1. **Manuscript Title:** **Internal-Edge Row Comparison In** ***Jajar Legowo* 4:1 Rice Planting Pattern At Different Frequency Of Fertilizer Application**

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**INTERNAL-EDGE ROW COMPARISON IN JAJAR LEGOWO 4:1 RICE PLANTING PATTERN AT DIFFERENT FREQUENCY OF FERTILIZER APPLICATIONS**

**ABSTRACT**

Jajar legowo 4:1 cropping pattern has been adopted by rice farmers; however, there has been limited information on comparison between internal and edge rows. In addition, the effects of timing and frequency of fertilizer applications on rice cultivated at riparian wetland have to be also understood. Therefore, the objective of this research was to compare agronomic performance of rice in internal and edge rows of jajar legowo 4:1 planting pattern at different timing and frequency of fertilizer applications. Timing and frequency of fertilizer application were: 15 DAT (T1), 30 DAT (T2), 45 DAT (T3), 15+30 DAT (T4), 15+45 DAT (T5), 30+45 DAT (T6), and 15+30+45 DAT (T7). Crops in the edge rows produced higher leaf area index but internal rows produced higher dry weight biomass. There was no different effect of row position on shoot and root growth and yield components. Fertilizer application three times did not affect shoot and root growth but increased weight of grains and number of filled spikelets. Fertilizer application increased leaf chlorophyll and nitrogen content. Jajar legowo 4:1 planting pattern and fertilizer application three times at 15, 30, and 45 DAT are recommended to improve yield in rice cultivated at riparian wetlands.

**KEYWORDS**

Cropping pattern, inorganic fertilizer, riparian wetland, split fertilizer application

**INTRODUCTION**

Rice is one of the most produced and consumed cereals worldwide since it served as the main stapple food, especially in Asia continent. There are more than 3.5 billion people in the world depend on rice for more than 20% of their daily calorie intake (IRRI, 2010). Increase of rice production and sustainable practices are important to the people who depend on rice for their livelihood. In order to meet rice demand, improving rice cultivation methods are necessary to increase its productivity and quality.

Among various agronomic factors, planting pattern has been considered as important factor in rice cultivation. One of widely practiced planting pattern for rice cultivation in Indonesia is *Jajar legowo*. There are numerous types of Jajar legowo, including 4:1 planting pattern. Jajar legowo 4:1 is a rice planting pattern by creating open rows after every 4 regular rows. Rice rows on both side of every open row are recognized as the edge rows and the other two rows within each 4 regular rows are the internal rows. For compensating the open row, plant spacing within each of edge rows is half of the normal plant spacing. Adjusting plant spacing is one of the important agronomic practices for increasing crop yield and reducing plants competition with weeds and plant-to-plant competition for available water and nutrient (underground competition) and light (above ground competition).

Jajar legowo 4:1 was adopted due to convenience in crop maintenance and higher population (Erythrina and Zaini, 2014). The other benefits of jajar legowo planting pattern are: (1) improving the quality of grain; (2) optimizing water and soil nutrient uptakes; (3) decreasing production cost (Mitrabuana et al., 2013). In addition, Jajar legowo was reported as an appropriate planting pattern to be applied as an effort to reduce GHG emissions (Toyibah et al., 2017). The most important effect of jajar legowo was producing higher yield and increased farmer income compare to that of conventional square or rectangle planting pattern (Toyibah et al., 2017; Mitrabuana et al., 2013).

Paddy field in Indonesia is under tremendous pressures of conversion to other uses, such as for housing and industrial areas. Thus, riparian wetlands have been targeted area for sustaining rice production in Indonesia. Riparian wetland is locally known as ‘rawa lebak’ which significantly affected by rainfall and water overflow from nearby river. Large acreage of riparian wetlands in Indonesia are found in Sumatra, Kalimantan, and Papua. Total area of riparian wetland in Indonesia is approximately about 13.30 million hectares. Since large acreage of wetland are still underutilized, it opens opportunity to increase rice production in this sub-optimal land. At present, rice productivity at riparian wetland is still very low, approximately 1-3 tons.ha-1. In addition to low productivity, cropping intensity is also low, due to environmental constraints. Crops usually encounter the risk of flood at vegetative growth phase and extreme drought at reproductive stage. Thus, increasing productivity and/or cropping intensity at suboptimal lands are very challenging.

