to their sole stand.

## 4. Conclusions

Relay cropping of mukhikachu with maize emerges as a productive and time-efficient technology where cultivable land is decreasing day by day with the increase of populations. Food security faces many challenges. From the current study results, it can be concluded that mukhikachu may be cultivated as a relay crop with hybrid maize. This study revealed that the growth indices as well as grain yield of maize were not influenced by the relay with mukhikachu. In the same way, the yield attributes and yield of mukhikachu were not hampered by the maize standing crops. Economically, the entire relay cropping system may be considered as a better alternative when considering that it produced a maize equivalent yield (MEY) of 28.48-29.18 t $ha^{-1}$, land equivalent ratio (LER) of 1.934-1.996 and benefit-cost ratio (BCR) of 2.33-2.39. Farmers can increase productivity with their limited cultivable land by adopting this technology. In addition, this technology can also increase the production area of mukhikachu (280-290 days) in a situation where farmers are reluctant to grow long growth cycle crops. Total crop failure can also be avoided through this technology.

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