Selected soil nutrient availability, plant nutrient uptake and upland rice yield in response to rice straw and mycorrhiza application

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Abstract. Climate change such as long drought will have an impact on food supply. Adaptation to these conditions must be conducted by improving food production. This study aims to determine the effect of straw and mycorrhizal use on soil moisture, nutrient availability and uptake as well as upland rice yield. This field trial used 3 x 2 factors, with 4 replications arranged in a Complete Randomized Block Design. The first factor consists of without straw; fresh straw (10 ton/ha); and weathered straw (10 ton/ha). The second factor was without and with mycorrhizae (5 gram/plant). The result showed that the application of fresh straw and weathered straw combine with mycorrhizal inoculation can increase soil moisture, improve the availability of soil N, P, K, increase the uptake of N, P, K. There is a positive correlation between soil moisture content with the uptake of N, P, K on the plant. Moreover, The highest grain yield (3.9 ton/ha) was obtained at the weathered straw combine with mycorrhizae. An application of rice straw in any condition can optimize soil fertility and can be used as a way of adaptation to climate change.

1. Introduction
Climate change such as long drought will have an impact on the development of dry land in Indonesia. The content of soil moisture content has a very important role in the absorption and movement of plant nutrients, so it will disrupt various physiological processes of plant growth and crop failure. In addition, the use of dry land will face obstacles such as fertility levels and low levels of organic matter [1]. Providing organic materials such as rice straw is one way to improve soil fertility. Gupta et al. [2] revealed that the return of straw plays a role in recycling plant nutrients and increasing soil organic carbon (C), as well as increasing nutrient content and can even reduce the use of N fertilizer [3]. The application of straw can also increase the potassium availability (exchangeable and nonexchangeable K) and the Cation-exchange capacity of the soil by 28.6% and 15.3%, respectively, while the straw added with biological fertilizers or organic fertilizers can reduce the use of artificial NPK fertilizers by up to 50% [4].

Syamsiah et al. [5] demonstrated that the application of mycorrhiza could improve soil aggregate stability. Indriani et al. [6] studied that the application of organic matter and mycorrhiza could improve
the uptake phosphate on the Kudzu Tropika (*Pueraria Phaseoloides* Benth.). Chairuman [7] declare that the combination of mycorrhiza and straw compostable to improve the productivity *gogo* paddy (dryland variety) and P uptake in the Ultisol soil. The application of organic ameliorants and mycorrhiza were increasing the status of soil phosphate and corn result on the Andisol soil [8]. However, research on the utilization of either fresh straw or weathered straw which combine with mycorrhiza is still limited. This study aims to determine soil moisture content, availability, nutrient uptake, and paddy yield on the dry field by utilize straw combine with mycorrhiza.

2. Methods
This study was conducted in a farmer's garden in the Sukasari village, Jumantono district, Karanganyar regency, Indonesia. The soil research site is classified as Alfisol which is usually used to plant secondary crops during the dry season and rice during the rainy season. The experiment used a completely randomized block design with two factors and four replications. The first factor consisted of without straw, fresh straw and weathered straw, while the second factor was without mycorrhizal and mycorrhizal. Weathered straw is straw that was harvested one growing season earlier whereas fresh straw is straw that has just been harvested. The straw was given 4 weeks before planting by planting it in an experimental plot measuring (2 x 3) m$^2$ while mycorrhiza is given along with planting. IR 64 rice seedlings aged 15 days were planted at a spacing (25 x 25) cm. Soil samples were taken before the experiment to see various soil properties such as texture, pH, C–organic, N, P and K, and at the end of the experiment for soil nutrient variables (total N, P available, K available) and the soil moisture level. Along with soil sampling at the end of the experiment, 5 plants were taken randomly, to observe the uptake of N, P and K, and rice yields. Data analysis used variance (F test) with a 95% chance, seen by the DMR test to compare data between treatments and trials.

3. Result and discussion
The soil in this research has a texture of clay texture because the soil fraction is dominated by clay and the organic C content is very low (Table 1). Both of these characteristics can affect the value of the soil CEC [3] and are correlated with the CEC of this land to be classified as moderate.

| Soil characteristic | Value | Type * |
|---------------------|-------|--------|
| pH H$_2$O (1:2.5)   | 5.93  | slightly acid |
| C organic (%)       | 0.95  | very low |
| N total (%)         | 0.11  | low |
| P$_2$O$_5$ available (ppm) | 6.90 | low |
| K available (cmol(+)/kg$^{-1}$) | 0.31 | low |
| KPK (cmol (+) kg$^{-1}$) | 20.00 | medium |
| Soil texture: Sand (%) | 27.49 | clay |
| Dust (%)           | 16.96 |
| Clay (%)           | 55.56 |

Table 2. Nutrient content in fresh straw and weathered straw.

| Kind of straw   | C (%) | N (%) | C/N  | P (%) | K (%) |
|-----------------|-------|-------|------|-------|-------|
| Fresh straw     | 57.01 | 0.92  | 61.97| 0.92  | 0.75  |
| Weathered straw | 39.44 | 1.15  | 37.56| 0.83  | 0.65  |

The availability of total N and P$_2$O$_5$ were low, this is related to the very low levels of organic C. Table 1 show that the value of available K is low, this result is suspected because the farmers never provide fertilizer especially K. Based on the characteristics of the soil in Table 1, the Alfisol soil used has low soil fertility. The straw used in this study has different properties which is the difference in
nutrient content and the ratio of C to N will affect the release of nutrients through the decomposition process (Table 2). has C/N value, the content of P and K in the fresh straw was higher than weathered straw.