Riparian wetland in Indonesia characterized by low soil pH and high soluble Al and Fe, as well as low nutrient availability. Fertilizer application is necessary to enhance rice growth and increase productivity at riparian wetland. Mahajan et al. (2011) suggested that inorganic fertilizer application was needed to provide sufficient nutrients at every growth stages. Nutrient availability is a very important for rice, not only for enhancing growth but also for improving yield. Local farmers have practiced various timing and splitting of inorganic fertilizer application, varied from once to thrice during rice growth after transplanting. Splitting fixed amount of fertilizer into two or more applications can increase nutrient use efficiency, promote optimum yields, and mitigate the loss of nutrients to open water. The excessive use of inorganic fertilizers causes low fertilizer use efficiencies and large amount of fertilizer polluting open water and atmosphere through various means. It brought negative impact on environment. Thus, the frequency and timing of fertilizer applications can play an important role in a nutrient management strategy to establish productive, profitable, and environmentally responsible rice cultivation practices.

Even though *jajar legowo* 4:1 planting pattern has been practiced by some rice farmers, there was limited study conducted on the comparison of rice plants positioned at internal and edge rows. In addition, the effect of timing and frequency of fertilizer application on rice cultivated at riparian wetland has to be also understood in order to increase nutrient use efficiency. Therefore, the objective of this research was to compare agronomic performance of rice plants at internal and edge rows of the jajar legowo 4:1 planting pattern at different timing and frequency of fertilizer applications.

**MATERIALS AND METHODS**

A field experiment was conducted from May to October 2016 at riparian wetland at Pemulutan District (3o01’49”S 104o44’07”E), South Sumatra, Indonesia. The soil was analyzed prior to research at the depth of 0–20 cm. The soil contained 43.65 g kg-1 C-organic, 2.63 g kg-1 total nitrogen, 85.05 mg l-1 available P, and 1.84 cmol.kg-1exchangeable K, with a pH of 4.47. The study area is 0.33 hectares of paddy field within a polder system equipped with an established water pumping system.

Ciherang variety was used in this study. Seeds were soaked in the water for 24 hours. Pre-germinated seeds were sown at a nursery plot applying *samir* system to produce rice seedlings. *Samir* system was done by placing growing substrate mix of soil and compost at 1:1 v/v on a 70 x 100 cm woven polyethylene mats and cover with the same mats until 1 week after sowing. The seedlings then transplanted to paddy field at age of 20 days after sowing. The plant spacing followed 4:1 jajar legowo planting pattern of 50 x 25 cm at open row, 25 x 25 cm at internal rows, and 12.5 x 25 cm at edge rows. Three seddlings were transplanted in soil at a depth of ±5 cm.

Timing and frequency of inorganic fertilizer application were: 15 DAT (T1), 30 DAT (T2), 45 DAT (T3), 15+30 DAT (T4), 15 +45 DAT (T5), 30+45 DAT (T6), and 15+30+45 DAT (T7). Each treatmet has three replications and separated with 30 cm high dike. However, total fertilizer application rate was similar for all treatments at 61 kg N ha-1, 15 kg P2O5 ha-1, 15 kg K2O ha-1, and 10 kg S ha-1. The rate, type, and method of fertilizer application were adopted from current local farmer’s practice. The fertilizers were evenly mixed and broadcasted to the experimental subplots according to each treatment.

The intensity of green color in leaves was measured a week after each fertilizer application using chlorophyll meter (Konica Minolta SPAD-502Plus). Based on SPAD value, chlorophyll and nitrogen contents were calculated. Crop biomass was sampled and partitioned at the end of vegetative growth stage and at harvest. Each crop organs (root, stem, leave) were separated and oven dried. Leaf length and width were measured to estimate leaf area, along with number of leaves. The collected data used for growth analysis, included: Leaf Area Index (LAI), Shoot to Root Ratio (SRR), Root Weight Ratio (RWR), and Total Dry Biomass (TDB).

