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Impact of Controlled-Release Fertilizer on Avaibility of Phosphorus, Sulphur, Iron, Copper, Zinc, Manganese, and Production of Red Onion (*Allium ascalonicum* L.)

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ABSTRACT

Fertilization plays a crucial role in meeting the nutrient requirements of plants to achieve optimal production. The application of controlled-release fertilizer (CRF) on red onion cultivation holds the potential to enhance fertilizer efficiency while reducing water pollution. This study aimed to investigate the impact of CRF application on the availability of essential nutrients of P, S, Fe, Cu, Zn, Mn, and production of red onion (*Allium ascalonicum* L.). The research was conducted in two stages, an incubation experiment in laboratories and field experiments. The treatments included three types of fertilizers, P1: NPKCaMgS (13-8-10-5-9-2), P2: NPKS (19-12-15-4), and Mutiara: NPK (16-16-16). For the incubation experiment, two fertilizer doses were used: D6 (600 kg/ha), D12 (1200 kg/ha), along with a control group. For the field experiments, four fertilizer doses were employed: D3 (300 kg/ha), D6 (600 kg/ha), D9 (900 kg/ha), D12 (1200 kg/ha), also with a control group. The results indicated that the availability of P, Cu, and Mn increased with a longer incubation period, while the availability of Fe and Zn decreased over time. The availability of S exhibited irregular patterns with an extended incubation period. Notably, the highest onion production was achieved using NPKCaMgS (13-8-10-5-9-2) at a dose of 300 kg/ha.

Keywords: controlled-release fertilizer, food security, micro nutrients, red onion.

INTRODUCTION

Fertilizer is a very important means of agricultural production to achieve food security. Many thorough studies have shown that fertilizer is vital for sustaining crop production (Wang et al., 2019). For the growth and development of plants, fertilizers give important minerals including potassium, phosphorus, and nitrogen (Sedlacek et al., 2022). Additionally, fertilizers offer several benefits for agriculture, including speeding plant development, improving soil health, controlling soil pH, allowing with human nutritional needs, and increasing crop yields (Zhai, 2022). The growth of plants and crops depends on fertilizers, which are also necessary for modern agriculture (Kaur et al., 2023). Food security consists of three major components: maintaining enough and balanced food availability, effective food distribution, and allowing population access to food both physically and economically (Suwardi, 2021). To achieve the goal of maintaining and balanced food availability, it is important to focus on effective plant growth, optimal development, and increased crop yields. One of the strategies to reach this goal is through the implementation of suitable fertilization practices (Nichols et al., 2024).

However, inappropriate or excessive fertilizer application can result in decreased nutrient use efficiency and environmental issues in agricultural systems. For example, excessive nitrogen fertilizers damage soil, contribute to water pollution and greenhouse gas emissions. Nitrogen fertilizer can also cause soil acidification. Phosporus fertilizers lead to water eutrophication and soil contamination with heavy metals (Bijay-Singh et al., 2023). Therefore, it is important to use fertilizer carefully to maximize productivity while minimizing harm to the environment (Yousaf et al., 2017). Using controlled-release fertilizers (CRF) is a valuable approach to maximize the utilization of fertilizers (Wu et al., 2023).

CRF are made to control how quickly nutrients are released into the soil so that it satisfies the individual needs of the plants. They provide a practical way to improve nutrient utilization effectiveness and reduce negative environmental effects (Rajan et al., 2021). When compared to quick-release fertilizers like ammonium nitrate or urea, ammonium phosphate, and potassium chloride, CRF supply the plant with nutrients that are available over a longer period of time (Liu et al., 2014). CRF fertilizer's release rate is created such that nutrients are released gradually and steadily, which is better for the growth and development of plants. By dynamically releasing nutrients, CRF may accommodate crops changing nutrient requirements throughout their growth cycle. This capability lessens the amount of nutrients used while increasing the effectiveness of nutrient usage (Vejan et al., 2021).