3.1. Soil nutrient
The application of Mycorrhizal accompanied by straw was significantly increased total N (P <0.05), soil available P content (P <0.05), but not significantly affected the available K (P > 0.05). This result is not in line with the research of Hasanudin [9], which concluded that there was no interaction between organic matter and mycorrhizae on the availability of N and P. Table 3 shown that the application of fresh straw with or without were not providing the increase of total N in the soil, but the application of weathered straw with mycorrhizae being able to provide a total N increase of 0.17%, it was 70% increase compared to control. This result is in line with Ardiani et al. [10], that the application vermicompost with mycorrhizae gave a total N increase by 85% compared to mycorrhizal alone.

The availability levels of P ranged from 8.08 to 9.70 ppm. The application of mycorrhizal without straw was able to increase available P by 13.6%. These results are in line with the research of Nurmasyitah et al. [11], that giving AMF was able to increase available P compared to without mycorrhizae. The treatment of straw in several ways with or without mycorrhizae was able to increase the soil available P. Giving Mikorriza accompanied by fresh and weathered straw gave a significant increase in available P by 12.6% compared to control.

Table 3. The content of N, P, K in the soil with straw and mycorrhizae.

| Mycorrizha | Straw   | N total % | Available P (ppm) | Available K (cmol/kg) |
|------------|---------|-----------|-------------------|-----------------------|
|            | 0       | 0.10 a    | 8.08 a            | 0.36 a                |
|            | Fresh (S 1) | 0.11 a   | 8.78 b            | 0.40 a                |
|            | Weathered (S 2) | 0.10 a  | 8.70 b            | 0.47 a                |
| with       | 0       | 0.13 b    | 9.18 b            | 0.50 a                |
|            | Fresh (S 1) | 0.11 a   | 8.80 b            | 0.51 a                |
|            | Weathered (S 2) | 0.17 c   | 9.70 c            | 0.53 a                |
| non +      | 0       | 0.10 a    | 8.08 a            | 0.36 a                |
|            | Fresh (S 1) | 0.11 a   | 8.78 b            | 0.40 a                |
|            | Weathered (S 2) | 0.10 a  | 8.70 b            | 0.47 a                |
|            | 0       | 0.13 b    | 9.18 b            | 0.50 a                |
|            | Fresh (S 1) | 0.11 a   | 8.80 b            | 0.51 a                |
|            | Weathered (S 2) | 0.17 c   | 9.70 c            | 0.53 a                |

The numbers in one line followed by the same letter were not significantly different according to the DMR test at the 95% confidence level.

3.2. Soil moisture content, N, P, K uptake and rice yield
The results showed that there was an interaction between the application straw and mycorrhizal inoculation toward N uptake (p = 0.022), P uptake (p = 0.012), and K uptake (p = 0.000).

Table 4. Soil moisture level, nutrient N, P, K uptake of rice treated with straw and mycorrhizae.

| Mycorrizha | Straw   | Soil Moisture Level (%) | N     | P     | K     |
|------------|---------|-------------------------|-------|-------|-------|
| non 0      | 0       | 13.41 a                 | 0.45 a| 0.15 a| 0.09 a|
| Fesh (S 1) | 17.35 b | 0.68 bc                 | 0.21 b| 0.18 c|       |
| Weathered (S 2) | 19.06 b | 0.55 ab                 | 0.19 a| 0.12 ab| 0.20 c|
| + 0        | Fesh (S 1) | 18.49 b | 0.55 ab | 0.17 a | 0.15 bc |
| Weathered (S 2) | 19.28 c | 0.79 c                 | 0.25 b| 0.25 d|       |

The numbers in one line followed by the same letter were not significantly different according to the DMR test at the 95% confidence level.

Mycorrhizal inoculation in the soil that was applying to the fresh straw or weathered straw could increase soil moisture content and the uptake of N, P and K. The highest soil water content was obtained
in the application of weathered straw and mycorrhizal, which increased by 43.77% compared to the control (no straw, no mycorrhiza). Table 4 shown that the inoculation of mycorrhizal on soils without straw were significantly increased nutrient uptake of N, P, K by 66.08; 63.34; 110.79%, respectively. Meanwhile, the N, P, K uptake in weathered straw treatment and mycorrhizal inoculation were showing increased by 72, 105, 172%, respectively. In addition, fresh straw with mycorrhizal inoculation was increasing by 65, 81, and 110% compared to controls.