**RESULTS AND DISCUSSION**

**Plant growth analysis**

Leaf Area Index (LAI) measures the amount of leaf material which imposes important controls on respiration, photosynthesis, rain interception, and other processes that link the vegetation to climate. In this study used to measure the amount of leaf in the internal and edge rows of rice cultivated in *jajar legowo* planting pattern. leaf area index (LAI) was higher on rice in the edge rows than those in the internal rows (Fig 1.A). Since edge rows had wider space, this might be due to the less competition for light interception and utilization than those at internal rows. Liu et al. (2016) reported that leaves exposed to optimum light are thicker, have a greater mass per area, a higher volume of photosynthetic machinery per unit leaf area and higher growth rates. In contrast, light deficit in internal rows weakened photosynthesis membrane system, decreased root and blocked photosynthate transport, then restrained leaf growth (Yang et al., 2011). Solar light provides energy source for photosynthesis. The carbohydrate produced by photosynthesis breakdown to release energy for growth. The balance of photosynthesis and respiration lead to optimum LAI. These arguments were also supported by Wang et al. (2013) who found that plants at edge rows tend to have a better ventilation and less competition for nutrient than those at internal rows.

Beside crop positions, timing and frequency of fertilizer application also affected LAI (Fig 1.A). Similar results obtained by previous study on cocoyam (*Colocasia esculenta*) cultivated in degraded ultisol soil (Anikwe et al., 2015) and on rice in irrigated rice in China (Chen et al., 2015). Twice fertilizer applications at 15+30 DAT or 30+45 DAT showed higher LAI as compared to others timing and frequency of fertilizer applications. LAI was also found higher with 3 times fertilizer applications at 15+30+45 DAT then those crops treated with once or twice applications at equal cumulative dosage. These findings suggested that split fertilizer application increased leaf size in an attempt to maximize light interception and maximize the production of assimilates needed for growth and development. LAI increased at higher doses of nitrogen, phosphorus, and potassium applied. LAI was reported to be significantly increase with split fertilizer applications due to more equal availability of nutrients at all plant growth stages. This might be the reason of small LAI on rice plants treated with fertilizer only at 15 DAT and 45 DAT. Nutrient availability at 30 DAT is necessary for leaf elongation in rice. Adequate and balance supply of nitrogen promoted vigorous vegetative growth and more green color of the crop and also influenced utilization of P, K and other nutrients which resulted in better crop growth.

On the other hand, total dry biomass (TDB) was higher on rice plants at internal than those at edge rows (Fig 1.B). Since internal crops obtained less light than edge rows, it triggers shoot growth. This finding was in contrast with Wang et al. (2013) who found that rice at internal rows produced lower biomass than those at the edge rows. Light deficit limited photosynthesis rate and then restrained leaf growth. The effect of timing and frequency of fertilizer on TDB was similar to LAI. Split fertilizer application tended to produce higher dry biomass than those crops treated with single fertilizer application. The possibility of fertilizer loss from the rhizosphere was higher at single application. Fertilizers might be lost through leaching, runoff, and/or volatilization if they are not absorbed by plants within a given period of time, dependent upon soil characteristics and environmental conditions. Split fertilizer applications reduce the potential losses. High TDBs were obtained with twice fertilizer application at T4 and T6 with an exception at T5, while the highest TDM found at 3 times split applications (T7). This indicated that the split fertilizer application was efficiently utilized by the plant, thus making it possible for the plant to translocate the carbohydrates into the organs.

Shoot to root ratio (SRR) of rice was relatively similar both at edge and internal rows if fertilizers split for 3 or 2 applications during vegetative stage. It was due to jajar legowo planting pattern makes all plants into plants aside to absorb sunlight and good air circulation. Interestingly, single fertilizer application at early vegetative stage increased SRR on rice at the edge rows (Fig 2.A). Yet, late fertilizer application increased SRR on rice at the internal rows. According to Hayat et al. (2013), decrease in light irradiance (a sum of total light that plant could absorb) caused an increase in shoot elongation. Shoot growth could be leaves and stems, but in this study LAI of plants at internal rows was lower than those at edge rows. It showed that shoot growth as affected by low light was mainly occurred in stem of rice. The effect of fertilizer application on SRR was supported by higher root weight ratio (Fig 2.B). It appeared that a smaller value of shoot to root ratio was mainly as a result of higher root weight rather than smaller shoot weight. Consistent with shoot response to above-ground conditions, so root biomass influenced by below-ground conditions. It means that low availability of either water or nutrients commonly leads to greater root:shoot ratio.