Notably, the nutrient release rate of CRFs is affected by various factors, such as coating thickness, the presence of micropores on the coating surface, and coating defects (Tian et al., 2022). In addition to improving the performance of the coating, the surface structure of the fertilizer core also has a great effect on the controlled release properties. The fertilizer particles are not smooth, ideal spheres but irregular spheres with a rough and uneven surface. Defects on the surface of these fertilizer cores will cause coating defects, resulting in uncontrolled and uneven nutrient release. Red onion is one of the strategic horticultural commodities in Indonesia, considering this commodity is very high consumption as a daily spice and fluctuating price. It has high economic value and makes a big contribution to the development of a region (Sudaryono et al., 2018). According to the Food Balance Sheet (FBS), the national consumption of red onions in Indonesia from 2005 to 2019 exhibited a consistent upward trend of 5.40% per year. Over the last five years, the average annual increase was 4.07%, resulting in an average national consumption of 857.17 thousand tons during this period (Kementan et al., 2020). The FBS defines availability as the net quantity obtained by subtracting exports, seeds, losses, and food use (including industrial use) from the sum of production and imports.

Based on previous studies, the application of phosphorus (P) fertilizer at a dosage of 80 kg/ha in red onion cultivation has resulted in the best growth and yield (Meena, 2007). The effect of P fertilization on yield and quality of onion bulbs was also studied, and the results showed that the highest yield was obtained with a dose of 120 kg/ha of P (Jose et al., 2016). N, P and other macronutrient and fertilization of red onions can be improved with CRF, which can enhance nutrient uptake and utilization by crops, reducing the risk of nutrient wastage and leaching (Geisseler et al., 2021). According to another study, fertilizer doses of 92 kg/ha N and 242 kg/ha NPS can enhance onion productivity. Onion productivity is low due to inefficient and ineffective utilization of soil macronutrients (Shura et al., 2022). It is critical to optimize the application of soil macronutrients in order to maximize onion output, raise farmer revenue, and improve the livelihoods of onion producers in the community. By utilizing CRF in red onion cultivation, the nutrient management practices can be optimized, leading to improved onion production and increased economic benefits.

Therefore, the objective of this study is to investigate the impact of CRF application on the availability of essential nutrients, including phosphorus (P), sulphur (S), iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn), as well as red onion (*Allium ascalonicum* L.) production.

MATERIALS AND METHODS

The fertilizer incubation study was conducted from December 2017 to March 2018, followed by soil analysis at the Laboratory of Soil Science and Land Resources Department, Faculty of Agriculture, IPB University. The field experiment was carried out from July to October 2018 in the agricultural land of Sagara Village, Argapura District, Majalengka Regency, at an elevation of 660 meters above sea level. Materials used in this experiment were composite samples of Latosol soil from Cikabayan for the incubation test and Latosol soil from the agricultural land in Sagara Village for the field experiment. The fertilizers used included chicken manure as the base fertilizer for red onion planting, CRF P1 NPKCaMgS (13-8-10-5-9-2) and P2 NPKS (19-12-15-4), and also NPK Mutiara (16-16-16). The CRF P1 and P2 were mixed with zeolite, with a quantity of 222.38 g added to P1 and 76.06 g added to P2 per 1 kg of fertilizer. The characteristics of zeolite are presented in Table 1. The experiment also utilized "Bima Brebes" red onion seeds, pesticides, and various chemicals for soil analysis. This study was separated into two sections. The first stage required evaluating the availability of P, S, Fe, Cu, Zn, and Mn. The second section included a field experiment to see how fertilizers affected the development and production of red onions.

Zeolite Tasikmalaya has different types of minerals, mainly clinoptilolite and mordenite, likely due to the environment it formed in. This zeolite has a lot of places with negative charges, making it good at swapping ions. It prefers to swap calcium ions, suggesting more clinoptilolite-Ca minerals. The zeolite also has high levels of base saturation (BS) and pH, meaning it has fewer acidic ions (H^+), resulting in a higher pH. Zeolite Tasikmalaya can absorb metal ions like Cu, Pb and Zn, which is linked to how it swaps ions. This ability comes from substituting Si with Al, creating extra negative charges. Because of these characterstics, Tasikmalaya zeolite seems promising for improving soil and helping the environment.

