INTRODUCTION

Tropical areas like Indonesia usually were exposed to ca. 12.38 MJ/m²/day of solar radiation. The solar radiation intensity is affected by the season, altitude, and geographic position of area. During rainy season with heavy clouds in Ambon, Maluku, the intensity was usually only ca. 47% and 70% during dry seasons (Septiadi, Nanlohy, Souissa, & Rumlawang, 2009). Suryanto, Guritno, Sugito, & Koesmaryono (2005) reported that the solar radiation intensity during wet months in Malang, East Java, from January to March, declines to 270 cal/cm²/day or ca. 261 W/m² with irradiation ca. 32%. The solar radiation intensity will remain relatively constant than many of natural resources other are becoming more limited, so that abundant radiation in tropics and sub-tropics can be utilized better crop production (Awal, Koshi, & Ikeda, 2006).

As one important environmental factor, light intensity contributes to maize yield and quality during the growing period (Setter, Flannigan, & Melkonian, 2001). The increase of maize production is related to the solar radiation that can be utilized by the plant and converted to the biomass accumulation and referred as radiation use efficiency (RUE) (Sinclair & Muchow, 1999) or the efficiency of solar energy conversion (Slattery & Ort, 2015). Slattery & Ort (2015) stated that the energy conversion efficiency is influenced by the plant and environmental factors. The environmental factors included season, latitude, cloud, CO₂ concentration. While the plant features that affected the amount of sunlight interception were the position and arrangement of leaves and vertical leaf character. Bisi 18 that has vertical leaf character were more efficient in utilizing solar radiation when intercropped with denser mungbean populations.
leaf area index (LAI), and the type of leaf pigment (Monteith, 1972; Monteith & Unsworth, 2014).

Selection of varieties and intercropping systems is one strategy to increase the solar energy conversion efficiency. The maize genotype determines to the canopy shape, crop growth rate, and plant age. These feature affected the amount of light interception to the plant leaves and ability of leaf plant to absorb light (Zhu, Long, & Ort, 2008). The upper leaves of the selected maize varieties positioned upright. These feature allows more sunlight interception into the canopy. The upright leaves might distribute the light evenly through the canopy. When the position of the light is right above the head, these characteristic also reduces the proportion of light-saturated leaf. The vertical leaf and light position increases the higher photosynthesis efficiency (up to 40%) than the canopy of the horizontal leaf (Long, Zhu, Naidu, & Ort, 2006). The more light interception and light harvesting area. Hammer et al. (2009) suggest that vertical leaves of maize at the top of the canopy can increase the light penetration to the bottom of the canopy and photosynthesis rate is more uniform in the canopy. The more light interception into the canopy and light harvesting area, might contribute to high photosynthetic activities.

The cultivating of two or more crops in the same field simultaneously or intercropping can increase the use of solar radiation related to the characteristic of the canopy (Awal, Koshi, & Ikeda, 2006; Lithourgidis, Dordas, Damalas, & Vlachostergios, 2011). The increase of the sunlight interception, radiation use efficiency (RUE) and productivity per unit incident radiation can be improved through intercropping (Wang et al., 2015).

In intercropping system, maize is mostly put as one of the main components and is often combined with legumes (Maluleke, Addo-Bediako, & Ayisi, 2005). In intercropping systems, the canopies of the combined plants can immediately cover the planting area/soil. These conditions lead to maximum light interception into the plant canopies and minimized the light escape. Tsubo, Walker, & Mukhala (2001) reported that photosynthetically active radiation (PAR) energy in intercropping maize and legumes was higher than maize monoculture. These situation increase RUE and biological yield of maize and bean in intercropping system (Nassiri-Mahallati, Koocheki, Mondani, Feizi, & Amirmoradi, 2015).

Based on the ability of plant to convert solar radiation energy into biomass, maize production is expected to be improved through the optimization of solar radiation interception into the plants. This research aimed to optimize the RUE of maize by selecting the variety and intercropping systems with mungbean related to canopy characteristics.

**MATERIALS AND METHODS**

The research was conducted at Gowa Regency, South Sulawesi, which is located at 119.3773° W, 120.0317° E, 5.0829342862° N, and 5.577305437° S. The research location has inceptisol soil with an altitude of 60.09 masl. The experiment was carried out during the rainy season from September 2016 until January 2017. The total radiation intensity was 56,320 cal/cm² and the total precipitation was 1,571 mm during growing season (Fig. 1).