Both shoot and root increases were associated with late fertilizer applications of 30 DAT, 45 DAT, and other treatments combined with both or either of these late applications. It assumed that existing nutrients at riparian wetland are sufficient for early vegetative stage of rice. The study of Yoseftabar (2012) revealed that young rice before the tillering stage grew slowly and did not need much fertilizer therefore only a small to moderate amount of fertilizer needed. However, at later growth stages, higher amount of nutrients was required for rice growth and development. In contrast, Binder et al. (2000) found that crop yields declined when fertilizer applications were delayed. Late fertilizer application probably does not allow sufficient time for nutrients uptake and utilization for supporting plant growth and development. Split fertilizer application was better in supplying sufficient nutrients to the plants. Split fertilizer application increased nutrient use efficiency.

Root length was measured to observe the effect of crop position, timing, and frequency of fertilizer application on underground competition. However, in our study the effect of crop position on root length was inconsistent, it was varied with different timing and frequency of fertilizer application (Fig 2.C). The wider spacing of tillers would probably improve the root growth both vertically and horizontally as compared with a narrower spacing narrower. In this study, RWR was not affected by root length. It was found that the higher RWR was in contrast with root length. According to Carmeis et al. (2017), the root length density was a genetically controlled character and caused the differences among cultivars. Root length increased at higher frequency of fertilizer application, especially for plants at internal rows. In order to sustain and improve mineral nutrition status, plants must either use: (1) an extensive strategy and invest assimilates, which leads to an increase in biomass and length of the fine roots; or (2) an intensive strategy, with morphological adaptations of the fine roots.

**SPAD value, chlorophyll content, and nitrogen content**

SPAD value on rice plants at both edge and internal rows were not significantly different at all scheduled observations (Fig 3.A). While, the frequency of fertilizer application strongly affected SPAD value as indicated by the trend of SPAD values at a week after each fertilizer application (Fig 3.B). SPAD value was higher on fertilized crops than unfertilized crops. It suggested that nutrients were absorbed by crop and utilized to increase leaf chlorophyll content and nitrogen content. Similar result was reported by Yoseftabar et al. (2012) that split fertilizer applications significantly affected SPAD values. Our study revealed that the SPAD value increased significantly with split fertilizer applications at 4 rice growth stages. Nitrogen application can be applied three or four times at different growth stage based on crop needs and growing conditions.

SPAD value was measured to estimate leaf chlorophyll contents and N kjeldahl contents (Table 1). Swain at al., (2010) reported that chlorophyll meter provides instantaneous and nondestructive information on crop N status. In addition, Hassan et al., (2009) stated that SPAD reading indicated the plant nitrogen status which could be used as reference for application of nitrogen fertilizer to satisfy nitrogen requirement of crop at different growth stages. In general, SPAD measurement is performed on the first fully expanded leaf at different developmental stages. Early-season readings of SPAD in plants provide useful information on plant nitrogen status. On the other hand, SPAD readings at heading can predict grain yield in a more accurate way. Nitrogen is one of the most limiting nutrients in agricultural ecosystems. It enters the soil only in miniscule amounts through natural precipitation and biological N fixation. Although N is present in the soil, only a limited amount is available to plants. Since plants require large quantities of N, the addition of greater dose than those of any other primary nutrients is important. In this study, split application of fertilizer increased SPAD value as well as N content due to higher N availability at all growth stage.

The increment of SPAD value in this study was also affected by the addition of potassium. According to Fanaei et al. (2012), increase in leaf SPAD values due to addition of potassium was associated with the increase of nitrate reductase enzyme activity. Potassium application promoted the activity of nitrate reductase enzyme and thus also nitrate assimilation by the plant, thereby increasing leaf chlorophyll content. SPAD value is important to estimate chlorophyll and N kjeldahl contents. However, successful use of SPAD to estimate chlorophyll contents can be influenced by many factors such as rice variety, growth stage, leaf position and the sampling point on the leaf (Huang et al., 2008).