Fertilizer incubation test

The incubation experiment was conducted for 10 weeks. Chemical analysis is performed three times during the incubation period: week 1, week 6, and week 10. P was examined using the Bray-1 method, S with ammonium acetate pH 7.0 and Fe, Cu, Zn, and Mn with diethylene triamine penta acetic acid (DTPA). It involved testing three types of fertilizers, namely P1 NPKCaMgS (13-8-10-5-9-2), P2 NPKS (19-12-15-4), and M Mutiara NPK (16-16-16), at two different doses: 600 kg/ha (D6) and 1200 kg/ha (D12), along with a control group. The soil used in the experiment was Latosol obtained from the Cikabayan Dramaga experimental garden in Bogor. Composite soil samples from a depth of 0–20 cm was collected and dried, followed by sieving with a 2 mm sieve. The soil moisture content and field capacity were determined, with the moisture content for incubation set at 41.08% and the field capacity at 63.86%.

Table 1. Characteristics of natural zeolite from Tasikmalaya utilized in this study

Parameters	Unit	Value
Type of zeolite	-	Clinoptilolite-Ca; Mordenite; Clinoptilolite-K; Clinoptilolite-Na
CEC	(me $100g^{-1)}$	137.58
Exch-K		3.31
Exch-Na		5.15
Exch-Ca		106.03
Exch-Mg		10.51
Base saturation	(%)	90.87
pH H_2O		7.28
Adsorption capacity		
Cu	(mg g^{-1})	77.33
Pb		98.39
Zn		34.12

For the incubation process, 100 g of oven-dry weight soil was placed into each incubation bottle. The measured doses of the experimental fertilizers, corresponding to 600 kg/ha and 1200 kg/ha, were added to the soil. Distilled water was then added to each bottle until it reached the field capacity, with a volume of 33.1 ml.

Field experiment

The field experiment in red onion growth and production was conducted in the field using 13 treatment combinations of three types of fertilizers: P1 NPKCaMgS, P2 NPKS, and Mutiara NPK, at four different doses (D3: 300 kg/ha, D6: 600 kg/ha, D9: 900 kg/ha, and D12: 1200 kg/ha) along with a control group. The parameters measured included plant height during the vegetative stage, and bulb diameter, number of offshoots, and fresh weight of red onion bulbs during the generative stage. The experiment was carried out on latosol soil that had been generated from 1-meter-wide ridges. The ridges were separated into $1m^2$ experimental plots spaced 30 cm apart. Each plot received 10 tons/ha of chicken manure as a base fertilizer. The red onion variety "Bima Brebes" was utilized, with bulbs weighing 3 to 5 grams and measuring 1.5 to 1.8 centimeters in diameter. Before planting, the treatment fertilizers were mixed into the soil in explained dosages.

Planting was accomplished by putting a piece of the shallot bulb in the plant growth media at a 20 cm spacing. Before planting, planting lines were drawn and watered. For better consistent growth, the shallot bulb ends were trimmed. Each plot had a plant population of 25, with 5 random samples picked from the plot's interior to reduce outer row bias, limit insect and disease damage, and provide more constant direct sunlight exposure.

Observations on onion growth and yield were carried out in this study to investigate the impact of CRF on onion production. Several parameters were measured, including the fresh weight of the bulbs, the fresh weight per cluster, and the weight per experimental plot were all yield-related variables. Additionally, the diameter of the bulbs and the number of shoots per cluster were also measured. After removing the dirt, roots, stems, and leaves, the weight of the bulbs was determined. The diameter was measured by measuring the widest section of the onion bulb with calipers.

RESULTS AND DISCUSSION

The effect of fertilizer incubation on P and S availability in soil

The available P concentrations were tested at weeks 1, 6, and 10. It can be seen from the data that the concentrations of available P differed among treatments and incubation weeks. At the beginning of the experiment (week 1), the control treatment had the lowest concentration of available P in the soil, while treatments P1D6, P2D6, and MD6 had relatively higher concentrations. Additionally, treatments P1D12, P2D12, and MD12 showed the highest values of available-P concentrations. P1D12 and P2D12 are considered CRF because they utilize zeolite. Zeolite can be used as a carrier of fertilizing medium to produce CRF, which can release nutrients for a longer period and prevent nutrient loss (Soltys at al., 2020). The available P in all treatments increased at week 10 as shown by Figure 1. P1D12, P2D12, and MD12 treatments had the highest amounts, ranging from 24.5 ppm to 27.1 ppm. The control treatment increased just little, reaching 9.0 ppm These data suggest that applying fertilizers, especially P based fertilizers, increased the concentration of available P in the soil. Throughout the incubation period, the treatments P1D12, P2D12, and MD12 consistently had the highest concentrations of available P. This is due to the different P ratios in the fertilizers used for these treatments: P1D12 has a ratio of 8, P2D12 has a ratio of 12, and MD12 has a ratio of 16. Similar findings by Rajput at al. (2014) reported that the availability of P can be affected by incubation time and different P sources.