The research was arranged in a factorial randomized block experiment with three replications. The maize varieties and intercropping system were the first and second factors respectively. The first factor was maize varieties, namely Bisi 18 (hybrid variety, vertical leaf), Lamuru (composite variety, semi-vertical leaf), and local variety (horizontal leaf). The second factor were dealt with intercropping system of maize with one, two, three, four lines of mungbean, and maize monoculture.

The land preparation was conducted through plowing and harrowing the soil. The weeds were collected and disposed from the experimental sites. The planting plot with the size of 3.5 × 5 m² with 1.5 m distance between plots was constructed for maize combination with mungbean each treatment. Maize seeds were planted in (100 × 50 cm) × 20 cm (double row spacing), i.e. each two line of maize (50 × 20 cm spacing) exist empty space with 100 cm distance. While in mungbean, the planting distance was arranged in 20 × 20 cm at empty space between two lines of maize (Fig. 2). Urea and NPK (15:15:15) with doses 300 kg/ha respectively were applied two times by simultaneously during the growing period. For each 300 kg/ha (urea+NPK) was applied at 10 and 35 days after planting (DAP). The climatic data during the conduct of the experiment were collected from Maros climatology station, South Sulawesi.
The observed parameters included leaf area index (LAI), crop growth rate (CGR) (g/cm²/day), total dry weight of crop (g/plant), yields (t/ha), land equivalent ratio (LER), and RUE (%). The leaf area per ground area was used to measure the LAI. The CGR was measured in terms of the total dry weight per ground area, and plant age. The LER was calculated based on the yield of each intercropped crop against the yield of each crop in monoculture. The RUE was measured based on Sinclair & Muchow (1999), and Suryanto, Maghfoer, & Karinaty (2018) (equation 1). The observations of LAI, CGR, and total dry weight of the crop were conducted at 30, 45, 60, and 75 DAP.
RUE = \frac{\Delta W \cdot K}{I \cdot T \cdot PAR} \times 100\% \quad \ldots \ldots \ldots \ldots .1)

Where \( \Delta W \) = the differences of crop dry weight (g/m\(^2\)), \( K \) = coefficient of burning heat (4,000 cal/g), \( I \) = daily radiation intensity (cal/m\(^2\)/day), \( T \) = a period of a specific time (day), and \( PAR \) = Photosynthetic Active Radiation (0.45). All variables were measured to estimate RUE.

RESULTS AND DISCUSSION

The research showed that Bisi 18 intercropped with mungbean had higher LAI than Lamuru and local varieties (Table 1). Bisi 18 intercropped with three lines of mungbean resulted in a higher LAI (7.08) than one and four mungbean lines, but with negligible differences with two lines of mungbean (6.98). Maize varieties and the line numbers of mungbean in the intercropping systems affected LAI. The differences of distribution, shape and leaf angle of maize affected LAI value causes variation on the absorption of solar radiation. As proposed by Rosati, Metcalf, & Lampinen (2004), the light absorption can be influenced by the differences between species and plant growth stages because each species has differences in leaf sizes and canopy characteristics. On each leaf of any species, photosynthetic is linearly related to daily PAR incident of the respected leaf. Factors affecting Photosynthetic radiation use efficiency (PhRUE) in maize is the leaf at the top of canopy, and daily pattern of the light incident. The high LAI on Bisi 18 variety with vertical leaves which causes more light interception in plants, the radiation is absorbed more effectively (Awal et al., 2006). Intercropping two to four lines of mungbean accelerate the soil cover, due to the dense of the leaves and thus reducing the light reaching the soil and increase light interception by leaves. Campillo, Fortes, & del Henar Prieto (2012) suggest that better spatial arrangement of plants can accelerate ground cover and increase light interception to the leaves. Intercropping of two species with different canopy structures, such as the intercropping of maize with mungbean (Awal, Koshi, & Ikeda, 2006) and soybean (Coll, Cerrudo, Rizzalli, Monzon, & Andrade, 2012; Gao et al., 2010), optimize light capture over space by increasing soil coverage and reducing the light reaching the ground proportion. Intercropping systems affected significantly the LAI and PAR intercepted (Matusso, Mugwe, & Mucheru-Muna, 2014).