**Effective tiller and other yield components**

Grain yield of rice is highly dependent upon the number of effective tillers per produced by each plant. However, in this study the effect of plant position on number of tillers and productive tillers were not consistent (Fig.4). The higher number of total and effective tillers at the edge rows showed at T1 and T4. The lowest of total and effective tillers at internal rows obtained by T3 and T5. While T2, T6 and T7 showed similar number at the edge and the internal rows. Results showed that number of tillers were more affected by fertilizer application frequency. Number of tillers in rice mainly affected by variety, time of transplanting, planting system, water supply and fertilizer application (Tian et al., 2017). In this study, twice fertilizer applications at early vegetative stage increased number of tillers as it was an active phase for tiller development. Number of effective tillers per hill is the most important yield component.

Increasing grain yield is the most important subject of rice cultivation in riparian wetland. Grain yield is a resultant of interactions among various yield components. Results indicated that there was no significant effect of crop positions on yield components, including panicle length, grains per panicle, filled spikelet and sterile spikelet. Whereas fertilizer application was significantly affect weight of grains per panicle, percentage of filled spikelet and sterile spikelet (Table 2). Panicle length and grains per panicle variables are important for resulting higher yield. Split fertilizer application at 15+30+45 DAT increased grains per panicle as compared to other treatments with once or twice fertilizer applications. The numbers of panicles are associated with the tiller production which is most important yield attributing character. The number of tillers are developed during vegetative stage. Therefore, an appropriate amount of fertilizer application would trigger tillering phase and resulting a higher yield.

Increase in nutrients uptake leading to increase in chlorophyll content, enhance carbohydrate synthesis, higher accumulation of photosynthates and their distribution to the developing ovules, better grain development, higher percentage of filled spikelet, increase in weight of grains per panicle, and at the end produces higher yield (Manjunath et al., 2008). Filled spikelet per panicle was a most importance yield component in which was affected rice yield. The crops fertilized with two and three times of applications showed the higher percentage of filled spikelet. Spikelet number and number of filled spikelets are largely determined in the reproductive stage. Once and twice fertilizer applications lead to insufficient nutrients during grain filling process and reduce grain numbers per panicle (Wei et al., 2011). One of the mayor factors determining grain filling is the shortage of assimilate supply due to inhibition of photosynthetic processes (Yoseftabar, 2013). There is no hesitation, if farmers usually apply fertilizer late at panicle initiation stage as it is highly effective in enhancing the spikelet number.

The study showed that there was no significant difference in panicles length was observed between timing and frequency of fertilizer application treatments. However, T1 fertilized at 15 DAT and T7 fertilized at 15+30+45 DAT resulted longer panicle than the other treatments did (Table 2). Nitrogen, phosphorus, and potassium are major nutrients associated with yield. Its availability promotes crop growth and tillering, finally determining the number of panicles and spikelets during the early panicle formation stage (Yoseftabar et al., 2012). In this study, weight of grains per panicle was associated with fertile spikelet. In rice, many factors affect the spikelets per panicle, such as genotype, cultural practices and growing conditions (Yoseftabar et al., 2012). Nutrients managemet is important in improving the balance between crop nutrients demand and nutrients supply from soil and applied fertilizer to produce high grain yield.

In this study, frequency of fertilizer application showed higher effect on rice growth at riparian wetland ecosystem. The indigenous nutrient supply of soils in riparian wetland is not sufficient to support the intensive cropping system. Meanwhile, nutrient availability plays very important role in supporting rice growth both of micronutrients and macronutrients. Rice cultivation, particularly in riparian wetland ecosystem, needs careful nutrients management. Nitrogen, phosphorus, and potassium are three most important elements for crop growth and are susceptible to being lost from soils, especially if a planting area receives high quantities of precipitation. Nitrogen can be loss through leaching, denitrification, erosion and surface volatilization. Phosphorus which the movement in the soils is very slow and crop roots can uptake only from very close surroundings. When first applied to soil it is in its soluble and available form but then quickly becomes unavailable for plants through fixation process. In addition, since phosphorus applied by broadcasted at the top soil layer, it mainly losses are through surface runoff and soil erosion. Additionally, timing of fertilizer application would also improve both vegetative growth and yield along with the management of application rate and its frequency. Earlier fertilizer application increases the risk of nutrient loss from the root zone, whereas nutrient application after the period of rapid nutrient uptake can reduce plant its uptake by plants. Appropriate fertilizer management practice is important for reducing the risk of negative environmental impact, especially in intensively manages cropping system. While, inappropriate or excessive application does not guarantee constantly increasing yields. It might result in low nutrient use efficiency, and can cause environmental problems in agro-ecosystems.