The availability of S in the soil during the 10-week incubation period is shown in Figure 2. At the beginning of the incubation period (week 1), a relatively low concentration of available S (41.71 ppm) was observed in the control treatment, indicating limited S availability in the soil. The treatment P1D12, which involved the use of a CRF with zeolite, exhibited the highest concentration of available S (290.67 ppm), indicating successful release of S into the soil. P1 has 222.38 g of zeolite while P2 contains 76.06 g of zeolite per 1 kg of fertilizer. This decision is consistent with an earlier study (Nainggolan et al., 2010) that found that increasing the amount of zeolite in the fertilizer improved adsorption efficiency.

The availability of S in the soil varied among the treatments during the 10-week incubation

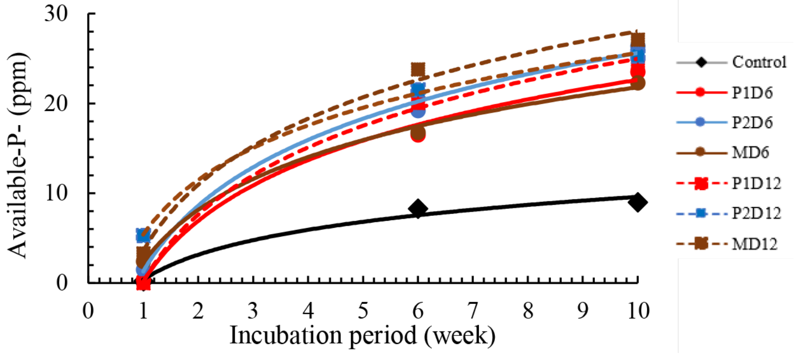

Figure 1. Changes in available P concentration in soil during a 10-week incubation period with different fertilizer treatments

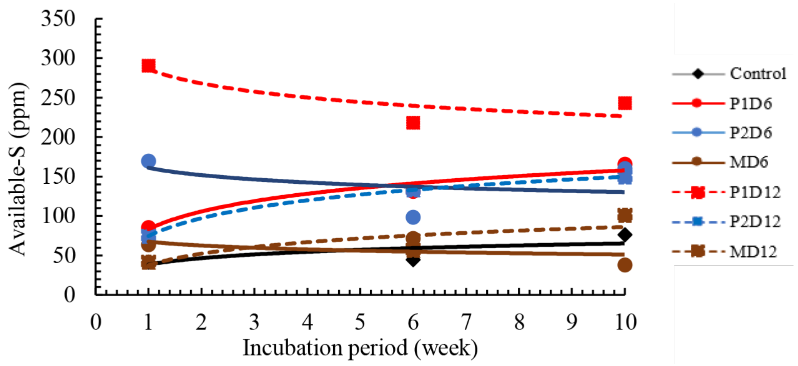

Figure 2. Changes in available S concentration in soil during a 10-week incubation period with different fertilizer treatments

period. Some treatments showed an increase in S concentration, while others showed a decrease. However, treatment P1D12 consistently had the highest concentration of S. On the other hand, the MD6 and MD12 treatments had the lowest S levels, as the Mutiara fertilizer formulations used in these treatments did not contain S. Another research by Hirzel et al. (2018) have also conducted incubation studies to estimate the release of S during the incubation period. Their studies found that the release of S from the soil can vary over incubation period.

The effect of fertilizer addition on Fe, Cu, Zn and Mn availability in soil

The difference in available Fe concentration between treatments was not substantial (Figure 3). This indicates that the tested fertilizer treatments did not significantly affect the availability of Fe in the soil during the incubation period. It's to be noticed that none of the treatments utilized Fe fertilizer. Generally the availability of Fe in the soil decreased from the beginning (week 1) to the conclusion (week 10) of the incubation period. This decrease in Fe availability can be attributed to the tendency of Fe in latosol soil to bind with P, forming Fe-P compounds. This binding may explain the observed increase in P availability in Figure 1 while decreasing the availability of Fe.