Table 1. Interaction effect of maize variety and intercropping system on leaf area indeks (LAI) at 60 day after planting

| Treatments\(^{\text{a,b}}\)   | LAI of maize variety \(^{\text{c,d}}\) |
|----------------------------|---------------------------------|
|                           | Local | Lamuru | Bisi 18 |
| Maize monoculture         | 3.93b | 5.56c  | 6.68c  |
|                           | C     | B      | A      |
| IC 1 MB                   | 3.93b | 5.59c  | 6.72c  |
|                           | C     | B      | A      |
| IC 2 MB                   | 4.16a | 5.89b  | 6.98ab |
|                           | C     | B      | A      |
| IC 3 MB                   | 4.25a | 6.24a  | 7.08a  |
|                           | C     | B      | A      |
| IC 4 MB                   | 4.06ab| 5.88b  | 6.95b  |
|                           | C     | B      | A      |

Remarks: \(^{\text{a,b}}\) Values followed by the different capitalized letters at the same rows differ significantly under DMRT (p ≤ 0.05); \(^{\text{c,d}}\) Values followed by the different undercase letters at the same column differ significantly under DMRT (p ≤ 0.05); \(^{\text{a,b}}\) IC = Intercropping, MB = Mungbean.

Maize variety and intercropping systems gave significant impact on CGR. Bisi 18 has a higher CGR than the Lamuru and local varieties. The highest CGR value was observed on Bisi 18 that intercropped with three and four lines of mungbean with value 0.0038 g/cm\(^2\)/day (Table 2). High CGR on Bisi 18 is influenced by plant density in the intercropping system. Bisi 18 can adapt with a more dense mungbean population by resulted in high LAI (Table 1). According to Moosavi, Seghatoleslami, & Moazeni (2012), plant density can increase LAI. LAI describes architectural leaf arrangement that efficient in radiation intercepted (Madonni, Cirilo, & Otegui, 2006). Maximum CGR reached at the stages of canopy closure and maximum leaf area, when optimum LAI (Dong et al. 2018; Zhang et al., 2008). Cirilo et al. (2009) mention that crop growth rate depends on RUE, which is the amount of intercepted PAR and the efficiency of the crop to convert intercepted PAR to above ground biomass. Size, architecture of canopies, and PAR incident are related to the intercepted PAR (Madonni, Otegui, & Cirilo, 2001). In this research, the amount of radiation intercepted by Bisi 18 canopy is related
to leaf characteristics i.e. vertical leaf (smaller leaf inclination angles). The leaf inclination angle as a feature of plant architecture influences the intercepts of solar radiation by plant canopy. The smaller leaf inclination angle contributed to the less potential overlapped leaves in receiving the PAR. Thus, the efficiency of photosynthetic conversion and biomass yield potential will be higher (Truong, McCormick, Rooney, & Mullet, 2015).

**Table 2.** Interaction effect of maize variety and intercropping system on crop growth rate (CGR) at 30-75 day after planting

| Treatments | CGR of maize variety (g/cm²/day)** | Local | Lamuru | Bisi 18 |
|------------|----------------------------------|-------|--------|---------|
| Maize monoculture | 0.0022c | 0.0032b | 0.0034a | C  B  A |
| IC 1 MB     | 0.0024b | 0.0032b | 0.0036c | C  B  A |
| IC 2 MB     | 0.0024b | 0.0033b | 0.0037c | C  B  A |
| IC 3 MB     | 0.0024ab| 0.0032b | 0.0038a | C  B  A |
| IC 4 MB     | 0.0025a | 0.0032b | 0.0038a | C  B  A |

Remarks: *) Values followed by the different capitalized letters at the same rows differ significantly under DMRT (p ≤ 0.05); **) Values followed by the different undercase letters at the same column differ significantly under DMRT (p ≤ 0.05); ***) IC = Intercropping, MB = Mungbean

Bisi 18 variety has a total dry weight higher than Lamuru and local varieties (Table 3). This shows that each variety has a different response to the growth environment. Bisi 18 intercropped with three mungbean lines (290.62 g/plant) was higher than one and two mungbean lines, but not significantly different from four mungbean lines (288.94 g/plant). According to Yulisma (2011), maize variety and planting distance have a significant impact to plant height, total leaf area, dry weight of the crop, and net assimilation rate. The value of dry weight is determined by the photosynthesis rate which is a process of photosynthate accumulation during the growth phase. Morales-Ruiz et al. (2016) state that one of the more important crop yield for production is the accumulation of dry matter. Lee & Tollenaar (2007) mention that during the growing cycle, dry matter accumulation is also influenced by the amount of PAR received by plants and the efficiency use of PAR for pertinent metabolic pathways the interception result, and use of the solar radiation on the crop leaf. The variety, developmental stage, and density and date of sowing influence the amount of intercepted radiation (Morales-Ruiz et al., 2014). Related to the total dry matter and the biological yield of crops, if a crop translocates assimilates efficiently, the total dry matter content and biological yield will increase (Ahmad & Tahir, 2017). The research results are inline with the results obtained by Nassary, Baijukya, & Ndakidemi (2020) which find that total mass of hybrid maize increases during the growing season in the rainy season.