**CONCLUSIONS AND SUGGESTION**

Rice plants at the edge rows in jajar legowo 4:1 planting pattern resulted higher leaf area index but the plants at internal rows produced higher total dry mass. Fertilizer application three times during vegetative growth increased grain weight per panicle, number of filled spikelet, chlorophyll and nitrogen contents. In order to improve rice growth and yield, jajar legowo 4:1 planting pattern and fertilizer application three times at 15, 30, and 45 DAT are recommended.

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**Figures and Tables**

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|  |

Fig 1. Contrary effect of different frequency of fertilizer application on leaf area index (A) and total dry mass (B) on rice in internal and edge rows 4:1 planting system

|  |
| --- |
| A |
| B |
| **C** |

Fig 2. Effect of different frequency of fertilizer application on shoot to root ratio (A), root weight ratio (B), and root length (C) on rice in internal and edge rows 4:1 planting system

|  |
| --- |
|  |
|  |

Fig 3. SPAD value on rice in internal and edge rows in 4:1 planting system (A) and on crops treated with different time and frequency of fertilizer application (B)

Fig 4. Effect of crop positions and frequency of fertilizer application on number of total and effective tillers

Table 1. Chlorophyll and nitrogen content during vegetative stage of rice treated with different frequency of fertilizer application

|  |  |  |  |
| --- | --- | --- | --- |
| Timing of fertilizer application  application | Sampling day | | |
| 22 DAT | 37 DAT | 52 WAT |
|  | Chlorophyll content (mg.g-1FW) | | |
| T1 | 2.220±0.113\* | 1.823±0.104 | 1.697±0.221 |
| T2 | 1.687±0.282 | 2.057±0.351 | 1.794±0.254 |
| T3 | 1.901±0.250 | 2.009±0.157 | 2.061±0.091 |
| T4 | 2.087±0.081 | 1.898±0.165 | 1.754±0.0.191 |
| T5 | 1.865±0.086 | 1.830±0.069 | 1.912±0.227 |
| T6 | 1.835±0.110 | 2.105±0.176 | 1.958±0.041 |
| T7 | 1.991±0.207 | 1.970±0.054 | 1.992±0.067 |
|  | N kjeldahl (mg.g-1) | | |
| T1 | 68.490±2.570 | 59.424±2.372 | 56.550±5.040 |
| T2 | 56.315±6.432 | 64.757±8.010 | 58.766±5.788 |
| T3 | 61.200±5.710 | 63.657±3.582 | 64.851±2.082 |
| T4 | 65.450±1.848 | 61.141±3.757 | 57.843±4.357 |
| T5 | 60.377±1.953 | 59.583±1.575 | 61.459±5.179 |
| T6 | 59.695±2.499 | 65.862±4.011 | 62.499±0.934 |
| T7 | 63.252±4.727 | 62.781±1.221 | 63.275±1.538 |

\* Mean ± standard deviation

Table 2. The effect of timing and frequency of fertilizer application and crop positions on yield components

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Treatment | Panicle length | Grains per panicle | | Filled Spikelets/Panicle | | Sterile spikelets/panicle | |
| (cm) | (g) | | (%) | | (%) | |
| Timing and splitting of fertilizer application | | | | | | | |
| T1 | 26.9 | 3.97 | b\* | 85.73 | b | 14.27 | b |
| T2 | 26.1 | 3.96 | b | 86.51 | b | 13.49 | b |
| T3 | 23.49 | 3.79 | b | 84.22 | b | 15.78 | b |
| T4 | 26.22 | 4.44 | a | 90.54 | a | 9.46 | a |
| T5 | 25.72 | 3.69 | b | 85.87 | b | 14.13 | b |
| T6 | 25.48 | 4.46 | a | 90.74 | a | 9.26 | a |
| T7 | 26.74 | 4.63 | a | 89.44 | a | 10.56 | a |
| LSD (0.05) |  | 0.45 | | 6.57 |  | 6.07 | |
| Crop position | | | | | | | |
| P1 | 25.81 | 4.02 | | 86.85 | | 13.15 | |
| P2 | 25.79 | 4.25 | | 88.31 | | 11.69 | |

\*Mean values within a column followed by the same letters are not significantly different at p < 0.05