According to the research Beck et al. (2018), Fe creates a solubility complex with P in latosol soil, limiting its availability in the soil. Similarly Brod et al. (2022) found that excess P fertilization can reduce plant's ability to absorb Fe, while high concentrations of available Fe can affect the uptake and utilization of P. These findings suggest that the binding of P to Fe plays a role in influencing the plant's uptake and utilization of both nutrients. Achieving a proper balance of P and Fe availability is crucial for optimal plant growth and nutrient utilization. According to the result in Figure 4, the six-fertilizer treatment had no significant influence on the available-Cu in the soil over the 10-week incubation period. The amounts of available-Cu in all treatments were low at the start of the incubation period (week 1), ranging from 2.78 ppm to 3.21 ppm. There was no consistent pattern in available-Cu in any treatment during the incubation although there were some

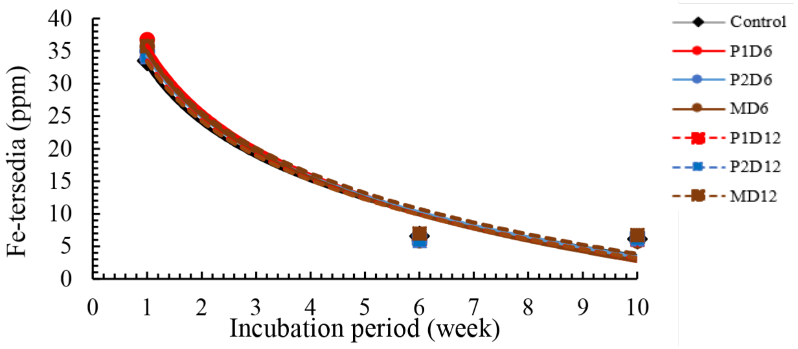

Figure 3. Changes in available Fe concentration in soil during a 10-week incubation period with different fertilizer treatments

slight increases or decreases from week to week. But, in general the available-Cu had increase from beginning to the end of incubation. Analysis of available-Cu in the treatments of P1D6, P2D6, P1D12, and P2D12 generally showed higher increase compared to other treatments. This can be cause by the presence of zeolite in the P1 and P2 treatments. According to Dewi et al. (2017) zeolite has a high cation exchange capacity (CEC), which results in a strong adsorption capacity for Cu. For additional information, basic fertilizers P1 and P2 used in this study contained CuO concentration of 3.33 g per kg of fertilizer or 0.3%. However, the present of CuO in CRF P1 and P2 also did not have a significant impact on the availability of Cu in the soil. Overall, the fertilizers utilized in this study had no significant effect on Cu availability in the soil. Our result is also in line with Wei et al. (2007), who found that Cu fertilizer did not significantly affect the distribution and transport of Cu in the soil. In addition, Gonzaga et al. (2020) did not find any significant effect of incubation on Cu availability in the soil.

Figure 5 shows the concentration of available Zn in the soil after a 10-week incubation period using different fertilizer applications. Overall, the findings show a decrease in available-Zn concentration from week 1 to week 10. This decrease can be related to the soil's binding of Zn with P (Zn-P). Zn binding with P may limit Zn availability. When P is added to fertilizers or is present in the soil as phosphate, Zn can bind to it and form less soluble phosphate-zinc (Zn-P) complexes, resulting in decreased Zn availability. Previous study conducted by Recena et al. (2021) found that P application may decrease Zn adsorption and binding energy to sorbent surfaces. This suggests that Zn-P binding can affect the availability of Zn in the soil. Another study by Lv et al. (2022) reported high levels of Zn significantly decreased the concentration of Ca-P but increased the concentration of O-P (occluded P), indicating that Zn can affect the available-P in the soil.