**Table 3.** Interaction effect of maize variety and intercropping system on the total dry weight of crop at 75 day after planting

| Treatments | Total dry weight of maize variety (g/plant)** | Local | Lamuru | Bisi 18 |
|------------|-----------------------------------------------|-------|--------|---------|
| Maize monoculture | 178.18d | 245.52b | 259.25d | C  B  A |
| IC 1 MB     | 188.07c | 247.69b | 272.41c | C  B  A |
| IC 2 MB     | 191.99ab| 255.02a | 282.49c | C  B  A |
| IC 3 MB     | 192.39ab| 249.18b | 290.62a | C  B  A |
| IC 4 MB     | 198.05a | 247.39b | 288.94a | C  B  A |

Remarks: *) Values followed by the different capitalized letters at the same rows differ significantly under DMRT (p ≤ 0.05); **) Values followed by the different undercase letters at the same column differ significantly under DMRT (p ≤ 0.05); ***) IC = Intercropping, MB = Mungbean

Intercropping of Bisi 18 with mungbean showed higher grain yield than Lamuru and local varieties. Grain yield obtained by Bisi 18 intercropped with three mungbean lines (11.22 t/ha) was higher than one and two mungbean lines, but not significantly different from four mungbean lines (11.14 t/ha) (Table 4). The high grain yield of Bisi 18 is influenced by leaf inclination angle (vertical leaf). The inclination angles of leaf impact on crop yield
can be distinguished by the different solar radiation of canopy in aspect of vertical distribution. Position of leaf that contributes to inclination angle increases carbon gain by maximizing the PAR interception and by reducing heat stress because of infrared radiation excess (Song, Zhang, & Zhu, 2013; van Zanten, Pons, Janssen, Voesenek, & Peeters, 2010; Zhu, Long, & Ort, 2008; 2010). To mitigate the radiation excess at the upper canopy (Long, Zhu, Naidu, & Ort, 2006; Mullet et al., 2014; Zhu, Long, & Ort, 2010), the small upper leaf angles as a form of canopy architecture redistribute PAR more uniformly throughout the canopy and this condition reduces shade-induced senescence of lower leaves (Song, Zhang, & Zhu, 2013; van Zanten, Pons, Janssen, Voesenek, & Peeters, 2010). The increasing green leaf area facilitates the increasing accumulation of nitrogen, and it can be a rate-limiting factor on a period of grain filling for modern high-yield cultivars (Hammer et al., 2009). Denser planting as an important factor for grain yield per hectare can be conducted if the vertical redistribution of solar radiation throughout the canopy are optimal (Duvick, 2005; Mansfield & Mumm, 2014; Tian et al., 2011). The high grain yield on Bisi 18 is related to the hybrid character of which has better interception light and RUE to increase the yield (Tohidi, Nadery, Siadat, & Lak, 2012).

Table 4. Interaction effect of maize variety and intercropping system on grain yield

| Treatments | Grain yield of maize variety (t/ha)** | Local | Lamuru | Bisi 18 |
|------------|--------------------------------------|-------|--------|--------|
| Maize monoculture |                                       | 3.09c | 6.82c | 10.59c |
| IC 1 MB    |                                       | 3.13c | 7.06bc | 10.60c |
| IC 2 MB    |                                       | 3.16bc | 7.65a | 10.99b |
| IC 3 MB    |                                       | 3.24ab | 7.43ab | 11.22a |
| IC 4 MB    |                                       | 3.30a | 7.29ab | 11.14ab |

Remarks: *) Values followed by the different capitalized letters at the same rows differ significantly under DMRT (p ≤ 0.05); **) Values followed by the different undercase letters at the same column differ significantly under DMRT (p ≤ 0.05); ***) IC = Intercropping, MB = Mungbean