Table 5 shows that there was an interaction between straw and mycorrhizal inoculation on the wight of milled dry grain (p = 0.011). However, the application of mycorrhizal inoculation without giving fresh straw or weathered straw did not significantly increase milled dry grain yields. The application of weathered straw with mycorrhiza inoculation increased rice yield by 23.7% compared to control.

Table 5. The Rice yield after being given straw and mycorrhizal inoculation (kg/ha).

| Straw          | Mycorrhiza inoculation | Arrange |
|---------------|------------------------|--------|
|               | without                | With   |        |
| Without       | 3166.67 c              | 3500.00 bc | 3333.34 |
| Fresh Straw   | 3333.33 bc             | 387500 a  | 3645.83 |
| Weathered straw | 3666.67 ab          | 3916.66 a  | 3791.67 |
| Arrange       | 3388.89                | 3791.66 |

The numbers in one line followed by the same letter were not significantly different according to the DMR test at the 95% confidence level.

The increase of rice yield on the provision of weathered straw without mycorrhizal inoculation was due to the treatment obtained a lot of N, P, and K uptake derived from a straw so that it would encourage better plant growth, with higher plant height and more tillers so that it would give better rice yields. In addition, mycorrhizae also produce enzymes that destroy organic compounds such as protein, chitin, pectin and others [12] and can increase plant yields, through their ability to overcome stress to water deficiency and increase nutrients absorption [13].

The application of organic matter such as straw into the soil will change the availability of plant nutrients through its effect on soil physical properties such as increasing the ability to bind water and soil porosity, soil looseness, and soil biology as well. The results of this study indicated that there was a significant increase in the application of straw and mycorrhizae on soil water content and nutrient availability in the soil, nutrient uptake, and rice yield in the Alfisol. However, the response shown by fresh straw is different from that of weathered straw. The application of weathered straw with mycorrhizal inoculation provided higher N, P, and K availability compared to fresh straw. This is assumed that weathered straw has a lower C/N. According to Neumann and George [14], organic matter with a low C/N ratio will decompose more quickly and release nutrients into the soil.

This research showed the increase of nutrient uptake on the rice that was inoculated by mycorrhizal with giving the straw. Neumann and George [14], reveal that mycorrhiza plays an important role in host plants because it could be assisting plants to absorb P, N, and K nutrients. The increase of plant nutrients by applying straw and mycorrhizal inoculation also occurred in Pelargonium which was inoculated by mycorrhizae and provided compost. Perner et al. [15] assumed by the influence of mycorrhizae in increasing the ability of plants to absorb nutrients supplied from decomposed organic matter in the soil. The high uptake of N and P nutrients in the plants inoculated by mycorrhizal is assumed that the uptake of P from the soil and organic matter is more efficient because the plant inoculated by mycorrhizal was producing phosphatase enzymes [13].

This research showed that mycorrhizal inoculation increased the uptake of N, P and K. This was due to that plant's given mycorrhizae had higher root CEC (data not shown). The root CEC has an important role in nutrient absorption [16]. The roots that are infected with mycorrhizae will have a wider range
due to the presence of external hyphae that develop outside the roots, so that plant nutrient uptake increases. In this study, there was a positive relationship between the root CEC with N absorption (r = 0.324), P absorption (r = 0.356) and K absorption (r = 0.370). That plants with mycorrhizal besides increasing the absorption of P nutrients, also absorb other nutrients such as N, K, and other elements such as Ca, Mg, Fe, Cu, Na, S, Mn, and Zn. Moreover, Smith et al. [17] stated that Arbuscular mycorrhizal fungi have many effects on plant nutrition, especially on nutrient uptake [13], such as N uptake [18] and P uptake [19].

The increase of milled dry grain yield from the application of straw with mycorrhizal inoculation is caused by increasing the content of soil moisture, which is very important for the movement and absorption of nutrients. The results of this study indicate that there is a positive correlation between soil moisture content and uptake of N (r = 0.734), P (r = 0.378), and K (0.405 **). Also, organic matter has functions to improve soil structure, stimulate granulation for increasing pore space that will provide oxygen to the development and mycorrhizal activity. This condition is very supportive of root development because the increase of root development makes the opportunity for mycorrhizae to colonize the roots of paddy gogo is greater. Moreover, this condition could increase the absorption of nutrients N, P and K which finally more milled dry grain was obtained. The analysis of this research showed that Dry Grain Milled was positively correlated with P uptake (r = 0.451 *), K uptake (r = 0.523 **) and N uptake (r = 0.368). Regarding Weil and Brady [3], there is an increase in the yield of paddy gogo by providing straw compost and mycorrhiza.

4. Conclusion

The application of straw together with mycorrhiza inoculation significantly increased soil moisture content, nutrient uptake, and rice yield. There is a positive correlation between soil moisture content with the uptake of N, P, K on the plant, as well as nutrient uptake with rice yields. The availability of soil N, P, K and the uptake of N, P, K increase by 65, 81, 110% and by 72, 105, 172% compared to control respectively The highest grain yield (3.9 ton/ha) was obtained at the weathered straw combine with mycorrhizae.

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