Although the decrease in available-Zn occurs in all treatments, there were no significant variations in the decrease in available-Zn. interestingly, the CRF treatments P1 and P2 contain a Zn source, namely ZnO, at a concentration of 4.44 g per kg of fertilizer and the other treatments did

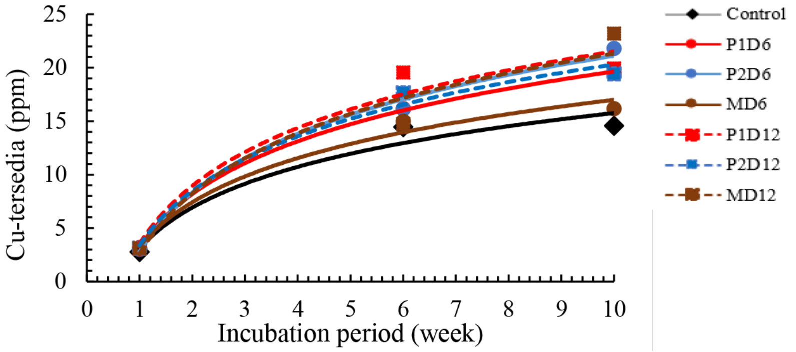

Figure 4. Changes in available Cu concentration in soil during a 10-week incubation period with different fertilizer treatments

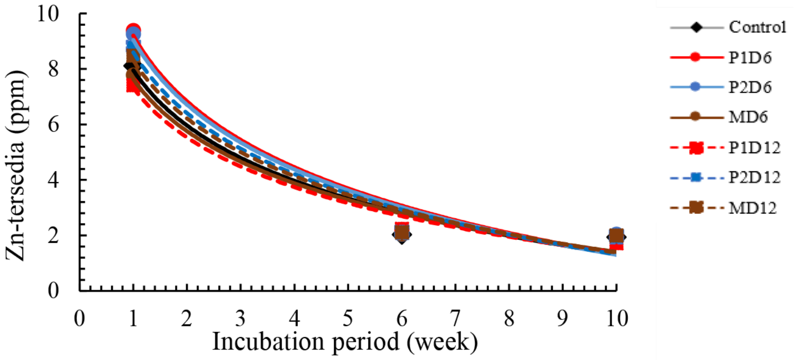

Figure 5. Changes in available Zn concentration in soil during a 10-week incubation period with different fertilizer treatments

not. However, no significant difference in available-Zn was seen in the P1 and P2 treatment when compared to the other treatments. This shows that the ZnO level of the fertilizer had no effect on Zn availability. A study on the development and characterization of slow-release fertilizer in a soil incubation experiment by Umar et al. (2022) also reported that did not any significant effect of the level of ZnO in the fertilizer on the availability of Zn in the soil. According to Mazhar et al. (2023) when compared to ZnO-based fertilizers, $ZnSO_4$ is more effective in promoting Zn diffusion in the soil. On the other hand, ZnO-based fertilizers have slower dissolution rates and may require microbial or chemical processes in the soil to convert them into plant-available forms (Garza-Alonso et al., 2023). The incubation results indicated the potential influence of the different fertilizer applications on Mn availability in the soil (Figure 6). The control treatment, which did not receive any additional fertilizer, displayed relatively stable available-Mn over time from 169.82 ppm at week 1 to 148.33 ppm at week 10. This suggests that there were minimal changes in Mn levels without the addition of specific fertilizer inputs. According to the research Wang et al. (2022) in the absence of Mn fertilizer application, the available-Mn gradually decreased. In contrast, the other treatments, namely P1D6, MD6, P1D12, P2D6, P2D12, and MD12, showed varying patterns of Mn concentration over the incubation period. Among these treatments, P2D12 consistently had the highest available-Mn concentrations at all incubation weeks. Especially, the available-Mn in the P2D12 treatment increased significantly from 283.60 ppm at week 1 to 480.01 ppm at week 10. This suggests that the composition in the P2D12 fertilizer formulation, including the Mn source $MnSO_4$, contributed to the enhanced available-Mn in the soil. The addition of 3.75 g per kg of fertilizer of $MnSO_4$ in the P1 and P2 treatments resulted in increased available-Mn compared to the other treatments. A similar study by Wang et al. (2023) also found that the addition of $MnSO_4$ to the soil significantly enhanced Mn availability.