The RUE of all maize varieties in intercropping with mungbean increased and was significantly different compared to the RUE of maize varieties in sole cropping. The RUE of Bisi 18 intercropped with mungbean was higher than the RUE of Lamuru and local varieties. The RUE of Bisi 18 intercropped with mungbean was different from the RUE of Lamuru and local varieties, where each RUE was 9.53%, 8.80%, and 6.43% respectively (Table 5). These results show that the intercropping system can increase radiation use efficiency for maize. These condition is inline with the research conducted by Wang et al. (2015), which states that an intercropped maize received high solar radiation by increasing PAR and RUE. The RUE of the intercropping system was higher than monoculture, and it was due to the rapid closing of the canopy and a better cover of soil (Karimian, Ghorbani, Koochaki, & Asadi, 2015). In this research, a higher growth rate of Bisi 18 intercropped with mungbean (Table 2) accelerated the covering of land by a canopy and thus reduced the solar radiation escaping and/or increased radiation interception efficiency. Kermah et al. (2017) state that the intercropping system converted the intercepted radiation into grain yield more efficiently than the monoculture. The research results are inline with the results obtained by Gong et al. (2020) which find that intercropping can increase proso millet yield by altering light distribution in canopy and consequently increasing RUE in comparison with monoculture.

Table 5. Interaction effect of maize variety and intercropping system on radiation use efficiency (RUE)

| Treatments | RUE of maize variety (%)*** |
|------------|-----------------------------|
|            | Local | Lamuru | Bisi 18 |
| Maize monoculture |       | 5.45a   | 8.12a   | 8.84a   |
| IC 1 MB    |       | 5.60d   | 8.29d   | 9.04d   |
| IC 2 MB    |       | 5.90c   | 8.51c   | 9.21c   |
| IC 3 MB    |       | 6.11b   | 8.64b   | 9.39b   |
| IC 4 MB    |       | 6.43a   | 8.80a   | 9.53a   |

Remarks: *) Values followed by the different capitalized letters at the same rows differ significantly under DMRT (p ≤ 0.05); **) Values followed by the different undercase letters at the same column differ significantly under DMRT (p ≤ 0.05); ***) IC = Intercropping, MB = Mungbean
Land Equivalent Ratio (LER) values obtained from intercropped maize with mungbean range from 1.70 – 1.89 (Table 6). LER values (>1.0) indicated that higher LER in the intercropping system significantly increased the RUE per unit area. The significant increase of RUE values were also observed in all maize varieties intercropped with mungbean. RUE was basically controlled by genetic construction (Monteith, 1972), but climate changes, planting geometry, and fertility of soil also play important roles in photosynthesis process (Akmal & Janssens, 2004; Ceotto & Castelli, 2002; Rosati, Metcalf, & Lampinen, 2004). The increase of RUE is caused by the increase in the accumulation of light harvest per cultivation area unit in the intercropping system due to the complement of elements in the interception of light against space and time (Zhang et al., 2008), and also the increase of radiation absorbed and the efficient radiation use per unit area (Bedoussac & Justes, 2010).

Table 6. Effect of maize variety and intercropping system on the land equivalent ratio (LER)

| Treatments | LER of maize variety |
|------------|----------------------|
|            | Local    | Lamuru   | Bisi 18 |
| IC 1 MB    | 1.76     | 1.71     | 1.70    |
| IC 2 MB    | 1.79     | 1.86     | 1.79    |
| IC 3 MB    | 1.82     | 1.87     | 1.85    |
| IC 4 MB    | 1.88     | 1.88     | 1.89    |

Remarks: IC: Intercropping, MB: Mungbean

The LER value (>1.0) in all treatments of intercropping between maize and mungbean (Table 6) indicates that there are better land cultivation and more efficient and productive land management in the intercropping system than monoculture. A similar result was obtained by Polnaya & Patty (2012), which find that LER were higher than 1.0 in all treatments of intercropping between maize and mungbean, and in intercropping maize with other types of legumes, like soybean, peanut, and cowpea (Kermah et al., 2017). LER value more than 1.0 explains that there was a complimentary and mutual interaction between mungbean and maize through the intercropping systems (Sabaruddin, Kilowasid, & Syaf, 2013). This indicates that by combining legume and cereal crops in the intercropping systems, competition between each plant (intraspecific and interspecific) to light could be minimized (Seran & Brintha, 2010; Worku & Demisie, 2012).

CONCLUSION

Radiation use efficiency (RUE) of maize in intercropping with mungbean was higher compared to maize monoculture. Having vertical leaves, Bisi 18 has higher RUE than Lamuru and local varieties when intercropped with mungbean with the values of 9.53%, 8.80%, and 6.43%, respectively. The highest RUE of Bisi 18 indicates that the vertical leaf of the respected variety is more efficient in utilizing the radiation when intercropped with dense mungbean population referring to the grain yield of 11.14-11.22 t/ha and LER values of 1.85-1.89.

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