Effects of different fertilizer treatments on red onion growth and production based on field experiment

The data presented in Table 2 provides insight into the effect of different fertilizer treatments on the growth and yield parameters of red onions. The diameter of the red onion bulbs did not show significant differences among the treatments, except for the P1D3 treatment, which had a slightly larger diameter of 2.40 cm compared to the other treatments. Similar result was also reported by Kazimierczak et al. (2021), who found that onion bulb yields in fertilized plots were slightly higher than those in control plots (non-fertilized). Additionally, Suddin et al. (2021) stated that no significant differences were detected between the control and all fertilizer treatments. However, the treatment with the highest number of shoots per cluster was P1D6. This suggests that the increased nutrient availability in the soil, resulting from the higher fertilizer dosage, may have been utilized for producing more bulbs rather than enlarging their size Aisyah, 2020).

In terms of bulb weight, the P1D3 treatment showed the highest average weight per bulb at 8.50 grams. The P1D3 treatment also exhibited the highest fresh weight per cluster at 83 grams. Similarly, the P2D9 treatment showed the highest fresh weight per plot, reaching 2.07 kilograms. The P1D3 treatment may have provided a composition of nutrients that improved bulb development and biomass accumulation because it had a higher weight per bulb and fresh weight per

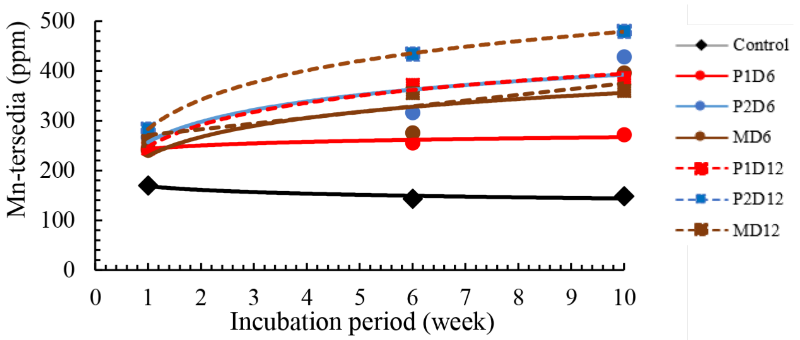

Figure 6. Changes in available Mn concentration in soil during a 10-week incubation period with different fertilizer treatments

Table 2. Comparison of growth and yield parameters of red onions under different fertilizer treatments

Treatment	Diameter (cm)	Number of shoots per cluster	Weight per bulb (g)	Fresh weight per cluster (g)	Fresh weight per plot (kg)
Control	2.10	8	5.92	47	1.21
P1D3	2.40	10	8.50	83	2.07
P2D3	2.30	8	6.88	55	1.40
MD3	2.10	14	5.66	79	2.00
P1D6	2.20	12	6.22	73	1.81
P2D6	2.10	9	5.93	51	1.37
MD6	2.20	11	7.04	75	1.87
P1D9	2.20	11	7.28	82	1.99
P2D9	2.30	11	7.69	83	2.05
MD9	2.40	10	7.86	77	1.95
P1D12	2.10	11	5.97	67	1.51
P2D12	2.30	11	6.40	70	1.86
MD12	2.20	9	6.37	57	1.50

cluster. Among three fertilizer treatments used, namely P1, P2, and M, only the fertilizer composition of P1 contains Ca and Mg nutrient. Previous studies by Kleiber et al. (2012) have found that optimizing Mg nutrient in red onion plants can improve their nutrient status and increase yielding. Leaves accumulate more N, K, Ca, and Mg than bulbs, and controlled Mg nutrient is an effective method for improving yields. Another study by Belo et al. (2023) has reported that the application of Ca to onion crops can enhance bulb firmness and improve the quality of stored onions. The application of 300 kg/ha dosage of CRF ensures a well-balanced and long-term supply of essential nutrients. Utilizing CRF enables a consistent and continuous supply of nutrients to red onion plants, leading to enhanced yield outcomes. A related study (Lee and Min, 2022) also reported that the implementation of CRF resulted in increased bulb yield, improved nutrient content, and enhanced storage quality of red onions.

CONCLUSIONS

The application of CRF does not significantly affect the dynamic availability of P, S, Fe, Cu, Zn, and Mn in the soil. However, the availability of P, Cu, and Mn increases with longer incubation time, while Fe and Zn decrease. However, the availability of S in the soil shows irregular patterns with longer incubation time. The highest onion production was observed in the treatment using CRF P1 NPKCaMgS (13-8-10-5-9-2) at a dosage of 300 kg/ha.

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